FORAGE INTAKE AND DIGESTION BY SHEEP AND CATTLE GRAZING FALKLAND ISLANDS' NATIVE PASTURES

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PREFACE

This report details a series of studies that were conducted during the period between 1997 and 2001 in response to requests for a greater understanding of the nutrient cycles experienced by sheep and cattle grazing Falklands' native pastures. The sheep studies have been published in the thesis "*Practical Approaches to Improve the Value of the Falkland Islands' Sheep and Wool Industry*" (Miller 2002) and have been extracted for inclusion in this report.

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SUMMARY

Studies were conducted between 1997 and 1999 with both sheep and cattle to determine which plants contributed to the diets of these animals, the seasonal quality of native pasture diets, nutritional limits to animal productivity from native pastures, and dietary competition and complementarity between sheep and cattle. The diets of weaner sheep, lactating ewes, mature lactating and non-lactating cows, and co-grazed sheep and cattle were determined at several sites on East Falkland. The studies were conducted in response to requests for more information on the nutrition of both sheep and cattle grazing Falklands' native pastures, and in recognition of the need to improve farm productivity and profitability.

Microhistology of animal faeces provided estimates of the botanical composition of the diets consumed by sheep and cattle. Dosed even-chain length alkanes (C_{32} and C_{36}) were used to estimate dry matter intake (DMI), faecal output and dry matter digestibility (DMD). Microhistology data were used to imply herbage concentrations of even-chain length (C_{32}) and odd-chain length (C_{31} and C_{33}) alkanes in the diets, and DMI was subsequently estimated from the ratio of these alkanes appearing in the faeces. Faecal output was estimated from the dilution of C_{36} in the faeces, and DMD was estimated as the difference between DMI and faecal output, expressed as a proportion of DMI. Animal performance was predicted using these estimates of DMI and DMD and compared to measured animal responses. Protein requirements of animals and dietary supplies of protein were calculated using the alkane-derived DMI data and implied concentrations of crude protein in the diets.

Sheep and cattle consumed substantial quantities of the dominant pasture species White-grass throughout the year, however weaner sheep consumed less of this species ($P<0.05$) in summer than all other times of the year. Cattle that were co-grazed with sheep consumed the greatest quantities of White-grass. Fine grasses, that are Smooth-stalked Meadow grass, Native Fescue and Bent, were the most common fine grasses consumed by sheep, and these higher quality grasses appeared to 'drive' sheep productivity during the warmer months of the year. Cattle also exhibited a seasonal change of diet that favoured fine grasses during the warmer months. However, cattle tended to consume proportionally more Hair grasses and Native rush than the Meadow grasses, Native fescue and Bent. These differences between sheep and cattle may be related to both differences in mouth anatomy of sheep and cattle that enable sheep to graze shorter swards than cattle, and competition between sheep, native geese and cattle for the more palatable fine grasses.

Daily DMI by weaner sheep varied from 2.5% to 3.3% of bodyweight from winter to summer, respectively, and for co-grazed wethers was 1.8% and 3.3% during winter and summer, respectively. DMI's by both groups of sheep were related to seasonal DMD of the diets, and increased from 57% to 71% for weaner sheep in winter and summer, respectively, and 57% to 66% for co-grazed wethers in winter and summer, respectively. DMI by non-lactating cows varied from 1.0% to 1.7% of bodyweight during the year, and for lactating cows was 1.7% to 2.1% of bodyweight for the eight months following calving. DMI consumed by co-grazed cattle varied from 0.8% to 1.8% of bodyweight during winter and late spring, respectively. For mature sheep and cattle, DMI as a proportion of bodyweight increased by

70% to 125% from the winter/early spring to late spring/summer. DMD of the diets consume by non-lactating and co-grazed cattle were similar throughout the year, and varied from 53% to 66% during early spring and late summer, respectively. DMD of diets consumed by cattle tended to be lower than DMD of sheep diets, however the differences were not significant.

Low rumen NH_3-N concentrations were measured in both sheep and cattle during autumn, winter and early spring and were indicative of a protein deficiency that inhibited fermentation of the pastures by rumen microorganisms. This conclusion was supported by empirical calculations that suggested rumen degradable protein (RDP) was insufficient to match ME intake during these periods. Poor RDP supply was attributable to both low apparent degradability of RDP and insufficient crude protein in the forage consumed. Phosphorus (P), calcium and vitamin D_3 concentrations in plasma exhibited distinct seasonal trends for both sheep and cattle, with lowest concentrations evident during autumn, winter, and early spring. P and vitamin D_3 intakes were apparently deficient for sheep and cattle during these periods.

The 'feast or famine' environment implied by the intake and nutritional quality of native pasture, as identified in these diet studies, places high stresses on animal physiology and undoubtedly contributes to the high mortality of young sheep particularly, and low annual and lifetime productivity of both sheep and cattle. The nutritional restrictions imposed on sheep and cattle were evident between March and October and for both animal species were due principally to a RDP deficiency, low ME intake, and an apparent P deficiency. Improved nutrition must be supplied and maintained during this period if substantially improved growth and survival rates are to be achieved, and although rotational grazing may offer some potential to extend the length of time that better quality feed is available for grazing, it is doubtful that native pasture can be satisfactorily manipulated to meet this requirement. Consequently, alternate feeding practices that integrate summer grazing of native pasture with forages of substantially higher quality than winter native pastures, or that provide supplemental protein and P to native pasture diets during the cooler months should be investigated as priorities.

1.0 REVIEW OF PAST STUDIES

The problems limiting the further development of Falklands' agriculture have been well documented during the last 80 years (Munro 1924, Davies 1939, Gibbs 1946, Davies *et al.* 1971). A common conclusion in each of these studies is that the nutrition of sheep may often be less than their basic maintenance requirement for much of the year. Cattle nutrition has not previously been studied in the Falklands. The forces responsible for the periods of low animal productivity, and less often high productivity, are poorly understood but are presumed to be related to the seasonal availability of better quality grasses (Davies 1988). Little is known about the dietary preferences of sheep and cattle consuming native pasture in the Islands, and seasonal protein and energy consumption by both species remains unquantified. The lack of such basic information limits wider application of much of the nutritional data that has been acquired for Falklands' plants (Davies 1988), and sheep and cattle (Whitley 1983). Knowledge of how and when the forages supply nutrients to grazing animals is implicit to understand grazing systems. In the rangelands environment of the Falkland Islands pasture provides the total ration for sheep and cattle, hence a key variable determining animal production in this system is the amount and quality of the pasture consumed during the year. During the past 20 years some attempts have been made to examine the animal-plant interactions in the Falklands, however their success and the value of the information they have generated have been limited. These experiments are reviewed below.

1.1 Grazing exclosures

Davies (1988) placed exclosures on a White-grass dominant sward maintained at 4cm in height by manipulating grazing pressure. Pasture growth and species composition was measured both inside and outside the exclosures and differences between the two were attributed to grazing. The study continued for the 6 months covering the spring and summer period of 1986/87 (October to April). The author concluded that as the summer season progressed, the sheep obtained between 42% and 76% of their diet from White-grass. Christmas Bush made a significant proportion of the diet during early spring and no contribution during late summer. Grasses other than White-grass, principally Native Fescue and Early Hair-grass contributed to only 8% to 13% of the diet apparently consumed (Table 1.1). Davies proposed that a low frequency of Native Fescue and Early Hair-grass in the exclosures may have accounted for their relatively small contribution to the diet.

Davies also conducted a three-year study to evaluate the effect of grazing on the botanical composition of White-grass swards maintained at 4cm, 8cm, 12cm or 16cm in height. No consistent effects on pasture composition were measured that could be attributed to grazing.

Table 1.1 Composition of the diet selected by sheep grazing a White-grass sward maintained at 4cm in height (Davies 1988)

Species	Contribution to diet on a dry weight basis (%)			
	Oct to Dec	Dec to Feb	Feb to Apr	Mean
Live White-grass	35	33	46	37
Dead White-grass	7	32	30	27
Live other grasses	10	8	10	9
Dead other grasses	0	6	6	4
Live Christmas Bush	31	12	0	12
Dead Christmas Bush	6	2	0	3
Live Herbs	6	4	2	4
Dead Herbs	6	2	7	5

1.2 Identifying plant fragments in the rumen

Davies (1988) collaborated with David Walton, Terrestrial and Freshwater Sciences Division of the British Antarctic Survey (BAS), to conduct a feasibility study to determine whether the techniques used by BAS to study diets of reindeer in sub-Antarctic South Georgia (Leader-Williams *et al.* 1981) could be used in the Falklands. Samples were collected from the rumens of 18 slaughtered sheep that had been grazing native pastures during February and March 1987. Nine sheep were allowed to graze a pasture maintained at 4cm in height and the other 9 sheep grazed pasture maintained at 16cm in height. The samples were separated into fractions using sieves, and the fraction providing specimens ≥2mm was floated in a water-filled petri dish overlying an 11cm x 11cm grid with 100 intersection points. Fragments touching each intersection were identified visually with reference to herbarium specimens.

Using this method, Buckingham (1987) concluded that diets of individual sheep could be differentiated with some precision (Table 1.2). Davies (1988) subsequently reported that differences were apparent between the diets of sheep grazing 4cm or 16cm high swards (Table 1.3).

The method was limited by an apparent difficulty to discriminate between several key plant species and the need to slaughter animals to collect samples. Furthermore, there was concern that different rates of digestion of the various plant species may distort the actual contribution of a particular component to the diet. With reference to these limitations, the author concluded that the technique could be useful to compare the botanical composition of sheep diets from different pastures.

These results were in general agreement with those obtained by Davies using grazing exclosures. The rumen sampling study coincided with the February/April sampling period in the exclosure study. Contributions of White-grass (84% *v.* 76%), Christmas Bush (2% *v.* 0%), and herbs (11% *v.* 9%) were similar for the diets measured by the rumen sampling technique and the grazing exclosure method, respectively. A relatively large discrepancy was apparent when comparisons were made for the consumption of 'other grasses' (2% *v.* 16%). The source of this difference may be differential digestion of

plant species in the rumen sampling method. This would lead to an overestimate of White-grass and an underestimate of the 'other grass' fraction.

Table 1.2 Plants consumed by sheep grazing White-grass (native pasture) swards (Buckingham 1987)

Plants		Proportion in diet, by occurrence (%)		
Common name	Scientific name	Mean	Range	std. dev.
White-grass	*Cortaderia pilosa*	79.5	66.0 - 90.5	6.15
Early Hair-grass	*Aira praecox*	0.9	0.0 - 2.0	0.72
Meadow-grasses	*Poa* sp.	3.4	0.5 - 8.5	2.07
Yorkshire Fog	*Holcus lanatus*	0.6	0.0 - 2.0	0.61
Native Rush	*Juncus scheuzerioides*	1.2	0.0 - 3.0	0.96
Mountain Berry	*Pernettya pumila*	1.5	0.0 - 4.0	1.17
Pig Vine	*Gunnera magellanica*	1.3	0.0 - 3.5	1.15
Christmas Bush	*Baccharis magellanica*	1.6	0.5 - 4.5	1.06
Malvina (Tea) Berry	*Myrteola nummularia*	7.8	2.5 - 18.0	4.57
Diddle-dee	*Empetrum rubrum*	0.1	0.0 - 0.5	0.19
Small Fern	*Blechnum penna-marina*	1.3	0.0 - 3.0	0.77
Mosses		0.4	0.0 - 2.0	0.57
Unidentified		0.5	0.0 - 3.0	0.84

Table 1.3 Diets selected by sheep grazing White-grass (native pasture) swards maintained at either 4cm or 16cm in height (Davies 1988). *Within rows, means with different letters differ significantly at P=0.05*

Pasture species	Proportion in diet, by occurrence (%)		
	4cm sward	16cm sward	s.e.m.
White-grass (*Cortaderia pilosa*)	84.2 a	74.8 b	1.21
Other grasses	2.4 a	7.2 b	0.64
Christmas Bush (*Baccharis magellanica*)	2.1 a	1.1 b	0.31
Herbs	11.3 a	16.9 b	1.52

1.3 Using plant alkanes to estimate diet composition and intake

Goats were imported to the Islands in the early 1990's and an attempt was subsequently made to determine the goats' ability to consume the widespread, prostrate shrub Diddle-dee (*Empetrum rubrum*). Dosed even-chain alkanes were used to estimate intake and botanical composition of the diet selected by goats and sheep (Baughan 1993). Alkanes absorbed onto shredded paper and compressed into pellets were given to goats and sheep daily during a sequence of experiments. The alkane composition of the pellets is not specified in DOA records, however the pellets were prepared by the Macaulay Land Use Research Institute, Scotland.

The experimental protocol proposed six study periods spread over 11 months, and conjointly evaluating sheep diets whilst goats and sheep grazed the same pastures (a White-grass dominant pasture and a Diddle-dee dominant pasture) for five of those periods. Data was collected for six goats and six sheep for

each study period. Due principally to difficulties of maintaining goats in the grazing areas, and the accessibility of the study site, only three studies were completed and only one of these included co-grazed sheep. The difficulty in keeping goats in the plots led the staff to graze the goats in a large paddock for the duration of the third period, and they captured the goats daily to collect faecal samples and administer the alkanes.

The studies produced results of limited value. The quantity of Diddle-dee consumed was estimated as;

> "*Faecal samples collected ... were analysed for proportion of species eaten when either two or three species were considered. Thus, for an estimate of the proportion of Diddle-dee and White-grass* (i.e. two species only) *that was consumed, analysis for Diddle-dee was carried out and the remainder* (i.e. 1 minus Diddle-dee) *was taken to be White-grass.*" (Baughan 1993)

The deduction that everything that was not calculated to be Diddle-dee was thus White-grass was flawed, however data were presented for the contribution of Diddle-dee to the diets of goats and sheep for the study (Table 1.4). There are no records in DOA files to indicate that feed intake was quantified in any of the study periods using the ratio of adjacent natural and dosed alkane concentrations in herbage and faeces (Dove and Mayes 1991).

The studies suggested that goats consumed only small quantities of Diddle-dee as a percentage of daily intake. Similarly, and unless little else was available, sheep tended to be disinterested in Diddle-dee. When sheep and goats were grazed together in period 2, sheep consumed significantly more Diddle-dee than goats in both White-grass (2.8 *v.* 1.1±0.36%, respectively) and Diddle-dee dominant plots (23.5 *v.* 3.5±2.63%, respectively). During the short grazing periods, goats lost 144g/d and 182g/d liveweight on the White-grass and Diddle-dee dominant pastures respectively, and sheep lost 583g/d and 1000g/d whilst grazing the same pastures. The goats apparently began to escape from the Diddle-dee dominant plots during the study and suggests that the goats were looking for alternate grazing in preference to Diddle-dee.

Table 1.4 Contribution of Diddle-dee to the diet of sheep and goats grazing native pastures in the Falkland Islands (Baughan 1993). *Within rows, means with different letters, and within columns, means with different numbers differ significantly at P=0.05*

	Proportion of Diddle-dee in the diet (%)		
Study period	Diddle-dee plot	White-grass plot	s.e.m.
Period 1 (December 1991)			
Goats	1.9 a	0.1 b[1]	0.42
Period 2 (February 1992)			
Goats	3.5 a	1.1 b[2]	0.50
Sheep	23.5 a	2.8 b[2]	2.47
Period 3 (May 1992)	When grazing in a large paddock		
Goats	5.1		0.57

Over the period from December to May, Diddle-dee formed an increasing component of the diet. In period 3 goats consumed significantly more Diddle-dee (5.1%) than in White-grass dominant plots in both periods 1 and 2 (0.1% and 1.1%, respectively). Unfortunately, the raw data generated by the study is no longer available, consequently a more detailed re-analysis of the botanical composition of the diets was not possible during the preparation of this thesis.

Reference is made in DOA files that an earlier attempt was made to quantify the diet of sheep grazing White-grass pastures maintained at either 8cm or 16cm in height (Hoppé[1] unpublished data, Table 1.5). Alkane pellets were provided to six sheep in each sward-height group. The time of year the study was conducted is not recorded but it is probable that it was completed during the summer months of the 1989/90 season as an adjunct to an established summer grazing study evaluating sheep performance on White-grass swards maintained at heights of 4cm, 8cm, 12cm or 16cm.

Table 1.5 Intake, digestibility and faecal output for mature wethers grazing native White-grass swards maintained at a height of either 8cm or 16cm (G. Hoppé unpublished data). *Within rows, means with different letters differ significantly at P=0.05*

	Sward height		
Parameter	8 cm	16 cm	s.e.m.
Dry matter digestibility (%)	63.5 a	47.1 b	1.47
Faecal output (g/day)	513 a	659 b	27.6
Intake (g/day)	1,412	1,251	81.6

The study suggested that sheep grazing shorter swards consumed a diet significantly more digestible and hence higher in energy than those grazing the taller sward. Although feed intake tended to be greater for the sheep grazing the more digestible shorter sward, the difference was not significant and is probably the result of the small number of sheep used to estimate intake.

1.4 Studies on ruminant diets in sub-Antarctic climates

The geographically similar region of Tierra del Fuego in the far south of Argentina and Chile is relevant to the Falklands. Many pasture species are common between the two regions, and several studies on ruminant diets in Tierra del Fuego have been published which may provide a guide to the prospective diets of sheep and cattle in the Falklands. *Poa sp.*, *Deschampsia,* sedges and rushes that are common between Tierra del Fuego and the Falklands were identified as the principal components of the diets selected by sheep in Tierra de Fuego (Posse *et al.* 1996), and shrubs were observed in increasing frequency during autumn and winter. Shrubs were not consumed in significant quantities during spring and summer. *Poa sp* were also the preferred forage of the camelid guanco (*Lama guanicoe*) grazing the same pastures (Raedecke 1980, Bonino and Pelliza Sbriller 1991). Further evidence of selection for *Poa*

[1] Gerry Hoppé, Agronomist, Falkland Islands Department of Agriculture 1989-1993

sp. comes from the study of reindeer diets in South Georgia (Leader-Wiliams *et al.* 1981). South Georgia is an island approximately 1,900 km to the south east of the Falklands and shares many similar plant communities with the Falklands.

1.5 Conclusions from past Falklands' studies

From the mid 1980's until 1997, substantial research efforts were expended in understanding the physiology of White-grass in particular, and the productivity of White-grass pastures for the wool industry when grazed in accordance with height-of-sward criteria. This was done without a basic understanding of the plants actually consumed by sheep, and the seasonal nutrient balances they experience.

Austin Davies (1988) wrote in his end of contract report;

> *"Another of my pet topics was that of sheep diet selection/behaviour. Having developed and evaluated the use of rumen sampling in sheep it was disappointing to have the topic dropped from ARC's programme during the funding debate. In my view the role that the poorly digestible shrub, Diddle-dee, plays in wool production, alone justified its inclusion. This technique would clarify the diet of (weaner sheep) during their first winter and so may have shed some light on one of the main problem areas of the animal production programme, as I understand it."*

The lack of such knowledge has continued to limit the understanding of the native pasture grazing system. There are no established benchmarks for estimating pasture quality, nor the potential productivity of the pasture. Furthermore, an understanding of how pasture intake and digestion affects the growth of young sheep, mortality of which approaches 50% within 2 years of birth, has not been addressed. There remains no information on the nutrition of cattle in the Falklands.

From the few Falklands' studies to date, it appears that when sheep are confined to small, White-grass dominant swards they consume large quantities of White-grass and choose fine grasses to supplement intake where possible. Since White-grass digestibility lies in the range from 45% to 55% (Davies 1988, Davies *et al.* 1991), and it is apparent that during the winter months sheep lose weight (Maitland 1988a-e), the general conclusion that sheep rely upon White-grass to supply a substantial proportion of their winter diet is logical but unproven. In contrast, sheep gain weight during summer in the Falklands (Bain 1990, Dickson 1993) thus the assumption that sheep rely less upon White-grass and more upon more nutritious, finer grasses at this time also appears valid. Due to the restricted designs of the experiments conducted previously it has not been possible to test these hypotheses. It is also apparent from the limited Falklands' studies that the prostrate shrub Diddle-dee is not consumed in substantial quantities by sheep or goats unless they are forced to do so. Moreover, when they are forced to consume Diddle-dee they loose liveweight at critical rates. This conclusion has substantial ramifications for large areas of West

Falkland where Diddle-dee is a dominant pasture association. It suggests that sheep grazing those areas may choose a substantially different diet to that apparently in abundance.

Despite the data generated by these past studies there remains a basic need to identify the diet of sheep consuming Falklands' pastures, and to determine the nutrient cycles encountered during the grazing seasons. Furthermore, with the drive to develop a beef industry to diversify agricultural production in the Islands there is an urgent need to understand cattle growth and production from native pastures. With this knowledge it is likely that strategies to better match pasture growth with animal requirements can be developed, indicator plants may be identified to provide keys to improved grazing management, supplements may be developed to overcome nutrient droughts, and grazing systems that better integrate the strategic use of native and improved pastures may be identified.

The focus of the following studies was to obtain a basic understanding of the diets of sheep and cattle and the nutritional cycles that these animals encounter as a consequence of consuming native pasture in the Falklands.

2.0 Introduction to the Studies

The following diet studies attempted to establish the nutritional cycles experienced by young sheep between 1997 and 1999, and mature cows during 1998 and 1999. The aim of the studies was to identify the plants consumed by sheep and cattle, the amount of dry matter (DM) consumed at different times during the grazing seasons, and the quality of the diet selected by sheep and cattle. A preliminary study was conducted with lactating ewes in order to establish whether the methods chosen for use in the studies were suitable to identify the botanical composition and nutritional quality of the diets selected by grazing sheep. Subsequently, a series of nine studies were conducted with weaner sheep (aged 8 months to 18 months), and shearling wethers (aged 24 months to 36 months) co-grazed with non-pregnant mature cows.

The weaner sheep studies examined forage intake and digestion at five intervals during a 10-month period. Shearling wether diets were examined at four intervals during a 12-month period and coincided with the austral seasons. During each of the 10 studies, plants consumed by the sheep grazing native pasture were identified microscopically from the patterns of undigested leaf cuticles appearing in the faeces. In addition, DMI and DMD of the diets consumed were estimated by using natural and dosed alkanes as digestive markers (Dove and Mayes 1991).

The cattle diet studies comprised two separate designs. Firstly, forage intake and digestion was determined for five non-pregnant and five lactating cattle for 5-day periods during late summer, early winter, and early spring. In addition, five dry cattle were examined for an additional 5-day period in late spring. The second design examined the diets consumed by five non-pregnant, mature aged female cattle that were grazing with shearling wethers in a paddock set-stocked for 12 months at approximately 1.0

DSE/ha. The diets were determined on four occasions; early winter, early spring, late spring and late summer. The diets of 5 shearling sheep that co-grazed with the cattle were examined simultaneously with the cattle diets.

3.0 Materials and Methods

3.1 Preliminary study - Intake and digestion by lactating ewes grazing Falkland Islands' native pasture

During December 1997 four Polwarth ewes with lambs at foot were selected at random from a larger flock of 300 ewes. Two days after lambing each of the ewes was dosed with a controlled release alkane capsule (batch no. 600243). Each alkane capsule contained 1g each of the two synthetic alkanes dotriacontane and hexatriacontane (C_{32} and C_{36}; Captec Ltd, New Zealand). The manufacturer of the capsules claimed approximately 50mg/day of each alkane would be released continuously into the rumen of sheep for a period of between 17 and 23 days.

A six-day faecal collection period commenced eleven days after the capsules were administered. This period corresponded to day 13 to day 18 post-parturition. Faecal samples were collected daily from each ewe by rectal grab sample. The ewes were set-stocked on native pasture at a stocking rate of approximately 1.0 DSE/ha for the duration of the study.

The ewes were milked by hand to estimate milk production during the study. The ewes were given 20 USP units of oxytocin (intravenous) to initiate milk letdown and then hand milked until dry. The lambs were removed from the ewes and the ewes were then left to graze for two hours. Milking was then repeated and milk volume recorded. This volume was used to estimate daily milk production.

3.2 Intake and digestion by weaner sheep grazing Falkland Islands' native pasture

In June, August, late October 1998, and January and late March 1999 small groups of Polwarth*Corriedale sheep (50 to 100 individuals) were gathered within a distance of 500m of the lamb-marking pens in the Bluff Creek, Teal Creek, and Clay Pass Corner paddocks on Goose Green Farm, East Falkland (Appendix 1). The sheep used in all five studies belonged to the same draft of weaner sheep born between October and November 1997 and weaned in February 1998.

Throughout the study, management for these animals followed the traditional pattern for Goose Green farm (Table 3.1).

In each study five healthy male (wether) weaner sheep were chosen from each group gathered. The wethers were given a controlled release alkane capsule (batch no. 600243) and for the first three studies

were fitted with a faecal collection harness (Cole *et al.* 1996). In the remaining two studies harnesses were not used and faeces were collected by rectal grab sampling. The sheep used for the diet studies were approximately 3kg heavier than the general mean of the flock they were grazing with. Heavier sheep were chosen deliberately to ensure they would cope with the demands of the faecal collection harness and to ensure they were able to swallow the alkane capsules without difficulty. This was particularly important since the capsules were recommended for use with sheep weighing 25kg to 80kg. The mean liveweight of the flock did not exceed 25kg until October (late spring).

Table 3.1 Grazing management regime for weaner sheep used in diet study 2.2

Place of grazing	Period	Total days	Approximate Grazing area	Approximate stocking rate
Bluff Creek	February to September	190	3,666ha	0.9 DSE/ha
Teal Creek	October	25	762ha	4.0 DSE/ha
Clay Pass Corner	November to January	75	2,279ha	0.9 DSE/ha
Bluff Creek	January to April	80	3,666ha	0.9 DSE/ha

Clearly visible marks were sprayed onto the flanks of each animal using a scourable spray-marker. These marks were used to help identify the individuals from afar during the period when faecal samples were collected. Immediately prior to administering the alkane capsule, a faecal sample was taken from the rectum of each animal to establish background concentrations of C_{32} and C_{36} excreted.

A radio-tracking collar (Sirtrack, New Zealand) was fitted to each wether as an aid to quickly locate and identify the study sheep in the paddocks. The transmitter in each collar had a discrete frequency between 155.000 and 155.160 MHz. This enabled each sheep to be individually identified and radio-located throughout the study period. Signals were transmitted from the radio collars at a rate of 45 pulses per minute and detected using a three-element, directional Yagi antenna attached to a Fieldmaster receiver (Advanced Telemetry Systems, Isanti, MN).

The sheep were kept in the lamb-marking pen overnight to allow them to adapt to the sensations of wearing the harness and radio-collar. For one hour following fitting of the harnesses, and for a short period immediately before releasing the animals back into the paddock the group of sheep was monitored to ensure they were not adversely affected by potential stresses imposed by wearing the harness and collar and having coloured markings on their flanks. Whilst the groups of sheep were in the pen, and within 30 minutes of mustering, blood and faecal samples were collected from 30 to 40 weaners not dosed with alkanes. These samples were used to monitor plasma Ca, inorganic P, urea, creatinine, and 25-hydroxyvitamin D_3 (25-OHD), and faecal N, Ca and P excretion during the year. The sheep were released approximately 24 hours after harnessing and allowed to return to normal grazing.

Nine days after the capsules were administered, each sheep was radio located and captured. A plastic bag measuring 30cm x 30cm was placed inside a canvas bag of similar dimensions and both were attached to the faecal collection harness and the sheep were released. On the following day, and for four days

thereafter, the sheep were located and re-captured to retrieve the full collection bags and to attach new bags. On the fifth (final) collection day the sheep were weighed and then released to rejoin the flock.

After the sheep had been radio-located and their identity confirmed by sight they were captured in the paddock. The time from capture to release was minimised to reduce any potential stress to the sheep that may affect their subsequent welfare and feeding behaviour. In the majority of instances the sheep were captured and released within five minutes of first sighting.

When each sheep had been located and released its position was recorded on a map. At the end of each study, the distances between each capture point were established for each sheep. This data was used to examine distances sheep moved during each study period and the relationship with day length. National Oceanic and Atmospheric Administration data (NOAA 2002) was used to calculate mean day length for each diet period.

3.3 Intake and digestion by lactating and non-lactating cattle grazing Falkland Islands' native pasture

On each of four occasions over a 12-month period, five mature non-lactating cows, and on three occasions five mature lactating cows were selected to examine the diet of cattle grazing native pasture. The collection periods were November (late spring, non-lactating cows only), February (late summer, non-lactating and lactating cows), June (early winter, non-lactating and lactating cows), and September (early spring, non-lactating and lactating cows). At the commencement of the first study period in June, the cows were between 4 and 5 years of age.

On day 1 of each study period each cow received an alkane capsule (batch no. 600215) and liveweight was recorded before the cows were released to resume grazing. Nine days after the capsules were administered, a five-day faecal collection period commenced. Faecal samples were collected from fresh dung deposits from each cow. Careful attention was exercised to collect the faeces: cows were followed and faecal samples were collected immediately after the faeces was expelled, and extraneous leaf material deposited on the faeces from the ground litter was removed before collection.

The cows used in the studies were drawn from the National Beef Herd and were grazed with 150 other similar animals in a grazing rotation that made use of all of the paddocks at Brenton Loch and several smaller paddocks on Saladero (Appendix 1). Generally, the cows grazed each paddock for one to two months before being moved to subsequent pastures on the basis of subjective assessments of the pastures.

In each five-day collection periods, faecal samples were collected from companion cows that had not received alkane capsules but were grazing with the dosed animals. The samples were bulked across the collection period and provided an estimate of background concentrations of C_{32} and C_{36} consumed.

Periodically, and generally coinciding with the seasonal diet study periods, blood samples were collected from approximately 30 mature cattle grazing with the subjects used in the studies. These samples were analysed for plasma Ca, inorganic P, urea, creatinine, and vitamin D_3 (25OH-D_3).

3.4 Intake and digestion by co-grazed mature, non-pregnant cattle and shearling sheep grazing Falkland Islands' native pasture

On each of four occasions over a 12-month period, five Polwarth wethers and five mature cows from the National Beef Herd were selected to examine dietary competition and complementarity between co-grazed sheep and cattle grazing native pasture (Breton Loch House paddock, Appendix 1). At the commencement of the study the wethers were 2 years of age and the cows were between 4 and 5 years of age. The four collection periods were November (late spring), February (late summer), June (early winter), and September (early spring). At the commencement of the first study period in June, the wethers were 21 months of age.

On day 1 of each study period each sheep and cow received an alkane capsule (batch nos. 600243 and 600215), and liveweight was recorded before the animals were released to resume grazing. The animals were maintained in a single paddock at Brenton Loch for the full 12 months such that the total stocking rate reflected the middle range of those recorded in the Islands. Stocking rate in the 129 ha paddock equated to approximately 1.0 DSE/ha, and was contributed to by seven dry cows and 70 mature wethers.

The wethers were fitted with a faecal collection harness for the first study, and the method used to collect samples was identical to that described in the weaner sheep diet studies (**3.2**). Nine days after the capsules were administered, a five-day faecal collection period commenced. The faecal bags were collected and changed daily. Harnesses were used for the first study to confirm that C_{36} dilution in the faeces would accurately predict faecal output. This was confirmed and harnesses were not used for the remaining three studies. For these studies, faecal samples were collected by rectal grab sampling. Faecal samples were collected from cows by the same method used for lactating and non-lactating cows (**3.3**).

Throughout the five-day collection period in each of the four studies, faecal samples were collected from companion wethers and cows that had not received alkane capsules but were grazing with the dosed animals. These samples were bulked across the collection period and were used to provide an estimate of background concentrations of C_{32} and C_{36} in the diet.

3.5 Chemical analyses

Plant, faeces, blood and rumen fluid samples were analysed using the methods described in Appendix 2.

3.6 Faecal microhistology

The microhistological techniques were adapted from the method described by Sparks and Malechek (1968). Samples of all plants found in the grazing areas were collected to make a reference slide collection. The plants were identified, dried at 70°C for 48 hours, and ground through a 1mm screen. A small sub-sample of each plant was placed in a vial containing sodium hypochlorite (household bleach) for 30 minutes (Holechek 1982) and then washed with clean water for one minute over a 0.1mm screen.

The washed sample was placed on a microscope slide and three or four drops of Hertwig's solution was added to the wet sample. A small alcohol burner was used to boil the Hertwig's solution off the slide. Hoyer's solution was then added to the slide and a cover slip was placed on the dispersed sub-sample. The edges of the cover slip were sealed with Hoyer's and the slides were allowed to harden for five days in a drying oven set at 55°C.

Slides made to examine plant cuticles in sheep faeces were prepared in the same manner as the plant slides. Five slides were prepared for each faecal sample. For each sheep, a 10g sub-sample of each days' faecal output was bulked over the five-day collection period to produce a single sample representative of the grazing period. Enough of each sample was placed on each slide to generate at least 6 identifiable fragments per field of view when observed at 100x magnification. This is a compromise on the objective of achieving a frequency of the most numerous item of 86%. At this frequency, the use of relative frequency calculations is optimised (Hansen 1971). Twenty-five fields were observed on each slide, assessing at least 750 recognisable fragments. Only fragments recognised as epidermal tissue were recorded. Slides were viewed with the aid of phase contrast microscopy (Olympus model CHA, Olympus Optical Company, Japan).

For each sheep, the number of fields in which each plant species was viewed was reported and presented as a percentage of the total number of fields viewed. This value, the percentage frequency (Hansen 1971), was then converted to density of particles using the formula;

$$Density = -\ln\left(1 - \frac{\%\ frequency}{100}\right) \tag{3.1}$$

Density was subsequently converted to relative density as follows;

$$Relative\ density = \frac{density\ of\ particles\ of\ species\ A}{total\ density\ of\ particles\ of\ all\ species} * 100 \tag{3.2}$$

On the basis of regressions relating the estimated percentage of dry weight (relative density) to actual percentage of dry weight being 1:1, the percentage dry weight of any component species in the diet was subsequently deduced to be numerically equivalent to relative density (Sparks and Malechek 1968).

Similarity indices were calculated to evaluate the seasonal effects on diet composition (Feisinger *et al.* 1981). The similarity index was calculated as;

$$Similarity\ (S) = 1 - 0.5 * \sum [p_{ij} - p_{ik}] \tag{3.3}$$

where p_i is the proportion of each plant in diet, and j and k are seasonal diets compared.

In addition, diversity of diets between seasons was calculated as;

$$Diversity\ (D) = \frac{1}{\sum ai^2} \tag{3.4}$$

where a_i is the proportion of each species in the diet (Hill 1973).

3.7 Interpreting alkane analyses

Estimating faecal excretion and correcting for incomplete alkane recovery

The end point of release of C_{36} and C_{32} from capsules was determined by collecting faeces from dosed sheep for 30 days after the capsules were administered to sheep. The mean release rates of alkanes from the capsules were then estimated according to the manufacturers instructions. Faecal C_{36} concentrations were adjusted for incomplete recovery using assumed recovery rates of 78.2%, 79.0%, and 73.2% for the studies involving weaner and shearling wethers, and ewes, respectively. Faecal DM excreted was then;

$$Faecal\ DM\ excreted\ = \frac{daily\ release\ of\ C36\ from\ capsule}{(faecal\ C36 \div recovery)} \tag{3.5}$$

The quantity of C_{32} excreted was calculated as the product of faecal DM (**Eq. 3.5**) and the concentration of C_{32} appearing in the faeces;

$$C32\ excreted = faecal\ DM * faecal\ C32 \tag{3.6}$$

C_{32} recovery was then calculated as;

$$C32\ recovery = \frac{daily\ release\ of\ C32\ from\ capsule}{C32\ excreted} * 100 \tag{3.7}$$

The recoveries for C_{32} and C_{36} were then plotted, and recoveries for alkanes over the range C_{25} to C_{36} were obtained by linear regression. Estimates for the recoveries of these alkanes were required to enable

faecal concentrations of natural alkanes to be corrected for use in the EatWhat diet calculator, and to then estimate botanical composition of the diet. The recovery of alkanes of different chain length varies in a curvilinear fashion (Dove 1998) and this linear regression approach would introduce a small error in subsequent dietary calculations. For this reason, faecal material was subjected to microhistological examination and plant cuticle fragments were identified to confirm that the botanical composition predicted by EatWhat reflected the actual plant species consumed by the animals. This additional measure was included to minimise the small error that may be introduced by the regression.

Estimating DM intake

Four estimates of DMI were calculated for each study period: DMI_M, DMI_{31}, DMI_{33} and DMI_{ADJ}

$\underline{DMI_M}$

The first estimate was an implied figure derived directly from the micohistological analysis of faecal material. Once the species composition of the diet had been determined by microscopic methods, the DMD's of each of the species contributing to the diet were summed in proportion to their representation in the diet, and in conjunction with faecal output, the summed DMD was subsequently used to calculate DMI_M using **Eq. 3.8**.

$$Forage\ intake = \frac{faecal\ output}{(1 - diet\ digestibility)} \tag{3.8}$$

$\underline{DMI_A}$

The remaining three DMI estimates were derived with the assistance of dosed and herbage alkane concentrations in the feed and faeces. These estimates are reported generally as DMI_A in the following text. To obtain these estimates, the herbage concentrations of C_{31}, C_{32} and C_{33} for use in **Eq. 3.9** (H_i and H_j) were first estimated by summing the products of the proportional representation of each plant species appearing in the diet, multiplied by their respective C_{31}, C_{32} and C_{33} concentrations.

$$Intake = \left(\frac{Fi}{Fj} * Dj\right) \div \left(Hi - \frac{Fi}{Fj} * Hj\right) \tag{3.9}$$

An implied value for herbage concentration of each alkane was then produced, and this approach is considered preferable to other pasture sampling methods to obtain a representative estimate of the concentration of herbage alkanes consumed (Dove 1998). Two estimates of DMI_A were then calculated using the implied herbage and uncorrected faecal concentrations of both the C_{31}:C_{32} and C_{32}:C_{33} alkane pairs in **Eq. 3.9**. DMI_A calculated by the C_{31}:C_{32} pair is reported as DMI_{31}, and where calculated by the C_{32}:C_{33} pair, DMI_{33}.

The third and final estimate of DMI_A was calculated using the ratio of the mean of C_{31} and C_{33} values adjusted for incomplete recovery using the values reported in Table 3, to the adjusted C_{32} content (DMI_{ADJ}). The value produced by this method is generally intermediate between DMI_{31} and DMI_{33}. It has been proposed that this method provides a correction for the imperfect adjustment for differences in recovery of adjacent pairs of alkanes that lead to discrepancies between the values produced by DMI_{31} and DMI_{33} (Herd *et al.* 1998). DMI_{ADJ} was subsequently chosen as the preferred figure to quantify the consumption of Falklands' native pasture.

Estimating DM digestibility

DMD of the diet consumed was estimated using both microhistological and alkane methods. Six estimates were subsequently derived for each study period and are reported as DMD_M, $DMD_{31:32}$, $DMD_{33:32}$, DMD_{31}, DMD_{33}, and DMD_{ADJ} as follows:

$\underline{DMD_M}$

The DMD's of each of the species contributing to the diet were determined by chemical analysis (Appendix 2). Once the species composition of the diet had been determined by microscopic methods, the chemically-determined DMD's for each species were summed in proportion to their representation in the diet. This generated an implied estimate of DMD_M.

$\underline{DMD_{AF}}$

DMD was estimated by alkane methods as a proportion of the difference between intake, estimated by $C_{31:32}$, $C_{33:32}$ or DMI_{ADJ}, and faecal output. This data is presented in the text under the general heading DMD_{AF}, and specifically as $DMD_{31:32}$, $DMD_{33:32}$ and DMD_{ADJ} for estimates derived from DMI_{31}, DMI_{33} and DMI_{ADJ}, respectively. These three estimates of DMD_{AF} were calculated as follows;

$$DMD_{AF} = \frac{DM\ intake\ (2.5) - faecal\ DM\ excreted\ (4.5)}{DM\ intake\ (2.5)} * 100 \qquad (3.10)$$

DMD_{ADJ} was subsequently chosen as the preferred figure to estimate the quality of Falklands' native pasture consumed by sheep during the studies.

$\underline{DMD_{AC}}$

Two estimates of DMD were derived from the dilution of herbage concentrations of C_{31} or C_{33} in the faeces, and are presented in the text under the general title DMD_{AC}, and specifically as DMD_{31} and DMD_{33} when derived from the dilution of C_{31} or C_{33}, respectively. An adjustment was made for incomplete recovery of the alkanes in the faeces using the recoveries presented in Table 3 as follows;

$$DMD_{AC} = 100 - \left(100 * \frac{concentration\ of\ alkane\ in\ herbage}{adjusted\ concentration\ of\ alkane\ in\ faeces}\right) \quad (3.11)$$

Additional calculations

The concentration of CP, NDF, P and Ca in diets was estimated with the assistance of microhistology. Implied concentrations of CP, NDF, P and Ca were calculated by summing the product of the DM proportion that each plant species contributed to the diet and the nutrient content of each species (Appendix 3). These implied concentrations are presented in the text as CP_M, NDF_M, and P_M intake and Ca_M intake. ME concentration in the diet was calculated for each diet by two methods. Firstly, ME_M was implied from microhistology by the same method as CP_M, NDF_M, P_M and Ca_M. ME concentration was also estimated from DMD_{ADJ} using the formula listed as **3.12** (Freer *et al.* 1997), and where ME intake is presented in the text, it is derived from this estimate of the ME content of the diet.

$$ME = 0.168\left[\left\{(0.95 * DMD) - 0.9\right\} + EE\right] - 1.19 \quad (3.12)$$

3.8 Statistical analyses

The statistical package Systat 5.03 (Wilkinson *et al.* 1992) was used to examine relationships within data. Analysis of variance (ANOVA) and analysis of covariance methods (ANCOVA), where appropriate, were used to establish significant differences between treatment means. Individual least squares means were compared using Tukey's HSD test. Standard errors denoted as **s.e.m.**, and reported in tables of means are based on the residual variance in the ANOVA. Standard errors denoted as **s.e.** estimate the variance within a single treatment group.

4.0 RESULTS

4.1 Botanical composition

Cuticle patterns were easily recognisable for most species encountered. However, several plants shared similar cuticle patterns hence some species have been allocated to general categories. In particular, Smooth-stalked Meadow-grass (*Poa pratensis*) was difficult to distinguish from Mountain Bluegrass (*Poa alopecuris*), consequently where this pattern was recognised it was described as *Poa pratensis* as this species is more widespread amongst White-grass (*Cortaderia pilosa*) communities than *Poa alopecuris* (Moore 1968). Wavy Hair-grass (*Deschampsia flexuosa*) and Native Rush (*Juncus scheuzerioides*) shared common patterns, however an attempt was made to distinguish between the two species. Consequently, this data may be viewed with some overlap. A number of forbs were not identifiable to the species level in the faeces, however common patterns shared by forbs were recognised and these were reported under the general heading 'unidentified forbs'. Forbs that were included in this group included Sorrel (*Rumex*

acetosella), Chickweed (*Cerastium arvense*), Carrot Weed (*Cotula scariosa*), Daisy (*Bellis perennis*), and *Pratia repens*. When CP and DMD were estimated for implied diets from microhistological results, seasonal values for 'unidentified forbs' were estimated by summing the nutrient concentrations, determined by chemical analysis (Appendix 3), of each of the individual species and calculating the mean.

In all 10 diet studies, microhistology proved to be the most suitable technique to estimate botanical composition of diets. The results from microhistology generally indicated that up to 95% of the DM consumed was made up of 8 to 11 species. Alkane patterns for these dominant species were subsequently used in EatWhat in an attempt to solve diets mathematically. However, EatWhat was unable to provide solutions for diets containing all, or even the majority of the component species identified by microhistology. Several correction factors were applied to correct for incomplete faecal recovery of alkanes (Dove and Olivan 1998, Dove and Mayes 1991), including the recoveries estimated in these studies, and uncorrected faecal concentrations, however no data set proved better than any other in providing solutions for botanical composition.

As an alternative to EatWhat, the Solver routine in Microsoft Excel was tested for an ability to estimate botanical composition. Solver was able to generate solutions for botanical composition, subject to the constraints placed on the model (i.e. forcing it to select species to include in the solution). However, when the Solver botanical compositions were later used to derive implied herbage concentrations of alkanes for subsequent estimation of DMI (**Eq. 3.9**), the solutions provided by Solver were no more robust than the estimates of DMI and DMD calculated using the herbage alkane concentrations implied by the composition of the diet established using the microhistological techniques. Consequently, microhistology results for botanical composition of diets were used in all studies to estimate herbage concentrations of alkanes, and to subsequently estimate DMI and DMD.

4.2 Alkane release rate from capsules

Sheep

The manufacturer of the alkane capsules (Captec, NZ) claimed that capsules for 25kg to 80kg sheep contained 1g each of the two alkanes C_{32} and C_{36}, and the capsule released these alkanes at a rate of approximately 50mg/day. In addition, Captec estimated an end point of release from the capsules occurring between 17 and 23 days following administration to the animal. Quality control assessments produced by CSIRO using fistulated sheep grazing a ryegrass and white clover pasture are available for each batch of capsules. For the capsules used in all of the sheep diet studies (batch no. 600243), C_{32} and C_{36} concentrations in the capsule tablets were 19.6% and 19.0% w/w respectively, and mean release rates were cited as 43.9mg/day and 42.6mg/day for C_{32} and C_{36}, respectively.

To confirm that the data provided by CSIRO for sheep grazing ryegrass and white clover was valid for sheep grazing Falklands' native pasture, the end point of release of the capsules was determined under Falklands' conditions using data collected from the five weaner sheep used during the first study period in winter (Fig. 4.1). Captec defines the end point of release as the day before a 50% drop in alkane concentration occurs. By this definition, the end point was day 23. Consequently, mean release rates of C_{32} and C_{36} were estimated to be 42.6mg/day and 41.3mg/day respectively, and were similar in magnitude to those estimated by CSIRO. These Falklands' figures were subsequently used in all calculations to estimate faecal output and feed intake.

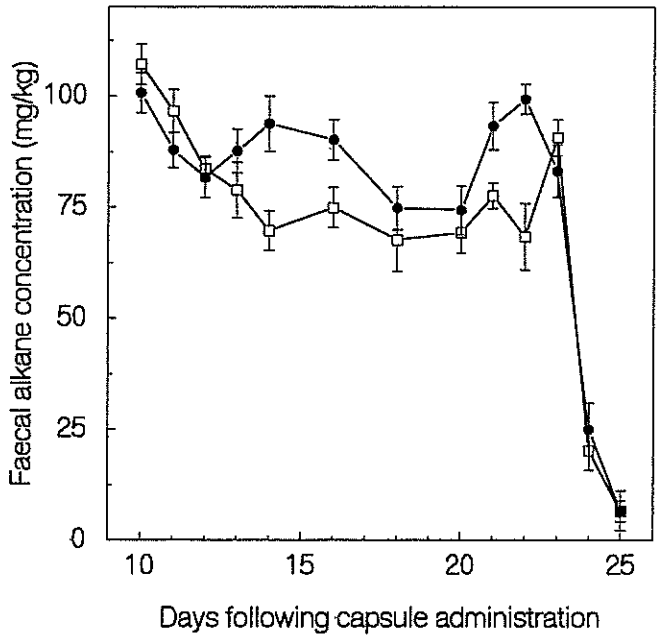

Figure 4.1 Daily faecal concentrations of n-alkanes C_{32} (●) and C_{36} (□) in sheep dosed with Captec alkane capsules for 25 days following administration of the capsule

Cattle

CSIRO quality control assessments determined release rates for alkane capsules from batch no. 600215 (for 300-650kg cattle) to be 409.5g/d and 395.3g/d for C_{32} and C_{36}, respectively. During the first study period for dry and lactating cows, faeces were collected for 30 days after the capsules were administered. Analysis of these faecal samples suggested that the capsules continued to release C_{32} and C_{36} for 30 days. Consequently, release rates for use in equations to predict faecal output and DMI were adjusted to reflect this extended release period, and were 249g/d and 240g/d for C32 and C36, respectively. These values were used in these Falklands' studies in preference to the values determined by CSIRO for cattle fed ryegrass-clover pastures.

4.3 Faecal recovery of alkanes

Assuming a faecal recovery of 95% for C_{36} (Dove and Mayes 1996), faecal output estimated from the dilution of dosed C_{36} during the first three study periods was substantially greater than that measured by the faecal collection harnesses. The source of this error was believed to be the method used to dry the samples (oven dried at 70°C), since it has been shown that oven drying reduces the recovery of alkanes when compared to freeze dried samples (Dove and Mayes 1991). Consequently, the recovery for C_{36} was recalculated by adjusting the estimated faecal output from C_{36} dilution to equate to faecal output measured by the harnesses. Using this procedure, mean C_{36} recovery (±s.e.) across all studies was calculated as 78.1±1.17%. Recoveries were also calculated for the alkanes C_{29} to C_{33} by summing implied herbage concentrations of each alkane, and calculating loss using actual faecal concentrations of each alkane. Recovery tended to decrease with decreasing carbon chain lengths across the range C_{33} to C_{29} (Table 4.1).

Table 4.1 Faecal recoveries of alkanes for diet studies with lactating ewes and weaner and shearling wethers

	Faecal recovery (%)					
	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{36}
Weaners						
mean	74.3	80.5	84.3	81.6	81.5	78.2
s.e.	3.65	4.92	2.15	1.97	1.93	1.53
Shearlings						
mean	74.4	77.3	78.7	80.8	80.8	79.0
s.e.	3.88	4.51	2.63	1.80	1.80	2.12
Ewes						
mean	83.3	53.6	70.6	76.9	76.9	73.2
s.e.	4.96	2.48	3.93	4.47	4.47	0.82
All sheep						
mean	75.3	76.6	80.7	80.8	80.8	78.1
s.e.	2.42	3.27	1.66	1.27	1.26	1.17

Actual faecal output was not determined for cattle. Consequently, mean faecal recoveries established for sheep in the Falklands were also used to estimate faecal output by cattle grazing Falklands' native pasture.

4.4 Preliminary study with lactating ewes

Composition of the diet

Fine grasses, particularly Smooth-stalked Meadow-grass, Annual Meadow-grass, Native Fescue and Bent comprised 62% of the diet selected by ewes grazing native pasture during early summer (Table 4.2). The proportion of White-grass in the diet was similar to Bent and Native Woodrush. Mountain Berry was the only shrub present in substantial quantities in the diet and made a similar proportional contribution to

Native Woodrush. The diversity of the diet (Table 4.3) was similar in magnitude to the diets consumed by weaner sheep (8.38) during summer, and mature wethers during early summer (7.56) and late summer (7.59).

Table 4.2 Estimated seasonal diet of lactating ewes grazing native pasture in early summer

Common name	Scientific name	Mean (% of DM)	s.e.
Grasses and sedges			
White-grass	*Cortaderia pilosa*	8.7	2.02
Smooth-stalked Meadow-grass	*Poa pratensis*	27.3	0.32
Annual Meadow-grass	*Poa annua*	10.6	0.38
Bent	*Agrostis capillaris*	8.5	0.39
Native Fescue	*Festuca magellanica*	15.8	1.14
Early Hair-grass	*Aira praecox*	0.5	0.26
Native Fog	*Trisetum spicatum*	0.1	0.07
Cinnamon Grass	*Heirochloë redolens*	0.9	0.32
Wavy Hair-grass	*Deschampsia flexuosa*	1.2	0.24
Native Woodrush	*Luzula aplopecuris*	7.3	1.84
Native Rush	*Juncus scheuzerioides*	3.6	0.97
Forbs			
Small Fern	*Blechnum penna-marina*	2.2	0.32
Pig Vine	*Gunnera magellanica*	1.0	0.71
Pale Maiden	*Sisyrinchium filifolium*	1.1	0.19
Daisy flowers	*Bellis perennis*	0.2	0.06
Scurvy Grass	*Oxalis enneaphylla*	0.1	0.06
Unidentified forbs		3.3	1.15
Shrubs			
Mountain Berry	*Pernettya pumila*	7.7	2.67
Christmas Bush	*Baccharis magellanica*	0.1	0.06
Diddle-dee	*Empetrum rubrum*	0.1	0.05

Table 4.3 Estimated diet of lactating ewes grazing native pasture in early summer. *Means with different letters differ significantly at P=0.05*

Species	% of DM
White-grass	8.7 bc
Fine grasses	62.8 a
Woody plants	7.8 bc
Forbs	5.6 bcd
Ferns	2.2 cd
Sedges	11.7 b
Berries	0.0 d
Wavy Hair-grass	1.2 cd
s.e.m.	1.62
Diversity index	7.14

Intake and digestion

Using the diet composition predicted by microhistology, the implied concentration of CP_M and NDF_M in the diet, and DMD_M and ME_M concentration was calculated by summing the proportional contribution of each nutrient for each species present in the faeces (Table 4.4).

During the study the ewes weighed 48.6±1.27kg and were gaining weight at a rate of 66±26.0g/d. Mean daily milk production for the period of the study (days 13 to 18 of lactation) was 1.29±0.320kg/d. Faecal output estimated from the dilution of C_{36} in the faeces did not differ between animals during the collection period and was 621, 551, 616, and 628±44.4g/d, respectively for the four ewes.

Table 4.4 Quality of the diet consumed by lactating ewes estimated using microhistological techniques

Parameter	Mean	s.e.
CP_M (%)	12.0	0.09
DMD_M (%)	61.5	0.34
Estimated ME_M (MJ/kg)	8.8	0.06
NDF_M (%)	53.1	0.65
P_M (%)	0.15	0.002
Ca_M (%)	0.25	0.016

Both values for DMI_A, estimated by alkane methods, were greater ($P<0.05$) than DMI_M, estimated by microhistological methods, and varied from 37% to 51% greater for DMI_A predicted by the $C_{31:32}$ pair (DMI_{31}) and the $C_{33:32}$ pair (DMI_{33}), respectively (Table 4.5). These differences were also reflected when DMI was expressed as a percentage of liveweight and metabolic liveweight.

Table 4.5 DM intake of native pasture by lactating ewes, and estimated with the aid of microhistological and alkane techniques. *Within rows, means with different letters differ significantly at P=0.05*

	DMI_M	DMI_A			
Parameter		DMI_{31}	DMI_{33}	DMI_{ADJ}	s.e.m.
DM intake					
kg/d	1.56 a	2.14 b	2.36 b	2.18 b	0.06
$g/kg^{0.75}$	84.5 a	116.7 b	128.6 b	118.8 b	4.54
% of liveweight	3.2 a	4.4 b	4.9 b	4.5 b	0.19

DMD_A calculated using alkane methods (DMD_{AF}, **Eq. 3.10** and DMD_{AC} **Eq. 3.11**) were greater ($P<0.05$) than DMD_M (Table 4.6). This difference was 10.5 and 13.5 units for DMD_{AF}, estimated with the $C_{31:32}$ and $C_{33:32}$ estimates of DMI_A, respectively. DMD_{AC} calculated from the dilution of herbage C_{31} and C_{33} were similar to DMD_{AF} for the $C_{31:32}$ pair. However DMD_{AC} derived by C_{31} was less than DMD_{AF} for the $C_{33:32}$ pair ($P<0.05$). Estimates of DMI_A and DMD_{AF} by the $C_{31:32}$ alkane pair tended to be lower than those estimated by the $C_{33:32}$ pair, but not significantly. DMD_{ADJ} was calculated using DMI_{ADJ} in

conjunction with faecal output estimated by C_{36}, and was close to the mean of all alkane DMD estimates (72.6% v.72.4%, respectively).

Table 4.6 Estimated DMD of native pasture consumed by lactating ewes, using microhistological (DMD_M) methods, and alkane methods using DMI estimated by $C_{31:32}$, $C_{33:32}$ (DMD_{AF}), or DMI_{ADJ} (DMD_{ADJ}), or from the dilution of herbage concentrations of C_{31} or C_{33} in the faeces (DMD_{AC}). *Means with different letters differ significantly at P=0.05*

	DMD_M	DMD_{AF}		DMD_{AC}		DMD_{ADJ}	
		$C_{31:32}$	$C_{33:32}$	C_{31}	C_{33}		s.e.m.
DM digestibility (%)	61.5 a	72.0 bc	74.6 c	70.3 b	72.7 bc	72.6	0.72

Estimates of OMD and digestible DMI and OMI were derived from the alkane estimates of DMI_{ADJ}, and OM% of feed and faeces respectively (Table 4.7).

Table 4.7 Intake and quality of the diet consumed by lactating ewes estimated using alkane techniques

Parameter	Mean	s.e.
DMD_{ADJ} (%)	72.6	0.74
OMD (%)	74.3	0.76
DDMI (kg/d)	1.58	0.050
DOMI (kg/d)	1.52	0.049
ME intake (MJ/d)	22.6	0.744
CP_M intake (g/d)	263	8.8
Apparent N digestibility (%)	63.0	4.63
P_M intake (g/d)	3.24	0.128
Ca_M intake (g/d)	5.41	0.358

4.5 Intake and digestion by weaner sheep

Liveweight change

The seasonal liveweight change of weaner wethers during the period that the diet studies were conducted is shown in Fig 4.2. Growth rates for these sheep were highest during November to January and March to June. Body growth was slowest during winter and spring (June to October).

Seasonal composition of diets

Botanical composition of the diet consumed by weaner sheep, determined by microscopic analysis of cuticle patterns, differed significantly between the five study periods (Table 4.8).

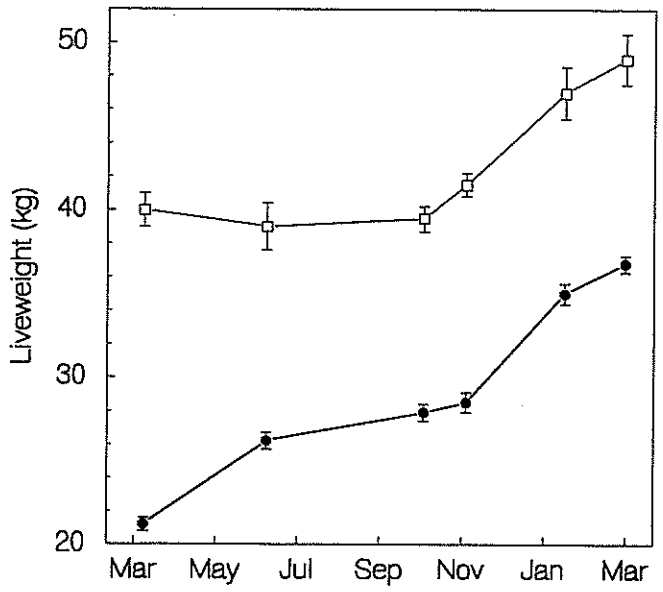

Figure 4.2 Annual liveweight changes of weaner (●) sheep and co-grazed sheep (□) grazing native pasture

Table 4.8 Estimated seasonal diet of weaner sheep grazing native pasture, derived using microhistological methods. *Within rows, means with different letters differ significantly at P=0.05*

Plant species Common name (*Scientific name*)	Winter	Early spring	Late spring	Summer	Autumn	s.e.m.
Grasses and sedges						
White-grass (*Cortaderia pilosa*)	37.9 a	45.9 a	32.1 a	7.3 b	42.3 a	3.32
Smooth-stalked Meadow-grass (*Poa pratensis*)	6.3 a	8.7 a	11.8 a	22.0 b	10.2 a	1.41
Annual Meadow-grass (*Poa annua*)	1.2 a	2.3 a	3.6 a	9.6 b	2.3 a	0.72
Bent (*Agrostis capillaris*)	2.2 a	1.4 a	1.1 a	5.0 b	2.7 a	0.51
Native Fescue (*Festuca magellanica*)	0.4 a	1.0 ab	2.8 ab	10.3 c	3.4 b	0.59
Early Hair-grass (*Aira praecox*)	1.3 a	0.0 a	1.0 a	5.0 b	1.2 a	0.44
Native Fog (*Trisetum spicatum*)	0.0 a	0.0 a	0.0 a	0.2 b	0.0 a	0.05
Cinnamon Grass (*Heirochloë redolens*)	0.8	0.6	0.3	0.3	2.3	0.50
Wavy Hair-grass (*Deschampsia flexuosa*)	9.2 a	4.1 ab	1.4 b	1.6 b	4.6 ab	1.51
Native Rush (*Juncus scheuzerioides*)	0.5 a	0.8 a	4.1 b	2.1 ab	2.7 ab	0.49
Native Woodrush (*Luzula alopecuris*)	1.4	4.6	5.8	14.0	9.3	1.84
Forbs						
Small Fern (*Blechnum penna-marina*)	7.2 a	8.6 ab	15.4 b	7.6 a	12.1 ab	1.82
Pig Vine (*Gunnera magellanica*)	1.4	0.3	0.3	0.3	0.2	0.25
Pale Maiden (*Sysyrinchium filifolium*)	0.6	0.1	0.3	0.5	0.0	0.13
Carrot Weed (*Cotula scariosa*)	0.3 ab	0.7 b	0.3 ab	0.0 a	0.0 a	0.12
Chickweed (*Cerastium arvense*)	0.0	0.2	0.0	0.2	0.0	0.07
Scurvy Grass (*Oxails enneaphylla*)	0.6	0.1	0.4	0.6	0.0	0.16
Unidentified forbs	0.3 a	1.0 a	3.3 b	4.1 b	3.1 b	0.37
Shrubs						
Mountain Berry (*Pernettya pumila*)	25.9 a	16.0 b	14.7 bc	7.2 cd	2.7 d	2.01
Christmas Bush (*Baccharis magellanica*)	0.6 a	0.2 ab	0.3 ab	0.1 b	0.2 ab	0.11
Diddle-dee (*Empetrum rubrum*)	2.0 ab	3.4 a	1.0 b	1.2 b	0.4 b	0.48
Diddle-dee berries	0.0	0.0	0.0	0.7	0.2	0.26

White-grass contributed a substantial part of the diet during all periods except summer, during which its contribution declined by 77% compared to late spring, and 83% compared to autumn. White-grass, Smooth-stalked meadow-grass, Wavy Hair-grass, Small Fern and Mountain Berry were amongst the most abundant species consumed during the year. Wavy Hair-grass was more abundant ($P<0.05$) in the winter diet compared to the summer and late spring diets.

During summer a wider range of species were identified in the faeces, of which Smooth-stalked meadow-grass, Bent, Native Fescue, and Annual Meadow-grass were the most abundant. The proportion of these 'fine grasses' in the diet was greater in summer than in any other diet period ($P<0.05$, Table 4.9). Consequently, fine grasses contributed more DM to the diet ($P<0.05$) than any other groups during summer. During late spring and autumn, White-grass and fine grass contributions to the diet were similar.

Sedges, that is Native Woodrush and Native Rush, made greater contributions to the diet during summer and autumn than during winter ($P<0.05$). Native Woodrush contributed the majority of DM to the sedges. Similarly, forbs including Pig Vine, Pale Maiden, Carrot Weed, Chickweed, Scurvy Grass, *Pratia repens*, Sorrel, Chickweed, Daisies and Carrot Weed were more abundant ($P<0.05$) in the summer diet than during early spring.

The proportion of woody species in the diet declined from winter to late spring ($P<0.05$), and further declined in summer compared to late spring, and in autumn compared to summer. The changes in the seasonal contributions of forbs, White-grass, fine grasses, sedges and woody species are clearly evident in Fig. 4.3. Neither Cinnamon Grass nor Diddle-dee berries contributed substantially to the diet, and their variable contributions to the diet were not significant during the year.

Table 4.9 Estimated seasonal diet of weaner sheep grazing native pasture, derived using microhistological methods. Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05

Species	Winter	Early spring	Late spring	Summer	Autumn	s.e.m.
White-grass and Cinnamon Grass	38.7 a^{1}	46.4 a^{1}	32.3 a^{1}	7.6 cd^{2}	44.6 a^{1}	3.31
Fine grasses	11.4 b^{1}	13.5 bc^{12}	20.3 b^{2}	52.2 a^{3}	19.8 b^{2}	1.77
Sedges	1.8 bc^{1}	5.1 cd^{12}	9.9 cd^{123}	15.9 b^{3}	12.0 bc^{2}	2.04
Forbs	3.4 $bc^{1,2}$	2.8 d^{1}	4.7 $de^{1,2}$	6.0 cd^{2}	3.5 $cd^{1,2}$	0.69
Ferns	7.2 bc^{2}	8.6 $cd^{1,2}$	15.4 bc^{1}	7.6 cd^{2}	12.1 $bc^{1,2}$	1.82
Wavy Hair-grass	9.2 bc^{1}	4.1 cd^{12}	1.4 e^{2}	1.6 cd^{2}	4.6 cd^{12}	1.51
Woody plants	28.4 a^{1}	19.7 $b^{1,2}$	16.1 $bc^{2,3}$	8.5 $c^{3,4}$	3.3 cd^{4}	2.04
Berries	0.0 c	0.0 d	0.0 e	0.7 d	0.2 d	0.26
s.e.m.	2.27	2.19	1.53	1.53	2.08	

The change in importance of White-grass, fine grasses and Mountain Berry to the diet were reflected in the similarity indices when seasonal diets were compared (Table 4.10). Winter and summer diets were the

least similar (S=0.41), whilst winter and early spring diets proved to be the most similar (S=0.81). When compared to all other study periods, the similarity index for the summer diet was commonly low.

Table 4.10 Similarities between seasonal diets of weaner sheep grazing native pasture

Season	Similarity index
Winter v. Early spring	0.81
Winter v. Late spring	0.70
Winter v. Summer	0.41
Winter v. Autumn	0.68
Early spring v. Late spring	0.79
Early spring v. Summer	0.47
Early spring v. Autumn	0.79
Late spring v. Summer	0.59
Late spring v. Autumn	0.79
Summer v. Autumn	0.55

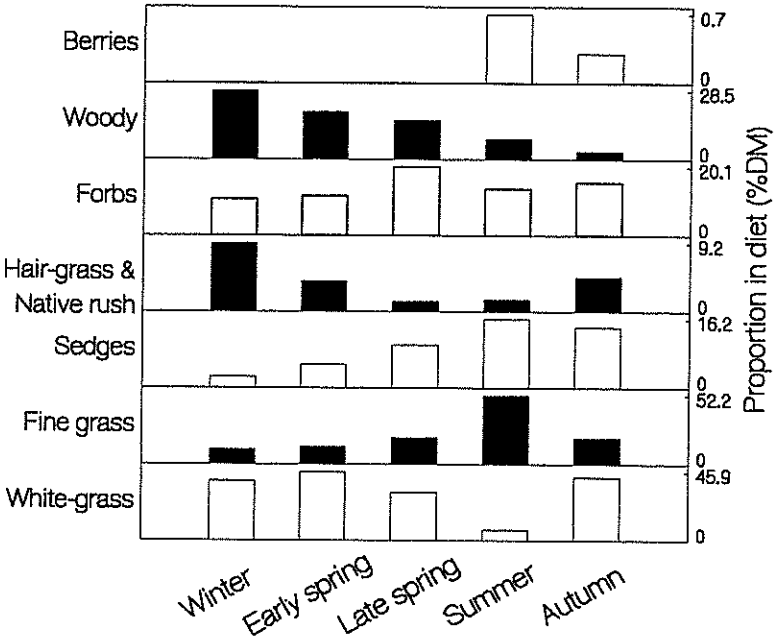

Figure 4.3 Seasonal contribution of White-grass, fine grasses, sedges, Wavy Hair-grass, forbs, woody plants, and Diddle-dee berries to the diet of weaner sheep consuming native pasture

The summer diet was more diverse ($P<0.05$) than the diet at all other times during the year (Table 4.11). The diet in late spring tended to be more diverse than during winter, early spring and autumn, however the trend was not significant.

Table 4.11 Diversity indices for seasonal diets selected by weaner sheep grazing native pasture. *Within columns, means with different letters differ significantly at P=0.05*

Season	Diversity
Winter	4.18 a
Early spring	4.01 a
Late spring	5.66 a
Summer	8.38 b
Autumn	4.54 a
s.e.m.	0.454

Faecal alkane concentrations

Mean faecal C_{32} concentrations tended to increase during the five-day collection periods in the winter, early spring and late spring studies, however C_{36} concentrations did not exhibit the same increasing trends (Fig. 4.4). Both C_{32} and C_{36} faecal concentrations tended to decline during the five-day summer collection period.

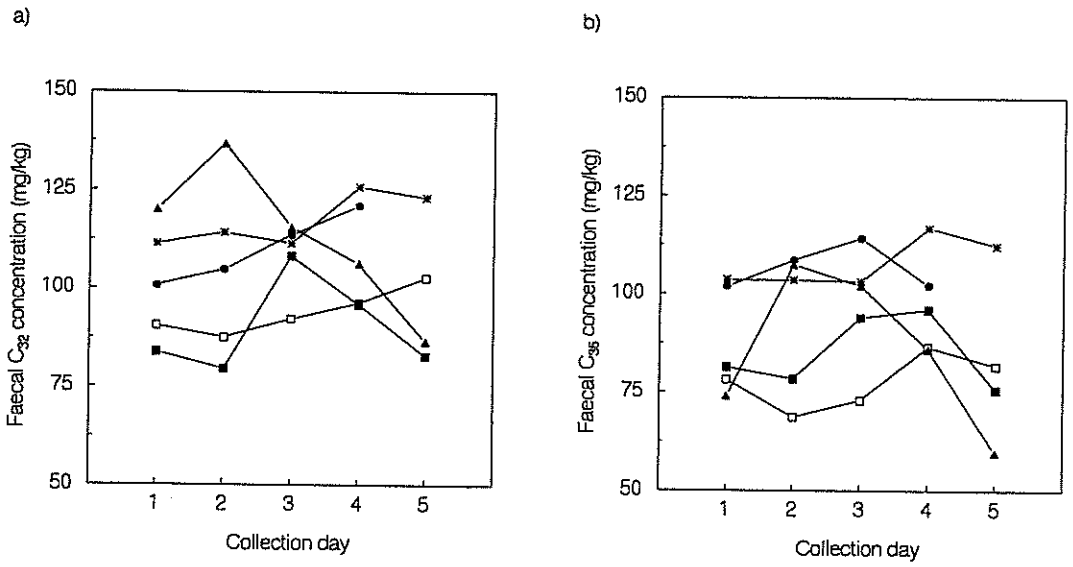

Figure 4.4 Mean faecal concentrations of (a) C_{32} and (b) C_{36} in weaner sheep consuming native pasture and dosed with Captec alkane capsules in winter (●), early spring (□), late spring (▲), summer (✱) and autumn (■)

Intake and digestion

Weaners were heavier ($P<0.05$) in summer and autumn than during winter, and early and late spring (Table 4.15). DMI_M (Table 4.13), DMD_M, CP_M and NDF_M content of the diet were estimated from microhistological data. DMD_M differed between seasons ($P<0.05$, Table 4.12). The diet consumed during summer was more digestible ($P<0.05$) than at all other times of the year and yielded more estimated ME.

The late spring and autumn diets were also more digestible ($P<0.05$) and had higher concentrations of ME/kg than the winter and early spring diets. CP_M content of the diet was also higher ($P<0.05$) during summer than the other four seasonal diets. The early spring diet contained less CP_M ($P<0.05$) than all other diets. NDF_M content of the diets was negatively correlated with DMD_M. Winter, early spring and autumn diets contained more NDF_M ($P<0.05$) than the late spring and summer diets. The summer diet contained less NDF_M ($P<0.05$) than all other diets.

Table 4.12 Estimated nutritional value of diets consumed by young sheep, using microhistological techniques. *Within columns, means with different letters differ significantly at P=0.05*

Diet quality	Early winter	Early spring	Late spring	Summer	Autumn	s.e.m.
CP_M (%)	8.6 b	7.9 a	9.0 bc	10.5 d	9.5 c	0.12
DMD_M (%)	47.9 a	48.2 a	54.0 b	57.0 c	53.5 b	0.052
Estimated ME (MJ/kg)	6.6 a	6.7 a	7.3 b	8.2 c	7.5 b	0.09
NDF_M (%)	62.2 c	63.3 c	54.2 b	49.5 a	61.0 c	1.02
P (%)	0.10 a	0.10 a	0.11 b	0.11 b	0.10 a	0.001
Ca (%)	0.33 a	0.23 b	0.23 b	0.19 bc	0.18 c	0.012

The late spring and summer diets contained more P than the winter, early spring and summer diets ($P<0.05$). However, Ca concentration of diets declined from a peak in winter to lows in summer and autumn ($P<0.05$).

DMI_M was less ($P<0.05$) during winter and early spring than during summer and autumn. DMI_M during late spring was intermediate between the other four periods and was similar to all other seasonal diets. Estimates of DMI_A derived by the two alkane pairs, $C_{31:32}$ and $C_{33:32}$ (DMI_{31} and DMI_{33}) and the mean of adjusted ratios of C_{31} and C_{33} to C_{32} (DMI_{ADJ}) were similar in magnitude to each other within each of the five study periods (Table 4.13). However DMI_{31} was consistently higher than DMI_{33} (10 to 60g/day). For the winter, and early and late spring periods, DMI_M tended to be lower than all DMI_A estimates (19% to 24%), however not significantly. DMI_M was lower ($P<0.05$) than DMI_A for the summer and autumn diets.

DMI_A were higher ($P<0.05$) in summer than during winter and early and late spring. This trend was consistent for DMI_M estimates. Autumn DMI_{31} and DMI_{33} tended to be intermediate between the summer, and winter and spring diets.

DMI_A expressed in terms of liveweight (%) and metabolic liveweight ($g/kg^{0.75}$/day) followed the general pattern of DMI (kg/day), and were higher ($P<0.05$) in summer than winter and early spring. Although the trend to higher summer DMI was apparent in the microhistological data, the differences between periods were not significant for DMI_M as a percentage of liveweight or metabolic liveweight. DMI_M ($g/kg^{0.75}$) was lower than DMI_A (by 9.3 to 28 $g/kg^{0.75}$/day), however the differences between methods for estimating DMI were only significant during summer and autumn ($P<0.05$). This trend was associated with the significantly higher DMD of the summer and autumn diets (Table 4.14).

Table 4.13 Estimated DMI for weaner sheep fed native pasture derived by microhistological (DMI_M) or alkane (DMI_A) methods using the $C_{31:32}$ (DMI_{31}) and $C_{33:32}$ (DMI_{33}) pairs. *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMI_M	DMI_A			
		DMI_{31}	DMI_{33}	DMI_{ADJ}	s.e.m.
		kg/d			
Winter	0.61 a	0.80 a	0.77 a	0.79 a	0.068
Early spring	0.63 a	0.82 a	0.76 a	0.81 a	0.075
Late spring	0.75 ab	0.90 a	0.89 a	0.89 a	0.071
Summer	0.86 b^1	1.29 b^2	1.23 b^2	1.28 b^2	0.068
Autumn	0.90 b^1	1.05 ab^2	1.06 ab^2	1.05 ab^2	0.032
s.e.m.	0.049	0.075	0.068	0.074	
		% of liveweight/d			
Winter	2.1	2.7 a	2.6 ab	2.7 a	0.19
Early spring	2.1	2.7 a	2.5 a	2.7 a	0.16
Late spring	2.3	2.7 a	2.7 ab	2.7 a	0.16
Summer	2.3 ^{1}	3.4 b^2	3.3 b^2	3.4 b^2	0.18
Autumn	2.2	2.6 a	2.6 ab	2.6 a	0.12
s.e.m.	0.13	0.20	0.16	0.20	
		$g/kg^{0.75}/d$			
Winter	47.7	62.8 a	60.6 a	61.8 a	4.28
Early spring	48.7	63.1 a	58.7 a	62.6 a	4.24
Late spring	54.9	65.5 ab	64.4 a	65.0 ab	3.78
Summer	56.9 ^{1}	84.9 b^2	81.2 b^2	84.4 b^2	4.48
Autumn	55.8 ^{1}	65.1 ab^2	65.3 ab^2	65.1 ab^2	2.39
s.e.m.	3.03	4.71	3.94	4.78	

DMD_M of the winter and early spring diets were lower ($P<0.05$) than for the late spring, summer and autumn diets. The summer diet was more digestible than all other diets ($P<0.05$). Alkane estimates of DMD also indicated that the summer diet was more digestible than the four other seasonal diets ($P<0.05$). DMD_{AC} and DMD_{AF} tended to be higher than DMD_M and the differences were significant for the winter, early spring, and summer. DMD_{AC} calculated from the dilution of herbage alkanes **(Eq. 3.11)** were similar to DMD_{AF} calculated by difference between forage intake and faecal excretion **(Eq. 3.10)**.

Table 4.14 Estimated DMD for weaner sheep fed native pasture derived by microhistological (DMD_M) or alkane methods using the $C_{31:32}$ and $C_{33:32}$ pairs (DMD_{AF}, Eq. 3.10), or the dilution of herbage concentrations of C_{31} or C_{33} (DMD_{AC}, Eq. 3.11). *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMD_M	DMD_{AF}		DMD_{AC}		
		$C_{31:32}$	$C_{33:32}$	DMD_{31}	DMD_{33}	s.e.m.
Winter	47.9 a^1	58.9 a^2	57.7 a^2	54.5 a^2	53.4 a^{12}	1.50
Early spring	48.2 a^1	60.0 a^2	56.8 a^{12}	58.4 a^2	55.5 a^{12}	2.19
Late spring	54.0 b	60.1 a	59.6 a	56.9 a	56.5 a	2.61
Summer	57.0 c^1	71.1 b^2	69.8 b^2	72.7 b^2	71.6 b^2	0.86
Autumn	53.5 b	60.5 a	60.6 a	59.3 a	59.3 a	1.78
s.e.m.	0.52	1.62	1.77	2.44	2.47	

ME intake during summer was greater ($P<0.05$) than at all other times, and was more than twice that estimated for winter (Table 4.15). CP intake followed a similar pattern, doubling during summer compared to winter, and was significantly higher in summer and autumn compared to winter and early spring. P intake was lower ($P<0.05$) during winter and early spring than in summer and autumn, and during winter and early spring was lower than the 0.9 g/d recommended for maintenance of 30kg of liveweight (SCA 1990). P intake was adequate for maintenance during late spring and autumn (≥1.1g/d for 40kg of liveweight). Ca intake during all periods was sufficient for maintenance, and was adequate to support growth rates of up to 100g/day. Apparent N digestibility was similar for each of the seasonal diets.

Table 4.15 Estimated DDMI, DOMI, ME intake, apparent N digestibility, and Ca and P intake from native pasture consumed by weaner sheep, and derived from DMI_{ADJ} and DMD_{ADJ} data. *Within rows, means with different letters differ significantly at P=0.05*

Parameter	Winter	Early spring	Late spring	Summer	Autumn	s.e.m.
Liveweight (kg)	29.8 a	30.2 a	33.0 a	37.6 b	42.6 b	1.72
DMD_{ADJ} (%)	57.0 a	59.7 a	59.9 a	70.9 b	60.2 a	2.00
OMD (%)	60.7 a	61.3 a	62.5 a	72.3 b	62.2 a	1.67
DDMI (g/d)	457 a	489 a	540 a	910 b	635 a	58.1
DOMI (g/d)	453 a	472 a	530 a	873 b	617 a	53.9
ME intake (MJ/d)	6.2 a	6.7 a	7.4 a	12.9 b	8.7 a	0.84
CP_M intake (g/d)	67.9 c	64.9 c	80.5 bc	134.2 a	100.3 b	6.77
Apparent N digestibility (%)	60.5	62.2	59.8	63.0	62.4	2.74
P_M intake (g/d)	0.74 a	0.76 a	0.99 ab	1.38 c	1.06 b	0.007
Ca_M intake (g/d)	2.54	1.76	2.01	2.36	1.86	0.020

Nitrogen intake, digestibility and excretion

Plasma urea concentrations demonstrated a marked seasonal pattern of change, falling significantly ($P<0.05$) from early autumn to winter, before rising again in early summer (Fig. 4.5). The same pattern was reflected in ammonia concentrations in rumen fluid collected from weaner sheep belonging to the same group of animals. Excretion of nitrogen in the faeces similarly increased ($P<0.05$) during spring and summer before tending to decline in late summer and autumn.

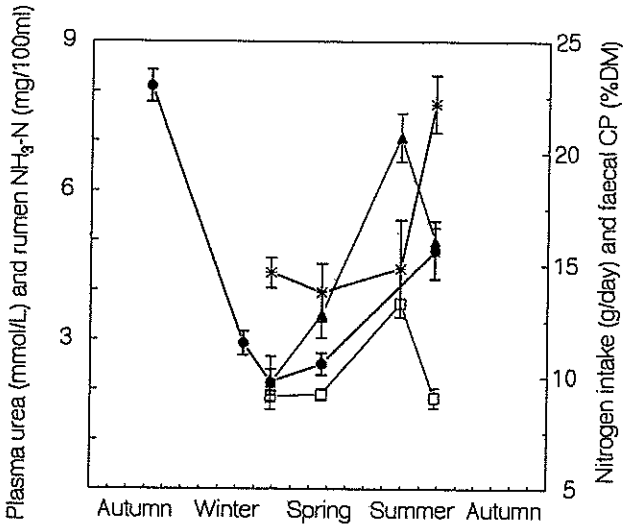

Figure 4.5 Seasonal nitrogen intake (▲, g/d), plasma urea (●, mmol/L), faecal crude protein (□, %DM) and rumen ammonia (✱, mg/100ml) for weaner sheep grazing native pasture during the dietary studies

Phosphorus and calcium intake and excretion

Intake of P_M and Ca_M varied during the year (Table 4.15). Plasma and faecal concentrations reflected the variation in estimated intake of both nutrients. Plasma inorganic P fell ($P<0.05$) from the end of summer to reach a low at the end of winter before rising again during spring and summer (Fig. 4.6). In contrast, although plasma Ca tended to increase from winter to summer, the increase was not significant. Faecal excretion of P and Ca followed similar patterns to the variation in plasma concentrations of Ca and inorganic P. Faecal Ca did not vary significantly during the study, however faecal P excretion increased ($P<0.05$) over the spring and summer period and decreased the following autumn.

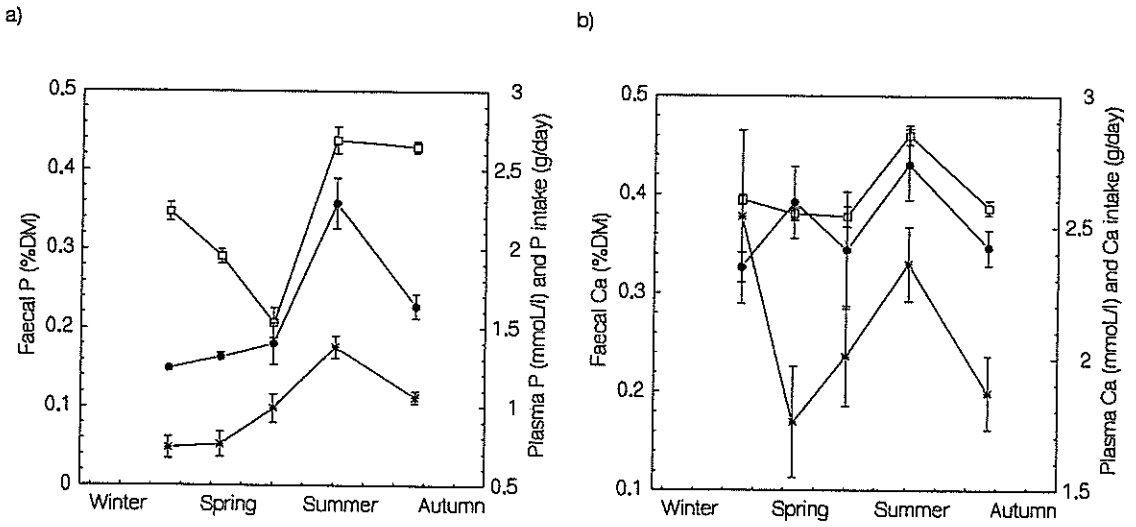

Figure 4.6 a) Seasonal phosphorus intake (✱, g/day), plasma inorganic phosphorus (□), and faecal phosphorus concentration (●, %DM), and b) seasonal calcium intake (✱, g/day), plasma calcium (□, mmol/L), and faecal calcium (●, %DM) for weaner sheep grazing native pasture

Plasma creatinine

Plasma creatinine levels rose ($P<0.05$) during the period from the end of summer to winter, whereupon circulating concentrations declined rapidly during spring and summer (Fig. 4.7).

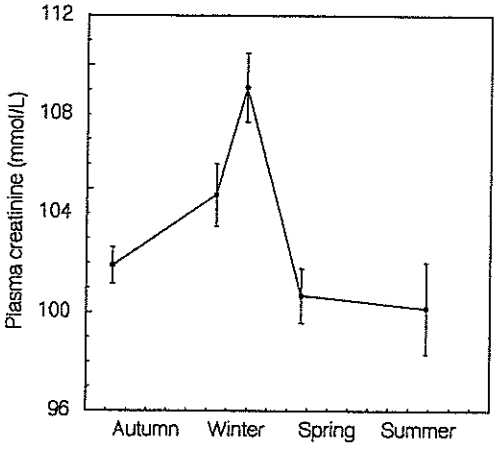

Figure 4.7 Seasonal plasma creatinine (●, mmol/L) concentrations in blood (±s.e.) collected from weaner sheep grazing native pasture

Plasma 25-OH D_3

Plasma concentrations of 25-OH D_3 varied during the year and were lowest during the period from winter to early spring (June to September, Table 4.16), and the concentrations for most weaners were generally deficient (<25nmol/L) between March and October. Highest concentrations were measured in summer (January). The lower limit of detection for assays in March and October was 11nmol/L, and 5nmol/L for all other assay periods. Although mean plasma values during March and October were close to the 25nmol/L concentration below which samples are considered deficient, a substantial number of samples were below this figure, and 65% and 88% of samples were considered deficient for these two months, respectively.

Table 4.16 Plasma concentrations of 25-hydroxyvitamin D_3 from weaner sheep grazing native pasture

	Sampling date						
	11-Mar	26-Jun	22-Jul	15-Sep	3-Oct	9-Dec	16-Jan
Mean (nmol/L)*	25	13	<5	<5	23	34	62
s.e.	2.1	5.5	-	-	4.1	2.3	3.2
No. of sheep sampled	40	40	10	10	40	10	40
No. of samples <5 nmol/L		37	10	9			
No. of samples <11 nmol/L	15				28		

* Mean for samples with 25-OHD_3 concentrations >11nmol/L

Distances travelled

Analysis of the locations of capture of each of the sheep on each day during the five-day diet studies enabled the travelling distances between capture sites to be estimated periodically during the year (Table 4.17). These distances were calculated as the shortest route between the capture sites from day to day, taking into account fence lines, lakes and other physical barriers between capture sites. It was apparent that during winter the sheep travelled shorter distances per day than they did during summer ($P<0.05$). These distances were significantly and positively correlated with day length (correlation=0.91). The curvilinear relationship for distance between capture site and day length was predicted by:

$$Distance\ travelled = (0.0000037 * daylength^2) - (0.0038 * daylength) + 1.9959 \quad (R^2=0.99, P<0.01) \quad (4.1)$$

Table 4.17 Distance between daily capture sites for weaner sheep during seasonal diet studies. *For daily travel, means with different letters differ significantly at P=0.05*

Tracking period	Distance travelled between capture sites (m/d)	Day length (hours:min)
Winter	1,037 a	8:09
Early spring	1,105 a	10:49
Summer	1,967 b	16:41
Autumn	1,314 ab	12:53
s.e.m.	198.2	

4.6 Intake and digestion by lactating and non-lactating cattle grazing Falkland Islands' native pasture

Composition of the diet

Data for the composition of diets consumed by lactating and non-lactating cows have been pooled as there were no significant effects of the physiological state of the cows on the botanical composition of the diets that they selected.

Early Hair-grass, Native rush, Wavy-Hair-grass and White-grass comprised the bulk of DM consumed throughout the year (48.4% to 83.3%, Table 4.18). Cows consumed more White-grass during winter and early spring than during late spring ($P<0.05$). Woody shrubs were not consumed in substantial quantities during the year, and peaked at 6.7% of DM consumed in early spring. Fine grasses were consumed in greater proportions ($P<0.05$) during late spring and late summer compared to early winter, and early winter and early spring, respectively (Table 4.19).

Table 4.18 Species contributing to the diet of mature, non-lactating and lactating cows grazing native pasture, derived using microhistological techniques. *Within rows, means with different letters differ significantly at P=0.05*

Plant species Common name (*Scientific name*)	Late spring	Late summer	Early winter	Early spring	s.e.m.
Grasses and sedges					
White-grass (*Cortaderia pilosa*)	28.2 a	31.9 ab	37.2 b	38.8 b	1.93
Smooth-stalked Meadow-grass (*Poa pratensis*)	3.1 a	6.0 b	1.5 a	2.1 a	0.58
Annual Meadow-grass (*Poa annua*)	0.6 a	3.9 b	1.0 a	1.1 a	0.30
Bent (*Agrostis capillaris*)	3.0 ab	4.0 a	1.3 bc	0.4 c	0.46
Native Fescue (*Festuca magellanica*)	2.0 a	10.3 b	1.9 a	2.3 a	0.91
Early Hair-grass (*Aira praecox*)	15.6 a	12.4 a	7.1 b	12.2 a	1.22
Native Fog (*Trisetum spicatum*)	0.1	0.5	0.1	0.1	0.12
Cinnamon Grass (*Heirochloë redolens*)	3.3 a	0.7 b	1.5 ab	0.7 b	0.42
Wavy Hair-grass (*Deschampsia flexuosa*)	11.1 a	1.2 b	11.7 a	4.9 b	1.28
Native Woodrush (*Luzula alopecuris*)	4.8 ab	8.5 b	1.9 a	3.1 a	0.79
Native rush (*Juncus scheuzerioides*)	20.5 ab	2.9 c	27.3 a	19.1 b	2.04
Forbs					
Small Fern (*Blechnum penna marina*)	2.1 a	2.3 a	4.0 ab	6.5 b	0.67
Pig Vine (*Gunnera magellanica*)	0.2 a	5.0 b	0.4 a	0 a	0.31
Pale Maiden (*Sisyrinchium filifolium*)	0	0.3	0.1	0	0.07
Carrot Weed (*Cotula scariosa*)	0.1	0.4	0.2	0.3	0.13
Chickweed (*Cerastium arvense*)	0	0.3	0.1	0.1	0.14
Daisy (*Bellis perennis*)	0	0.5	0.1	0	0.15
Scurvy grass (*Oxalis enneaphylla*)	0	0.1	0	0.1	0.06
Sorrel (*Rumex acetosella*)	0.5 a	2.1 b	0.4 a	0.5 a	0.30
Pratia repens	0	0.2	0	0.1	0.07
Unidentified forbs	1.4 ab	2.1 a	0.6 b	1.0 ab	0.32
Shrubs					
Mountain Berry (*Pernettya pumila*)	1.7 a	2.3 a	0.9 a	5.0 b	0.62
Christmas Bush (*Baccharis magellanica*)	0.4	0.9	0.6	1.3	0.32
Diddle-dee (*Empetrum rubrum*)	1.0	1.0	0.2	0.3	0.37
Diddle-dee berries	0	0.1	0	0	0.04

Table 4.19 Estimated seasonal diet of mature, non-lactating and lactating cows grazing native pasture. *Within rows, means with different letters, and within columns, means with different numbers differ significantly at P=0.05*

Species	Late spring	Late summer	Early winter	Early spring	s.e.m.
White-grass and Cinnamon Grass	31.6 a^1	32.6 a^2	38.7 ab^1	39.5 b^1	1.97
Fine grasses	29.3 ab^1	45.6 a^1	14.8 c^2	21.2 bc^2	1.92
Forbs	2.2 a^2	11.1 b^3	1.9 a^3	2.1 a^3	0.48
Ferns	2.1 a^2	2.3 a^4	4.0 ab^3	6.5 b^3	0.67
Woody plants	3.2 ab^2	4.2 ab^4	1.6 b^3	6.7 a^3	0.85
Wavy Hair-grass and Native rush	31.7 ab^1	4.1 c^4	38.9 a^1	24.0 b^2	2.14
Berries	0 ^{2}	0.1 ^{4}	0 ^{3}	0 ^{3}	0.04
s.e.m.	1.56	1.37	1.28	1.67	

During late summer, Early Hair-grass and Native fescue were the most abundant fine grasses consumed. Early Hair-grass was consumed proportionally more in spring and summer compared to winter ($P<0.05$). Smooth-staled and Annual Meadow grasses, Bent and Native Fescue were more abundant in cattle diets ($P<0.05$) during late summer compared to winter and early spring (Table 4.18).

The winter and early and late spring diets consumed by cattle were most similar in botanical composition (Table 4.20). The least similar diets were the late summer diet when compared to the winter and early spring diets.

Table 4.20 Similarities between seasonal diets of mature, non-lactating and lactating cows grazing native pasture

Seasons	Similarity index
Late summer v. Early winter	0.51
Late summer v. Early spring	0.53
Late summer v. Late spring	0.63
Early winter v. Early spring	0.84
Early winter v. Late spring	0.80
Early spring v. Late spring	0.76

The botanical diversity of the diets consumed by cattle were greater ($P<0.05$) in late spring and late summer when compared to the winter and early spring diets (Table 4.21).

Table 4.21 Diversity indices for seasonal diets selected by mature, non-lactating and lactating cows grazing native pasture. *Means with different letters differ significantly at P=0.05*

Season	Diversity
Late spring	6.28 a
Late summer	6.59 a
Early winter	4.14 b
Early spring	4.63 b
s.e.m.	0.255

Liveweight changes

Liveweight changes of non-lactating cows, and lactating cows and their calves is presented in Fig. 4.8. Non-lactating cows maintained liveweight for longer than lactating cows, and all cattle lost weight rapidly during winter. Suckling calves gained weight rapidly from birth in January until May (late autumn) and tended to maintain weight through winter.

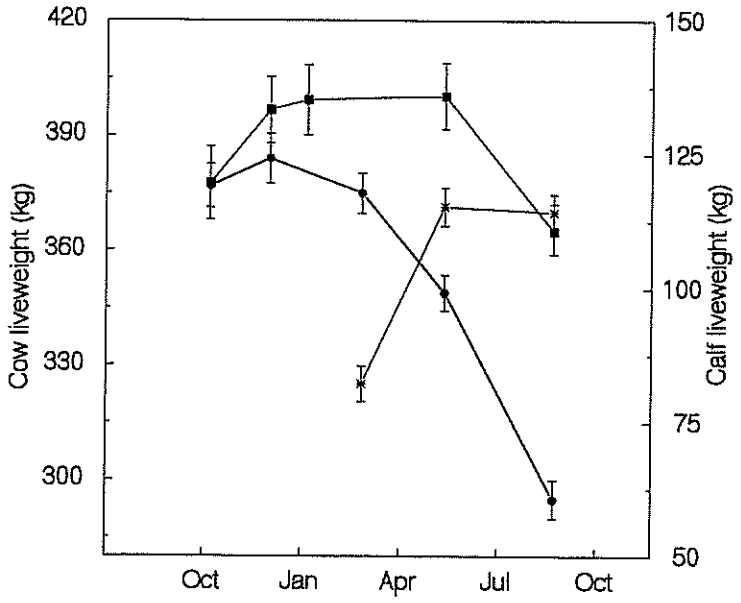

Figure 4.8. Liveweight changes of non-lactating (■) and lactating (●) cows, and calves born to lactating cows (✱)

Faecal alkane concentrations

Faecal concentrations of the dosed alkanes (C_{32} and C_{36}) varied between collection days during each of the four diet studies, however they showed no significant increasing or decreasing trends during the four five-day faecal collection periods (Fig. 4.9).

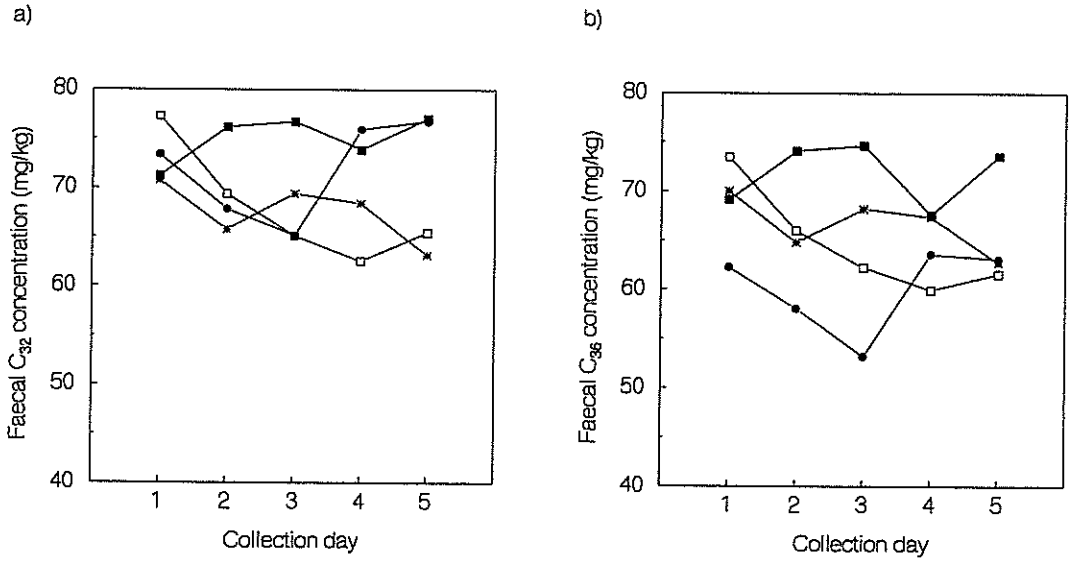

Figure 4.9 Mean faecal concentrations of (a) C_{32} and (b) C_{36} in cattle consuming native pasture and dosed with Captec alkane capsules in late spring (●), late summer (✱), early winter (■), and early spring (□)

Intake and digestion

The implied concentrations of CP_M, ME_M, NDF_M, P_M and Ca_M in the diets consumed by non-lactating and lactating cows was similar throughout the four study periods (Table 4.22). CP_M was higher ($P<0.05$) in late summer than all other periods. P_M content of late spring and late summer diets were greater ($P<0.05$) than diets consumed during winter and early spring, and Ca_M was higher ($P<0.05$) in late summer than all other times. NDF_M concentrations of the late spring and late summer diets were lower than during winter ($P<0.05$). ME_M content was highest during late summer ($P<0.05$).

Table 4.22 Nutritional value of diets consumed by mature, non-lactating and lactating cows, using microhistological techniques. *Within rows, means with different letters differ significantly at P=0.05*

Diet quality	Late spring	Late summer	Early winter	Early spring	s.e.m.
			Dry cows		
CP_M (%)	8.7 a	11.4 b	8.5 a	8.7 a	0.16
Estimated ME_M (MJ/kg)	7.2 b	7.9 a	6.6 c	6.4 c	0.06
NDF_M (%)	66.7 b	59.7 c	69.4 a	67.2 ab	0.61
P_M (%)	0.10 a	0.10 a	0.08 b	0.09 b	0.002
Ca_M (%)	0.10 a	0.17 b	0.11 a	0.10 a	0.006
			Lactating cows		
CP_M (%)	-	10.8 a	8.8 b	8.6 b	0.09
Estimated ME_M (MJ/kg)	-	8.0 a	6.7 b	6.7 b	0.08
NDF_M (%)	-	58.3 a	68.2 b	67.3 b	0.74
P_M (%)	-	0.10 a	0.08 b	0.09 a	0.002
Ca_M (%)	-	0.18 a	0.13 b	0.14 b	0.010

Non-lactating cows

Implied DMI_M for non-lactating cows was similar to DMI_A for three of the four diet study periods, however in all cases DMI_M was lower than DMI_A (Table 4.23). DMI_A was greater than DMIM in late spring ($P<0.05$). For each method used to estimate DMI, non-lactating cows consumed more native pasture ($P<0.05$) in late spring and late summer than during early spring. Although DMI tended to decrease from late summer to early winter, the differences were not significant.

When DMI was expressed in terms of liveweight and metabolic liveweight, DMI_M was lower than DMI_A in each of the four study periods. Intake tended to decline from late spring through until early spring in the following year, and the differences between late spring and late summer compared to early spring were significant. When expressed in terms of metabolic liveweight, DMI decreased by almost 50% from in early spring compared to the preceding late spring period.

Table 4.23 Estimated DMI for mature, non-lactating cows fed native pasture, derived by microhistological (DMI_M) or alkane (DMI_A) methods using the $C_{31:32}$ (DMI_{31}) and $C_{33:32}$ (DMI_{33}) pairs. *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMI_M	DMI_A			
		DMI_{31}	DMI_{33}	DMI_{ADJ}	s.e.m.
		kg/d			
Late spring	5.07 a[1]	7.08 a[2]	7.30 a[2]	7.13 a[2]	0.367
Late summer	4.67 a	6.22 ab	5.97 ab	6.20 ab	0.415
Early winter	4.05 ab	5.03 bc	4.91 bc	5.02 bc	0.535
Early spring	3.33 b	3.80 c	3.75 c	3.80 c	0.327
s.e.m.	0.315	0.456	0.435	0.452	
		% of liveweight			
Late spring	1.2 a[1]	1.7 a[2]	1.8 a[2]	1.7 a[2]	0.09
Late summer	1.1 ab	1.4 ab	1.4 b	1.4 ab	0.12
Early winter	1.0 b	1.2 bc	1.2 bc	1.2 bc	0.08
Early spring	0.8 b	1.0 c	1.0 c	1.0 c	0.06
s.e.m.	0.08	0.10	0.09	0.10	
		$g/kg^{0.75}$			
Late spring	55.8 a[1]	77.7 a[2]	79.8 a[2]	78.2 a[2]	3.93
Late summer	49.1 ab	65.4 ab	62.8 b	65.2 ab	5.12
Early winter	43.8 ab	53.9 bc	52.7 bc	53.9 bc	3.82
Early spring	37.4 b	42.7 c	42.2 c	42.6 c	2.14
s.e.m.	3.15	4.34	3.77	4.22	

Implied DMD_M tended to be lower than the alkane estimates of DMD (DMD_{AF} and DMD_{ADJ}), and these differences were significant for the late spring, late summer and early spring diets ($P<0.05$, Table 4.24). All estimates of DMD for the late spring and late summer diets indicated that these two periods provided native pasture of higher digestibility ($P<0.05$) than the native pasture consumed during either early winter or early spring. The digestibility of the late summer and late spring diets was similar when estimated by DMD_{ADJ} and DMD_{AF}, however the late summer diet was more digestible ($P<0.05$) than the late spring diet when DMD was implied by DMD_M.

Table 4.24 Estimated DMD for mature, non-pregnant cows fed native pasture, derived by microhistological (DMD_M) or alkane methods using the $C_{31:32}$ and $C_{33:32}$ pairs (DMD_{AF}, Eq. 3.10), or the dilution of herbage concentrations of C_{31} or C_{33} (DMD_{AC}, Eq. 3.11). *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMD_M	DMD_{AF}		DMI_{ADJ}	s.e.m.
		$C_{31:32}$	$C_{33:32}$		
		% of DM digested			
Late spring	51.3 b[1]	65.0 a[2]	65.9 a[2]	65.3 a[2]	1.91
Late summer	55.8 a[1]	66.6 a[2]	65.3 a[2]	66.4 a[2]	0.98
Early winter	47.4 c	56.5 b	55.7 b	56.4 b	3.03
Early spring	46.3 c[1]	52.9 b[2]	52.3 b[2]	52.8 b[2]	1.07
s.e.m.	0.40	2.04	2.05	2.04	

DDMI and DOMI by non-lactating cows followed the same general trends as DMIA, and were higher ($P<0.05$) in late spring and late summer than early spring (Table 4.25). ME intake was also greater in late spring and late summer than in early spring ($P<0.05$). CP intake was lower ($P<0.05$) in winter and early spring than for late spring and early summer, and tended to be highest in late summer. Apparent N digestibility was unaffected by the seasonal diet. P intake was similar in late spring and late summer, and for both of these periods was greater ($P<0.05$) than during winter and early spring. Ca intake was highest in late summer ($P<0.05$), and Ca intake in winter and early spring was lower ($P<0.05$) than during the late spring study period.

Table 4.25 Estimated DDMI, DOMI, ME intake, apparent N digestibility, and Ca and P intake from native pasture consumed by mature, non-pregnant cows, based on DMI and DMD estimated by the $C_{33:32}$ alkane pair. *Within columns, means with different letters differ significantly at P=0.05*

Parameter	Late spring	Late summer	Early winter	Early spring	s.e.m.
OMD (%)	68.1 a	68.0 ab	58.5 bc	54.2 c	3.15
DDMI (g/d)	4.66 a	4.13 a	2.88 b	2.01 b	0.338
DOMI (g/d)	4.58 a	3.98 ab	2.81 bc	1.97 c	0.359
ME intake (MJ/d)	64.9 a	57.9 ab	39.0 bc	26.6 c	4.89
CP intake (g/d)	618 a	712 a	427 b	329 b	44.9
Apparent N digestibility (%)	0.72	0.71	0.71	0.65	0.023
P intake (g/d)	6.9 a	6.0 a	3.9 b	3.2 b	0.37
Ca intake (g/d)	7.3 b	10.5 a	5.4 bc	3.7 c	0.56

Calcium, phosphorus, and nitrogen intake and excretion

Ca, P and N intake and excretion exhibited marked seasonal variations (Fig. 4.10 & 4.11). The pattern of Ca consumed from native pasture was implied from the product of DMI_{ADJ} and Ca_M, and mirrored the seasonal concentrations of Ca in the faeces. A less pronounced pattern was observed in plasma samples. Generally, Ca intake, excretion and circulating concentrations of Ca in plasma decreased from summer to winter before rising again in late spring (Fig. 4.10a). The same patterns were observed with P intake, and faecal P and plasma inorganic concentrations (Fig. 4.10b).

CP intake and faecal concentrations followed similar patterns across the four study periods, and these patterns were reflected by plasma urea concentrations and NH_3-N concentrations in rumen fluid (Fig. 4.11a). The seasonal pattern of N intake and excretion was similar to the patterns noted for Ca and P, and constituted a general decline in intake and excretion from summer to winter, and rising again in late summer.

Plasma creatinine levels also exhibited marked seasonal variation (Fig. 4.11b). Concentrations fell from mid-summer to early autumn before rising during winter and early spring.

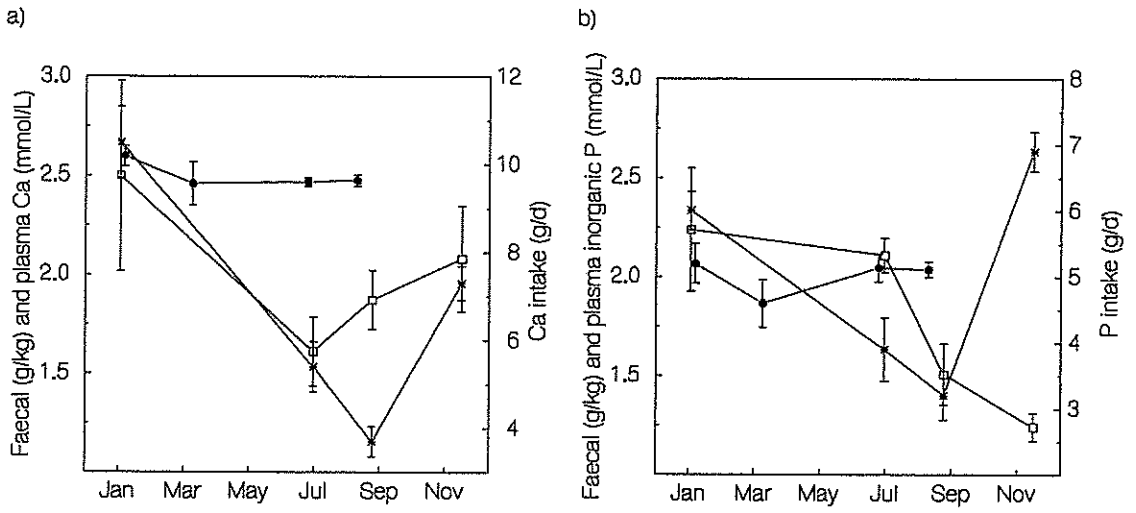

Figure 4.10 a) Plasma (●, mmol/L) and faecal (□, g/kg) concentrations of calcium, and calcium intake (✱, g/day) by mature, non-pregnant cows grazing native pasture, and b) plasma inorganic phosphorus (●, mmol/L), faecal (□, g/kg) phosphorus concentration, and phosphorus intake (✱, g/day) by mature, non-pregnant cows grazing native pasture

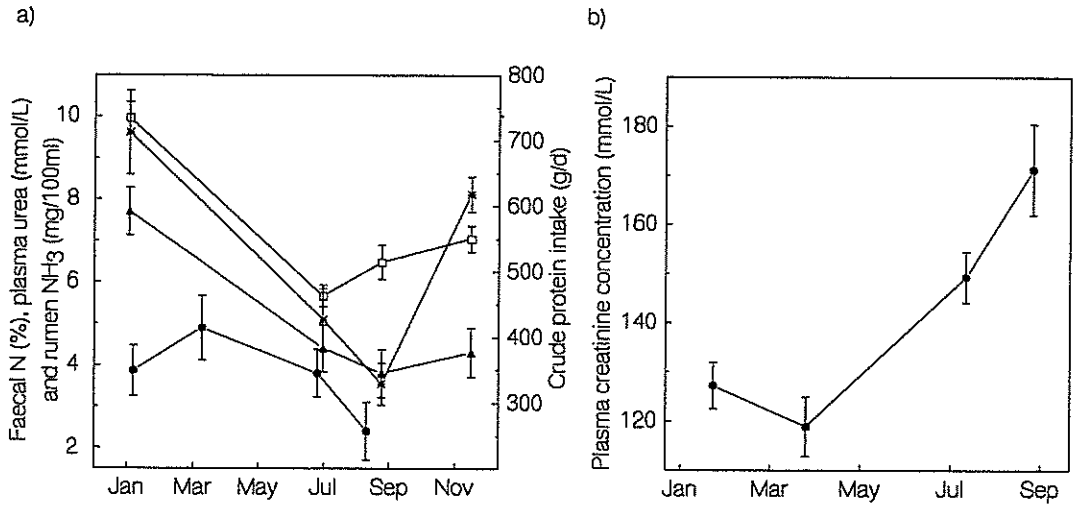

Figure 4.11 a) Plasma urea (●, mmol/L), faecal nitrogen (□, %), and rumen NH_3-N (▲, mg/100ml) concentrations, and crude protein intake (✱, g/day) by mature, non-pregnant cows grazing native pasture, and b) plasma creatinine concentrations (●, mmol/L) for mature, non-pregnant cows grazing native pasture

Plasma concentrations of 25-OH D_3 were determined in samples obtained from five non-lactating cows at several times during the year. Seasonal variations in 25-OH D_3 concentrations were detected and were lowest during the period from winter to early spring (June to September, Table 4.26). The concentrations for most cows were generally deficient (<25nmol/L) between July and September. Highest concentrations were measured in summer (January). The lower limit of detection for assays in August and September was 11nmol/L, and 5nmol/L for all other assay periods.

Table 4.26 Plasma concentrations of 25-hydroxyvitamin D_3 from mature cows grazing native pasture

	Sampling date				
	29-Mar	13-Jul	27-Aug	8-Sep	26-Jan
Mean (nmol/L)*	34	22	13	23	45
s.e.	3.1	9.2	5.0	7.7	2.9
No. of samples	5	5	5	5	5
No. of samples <5 nmol/L		1			
No. of samples <9 nmol/L			1	2	

* Mean for samples with 25-OH Vitamin D_3 concentrations >9 nmol/L

Lactating cows

Implied DMI_M estimates were not significantly different to DMI_A for each of the three study periods for lactating cows consuming native pasture (Table 4.27). Moreover, DMI (g/d) was similar across the three periods, but tended to decline from late summer to early spring. When DMI was expressed in terms of liveweight and metabolic liveweight, implied DMI_M tended to be lower than DMI_A estimates, however not significantly.

Table 4.27 Estimated DMI for mature, lactating cows fed native pasture, derived by microhistological (DMI_M) or alkane (DMI_A) methods using the $C_{31:32}$ (DMI_{31}) and $C_{33:32}$ (DMI_{33}) pairs

	DMI_M	DMI_A			
Season		DMI_{31}	DMI_{33}	DMI_{ADJ}	s.e.m.
		kg/d			
Late summer	5.61	7.21	7.24	7.17	0.767
Early winter	5.38	6.72	6.44	6.69	0.350
Early spring	4.93	5.50	5.56	5.50	0.554
s.e.m.	0.401	0.523	0.659	0.519	
		% of liveweight			
Late summer	1.5	1.9	1.9	1.9	0.17
Early winter	1.7	2.1	2.0	2.1	0.13
Early spring	1.6	1.7	1.8	1.7	0.10
s.e.m.		0.14	0.14	0.13	
		$g/kg^{0.75}$			
Late summer	66.0	85.2	84.7	84.7	7.60
Early winter	72.0	89.9	86.1	89.5	5.08
Early spring	65.8	73.5	74.1	73.5	4.91
s.e.m.	4.00	5.88	6.35	5.65	

Implied DMD_M was lower ($P<0.05$) than DMD_{AF} and DMDADJ for the early winter and early spring diets (Table 4.28). Although DMD_M tended to be lower than DMD_{ADJ} and DMD_{AF} for the late summer diet, the difference was not significant. DMD estimated using DMI derived from the $C_{31:32}$ alkane pair

was similar to that derived from the $C_{33:32}$ pair. DMI_{ADJ} estimates were intermediate between these two estimates. The early spring diet was less digestible ($P<0.05$) than the late summer diet for each method of determining DMD. $DMD_{33:32}$ and DMD_{ADJ} estimates indicated that the early winter diet was also less digestible ($P<0.05$) than the late summer diet.

Table 4.28 Estimated DMD for mature, lactating cows fed native pasture, derived by microhistological (DMD_M) or alkane methods using the $C_{31:32}$ and $C_{33:32}$ pairs (DMD_{AF}, Eq. 3.10), or the dilution of herbage concentrations of C_{31} or C_{33} (DMD_{AC}, Eq. 3.11). *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMD_M	DMD_{AF} $C_{31:32}$	DMD_{AF} $C_{33:32}$	DMI_{ADJ}	s.e.m.
		% of DM digested			
Late summer	56.4 a	65.3 a	65.3 a	65.3 a	2.67
Early winter	48.0 b[1]	58.3 ab[2]	56.5 b[2]	58.2 b[2]	0.91
Early spring	48.3 b[1]	53.7 b[2]	53.8 b[2]	53.7 b[2]	1.25
s.e.m.	0.51	1.87	1.69	1.75	

OMD, DDMI, DOMI, and ME and CP intake were lower for the native pasture diets consumed during early spring compared to late summer (Table 4.29). Values for the winter diet were intermediate between the summer and early spring diets, but were not different from either. P intake did not differ significantly between the three study periods, however more P was apparently consumed in late summer compared to the other two periods. Ca intake was highest in late summer and was more than ($P<0.05$) that quantity consumed in early spring.

Table 4.29 Estimated DDMI, DOMI, ME intake, apparent N digestibility, and Ca and P intake from native pasture consumed by mature, lactating cows, based on DMI and DMD estimated by the $C_{33:32}$ alkane pair. *Within columns, means with different letters differ significantly at P=0.05*

Parameter	Late summer	Early winter	Early spring	s.e.m.
OMD (%)	66.9 a	60.2 ab	55.9 b	1.69
DDMI (g/d)	4.73 a	3.89 ab	2.96 b	0.383
DOMI (g/d)	4.56 a	3.78 ab	2.90 b	0.365
ME intake (MJ/d)	66.1 a	52.8 ab	39.3 b	5.53
CP intake (g/d)	774 a	591 ab	478 b	53.2
Apparent N digestibility (%)	0.68	0.73	0.64	0.015
P intake (g/d)	7.1	5.5	5.0	0.59
Ca intake (g/d)	13.1 a	8.4 ab	7.7 b	1.32

Lactating *v.* non-lactating cows

DMI differed between non-lactating and lactating cows for the early winter and early spring study periods ($P<0.05$, Table 4.30).

Table 4.30 Estimated dry matter intake and digestibility of native pasture diets consumed by mature, non-pregnant and lactating cows. *Within rows, means with different letters differ significantly at P=0.01*

Season	Dry cows	Lactating cows	s.e.m.
	Dry matter intake (% of liveweight)		
Late summer	1.4	1.9	0.15
Early winter	1.2 a	2.1 b	0.11
Early spring	1.0 a	1.7 b	0.08
	Dry matter intake ($g/kg^{0.75}$)		
Late summer	65.2	84.7	6.27
Early winter	53.9 a	89.5 b	4.84
Early spring	42.6 a	73.5 b	3.63
	Dry matter digestibility (%)		
Late summer	66.4	65.3	2.03
Early winter	56.4	58.2	2.60
Early spring	52.8	53.7	1.25

Expressed as a percentage of liveweight or per kg of metabolic liveweight, lactating cows consumed 75% to 80% and 66% to 73% more DM than non-lactating cows in early winter and early spring, respectively. Although lactating cows tended to consume more DM than non-lactating cows in late summer, that is 36% and 30% for DMI as a percentage of liveweight and per kg of metabolic liveweight, respectively, the differences were not significant.

The native pasture diets consumed by non-lactating and lactating cows did not differ in digestible dry matter content during any of the three study periods.

4.7 Intake and digestion by co-grazed sheep and cattle

Seasonal composition of diets

Sheep

The composition of diets consumed by shearling wethers differed significantly ($P<0.05$) between the four study periods (Table 4.31). White-grass was a substantial contributor to sheep diets throughout the year, however it was present in higher proportions ($P<0.05$) during winter than in late spring and summer

(Table 4.32). Forbs and fine grasses made significantly greater contributions to the diet in summer than during winter. Sedges were consumed in greater proportions ($P<0.05$) during spring and late summer than during winter. Smooth-stalked Meadow-grass was the dominant fine grass consumed throughout the year. Native Fescue, Annual Meadow-grass and Bent tended to contribute more to the diet during the spring and summer periods than during winter. During late summer and winter, Smooth-stalked Meadow-grass consumption was 60% to 70% greater than the Native Fescue, Annual Meadow grass and Bent combined. During early and late spring consumption of the combined proportion of these three grasses was similar to Smooth-stalked Meadow-grass.

Table 4.31 Species contributing to the diet of shearling wethers grazing native pasture, derived using microhistological techniques. *Within rows, means with different letters differ significantly at P=0.05*

Plant species Common name (*Scientific name*)	Late spring	Late summer	Early winter	Early spring	s.e.m.
Grasses and sedges					
White-grass (*Cortaderia pilosa*)	25.8 ab	23.8 a	42.9 b	36.2 ab	4.28
Smooth-stalked Meadow-grass (*Poa pratensis*)	15.1 bc	16.5 c	11.5 ab	7.8 a	1.11
Annual Meadow-grass (*Poa annua*)	7.8 b	2.9 a	2.7 a	4.9 a	0.70
Bent (*Agrostis capillaris*)	3.1	2.8	1.1	2.4	0.52
Native Fescue (*Festuca magellanica*)	3.9	4.3	2.9	3.2	0.55
Early Hair-grass (*Aira praecox*)	1.3	1.8	1.1	3.4	0.78
Native Fog (*Trisetum spicatum*)	0.1	0	0	0.3	0.17
Cinnamon Grass (*Heirochloë redolens*)	0.2 a	0.1 a	0.9 b	0.3 ab	0.16
Wavy Hair-grass (*Deschampsia flexuosa*)	2.9 a	2.3 a	7.0 b	7.6 b	1.52
Native Woodrush (*Luzula alopecuris*)	5.3 b	3.9 bc	2.1 c	10.2 a	0.67
Native rush (*Juncus scheuzerioides*)	7.0 a	7.9 a	1.8 b	6.1 a	0.97
Forbs					
Small Fern (*Blechnum penna marina*)	6.7	5.4	9.2	9.3	1.08
Pig Vine (*Gunnera magellanica*)	1.2 b	0 a	0 a	0 a	0.21
Pale Maiden (*Sisyrinchium filifolium*)	0.9	0.4	0.8	0.2	0.24
Carrot Weed (*Cotula scariosa*)	1.5 b	0.1 a	0.1 a	0.1 a	0.30
Chickweed (*Cerastium arvense*)	0	0	0	0.3	0.08
Unidentified forbs	9.9 b	5.1 a	4.1 a	2.8 a	1.05
Shrubs					
Mountain Berry (*Pernettya pumila*)	6.6 bc	1.8 a	8.3 c	2.6 b	1.17
Christmas Bush (*Baccharis magellanica*)	0.8	1.1	0.8	2.2	0.41
Diddle-dee (*Empetrum rubrum*)	0 c	4.4 a	1.6 b	0.1 bc	0.37
Diddle-dee berries	0.0 b	15.4 a	1.1 b	0.1 b	1.07

Consumption of Native Woodrush was greater ($P<0.05$) during early spring than at other times. Forbs were represented in substantial quantities throughout the year, and peaked in late spring. Small Fern contributed most to the forbs consumed. Wavy Hair-grass/Native Rush made a greater contribution ($P<0.05$) to the diet during winter and early spring than during late spring and summer. Diddle-dee berries made a significant contribution to the diet in late summer, and little or no contribution at other times during the year. In addition, Diddle-dee was consumed most during late summer, however Mountain Berry was the dominant shrub consumed at other times during the year. The seasonal patterns of the diets are illustrated (Fig. 4.12).

Compared to the diet of weaner sheep, wethers tended to consume more White-grass and fewer fine grasses during the summer period, and more forbs and Diddle-dee berries (Table 4.9 *v.* 4.32).

Table 4.32 Estimated seasonal diet of shearling wethers grazing native pasture. *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Species	Late spring	Late summer	Early winter	Early spring	s.e.m.
White-grass and Cinnamon Grass	26.0 b^2	23.9 b^2	43.9 a^1	36.5 $a^{1,2}$	4.26
Fine grasses	43.4 a^1	39.9 a^1	23.1 b^2	38.4 a^1	2.88
Forbs	13.6 c^1	5.7 d^2	5.0 cd^2	3.3 b^2	1.15
Ferns	6.7 cd	5.4 d	9.2 c	9.3 b	1.08
Woody plants	7.4 $cd^{1,2}$	7.4 $cd^{1,2}$	10.7 c^1	4.8 b^2	1.36
Wavy Hair-grass and Native rush	2.9 d	2.3 d	7.0 cd	7.6 b	1.52
Berries	0.0 d^2	15.4 c^1	1.1 d^2	0.1 b^2	1.07
s.e.m.	2.11	1.80	1.54	3.08	

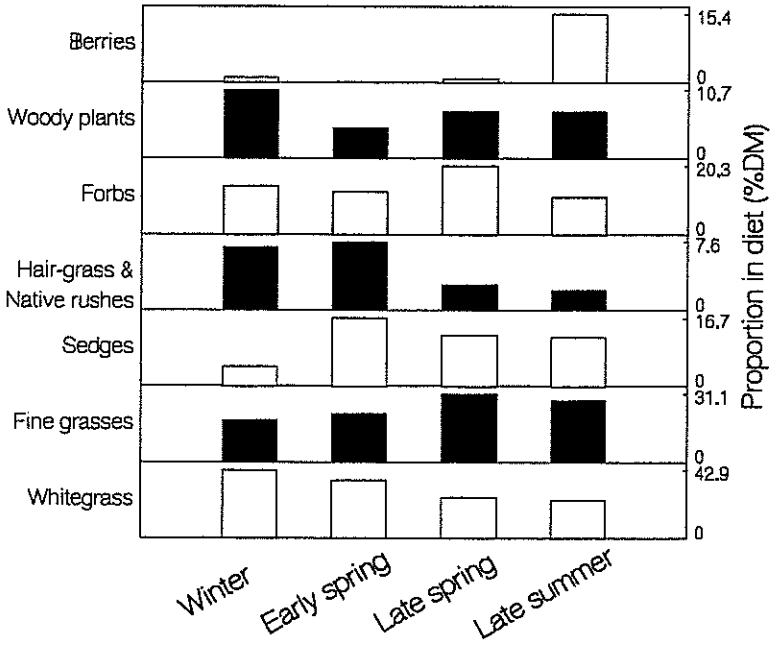

Figure 4.12 Contribution of White-grass, fine grasses, sedges, Wavy Hair-grass, forbs, woody plants, and Diddle-dee berries to the seasonal diet of shearling wethers consuming native pasture in the Falklands

Cattle

Cattle consumed less White-grass ($P<0.05$) during late spring than during the late summer, winter and early spring study periods (Table 4.33). Fine grasses such as Smooth-stalked Meadow-grass, Bent, Naïve Fescue and Early Hair-grass contributed proportionally more DM to the diet during late spring and late summer than during winter and early spring. The greater contribution of these plants to the diets during

these warmer periods was also reflected by the higher proportion of 'fine grasses' generally ($P<0.05$) compared to the cooler winter and early spring periods (Table 4.34). Wavy Hair-grass and Native rushes were consumed in greater proportions ($P<0.05$) in winter and early spring than during late spring and summer.

Table 4.33 Species contributing to the diet of mature, non-pregnant cows grazing native pasture, derived using microhistological techniques. *Within rows, means with different letters differ significantly at P=0.05*

Plant species Common name (*Scientific name*)	Late spring	Late summer	Early winter	Early spring	s.e.m.
Grasses and sedges					
White-grass (*Cortaderia pilosa*)	32.6 a	54.2 b	58.8 b	49.5 b	2.80
Smooth-stalked Meadow-grass (*Poa pratensis*)	3.1 a	4.0 a	0.5 b	0.3 b	0.54
Annual Meadow-grass (*Poa annua*)	1.8	1.4	0.9	1.8	0.34
Bent (*Agrostis capillaris*)	5.5 a	2.7 b	0.7 b	1.0 b	0.61
Native Fescue (*Festuca magellanica*)	1.2 ab	2.8 a	0.5 b	0.8 ab	0.53
Early Hair-grass (*Aira praecox*)	16.3 a	15.0 a	7.9 b	5.4 b	1.71
Native Fog (*Trisetum spicatum*)	0.1 a	3.1 b	0.2 a	0.4 a	0.40
Cinnamon Grass (*Heirochloë redolens*)	0.7	0.7	0.1	0.2	0.23
Wavy Hair-grass (*Deschampsia flexuosa*)	3.9 ab	0.3 b	8.9 a	9.0 a	1.53
Native Woodrush (*Luzula alopecuris*)	3.9 ab	3.7 ab	1.0 b	4.2 a	0.81
Native rush (*Juncus scheuzerioides*)	1.9 a	0 a	8.4 b	11.0 b	0.71
Forbs					
Small Fern (*Blechnum penna marina*)	3.7 ab	1.1 c	1.9 bc	4.6 a	0.56
Pig Vine (*Gunnera magellanica*)	7.1 a	2.1 b	0.1 c	0 c	0.46
Pale Maiden (*Sisyrinchium filifolium*)	0.8 a	0 b	0 b	0.11 ab	0.19
Carrot Weed (*Cotula scariosa*)	1.2	0.1	0.5	1.0	0.47
Chickweed (*Cerastium arvense*)	0	0.1	0.1	1.0	0.10
Daisy (*Bellis perennis*)	0.5	0	0	0.2	0.15
Scurvy grass (*Oxalis enneaphylla*)	0.7	0	0	0	0.18
Sorrel (*Rumex acetosella*)	5.2 a	3.1 ab	1.3 ab	0.8 b	1.03
Unidentified forbs	4.2	3.5	1.6	2.9	0.70
Shrubs					
Mountain Berry (*Pernettya pumila*)	2.1 b	0.7 b	4.5 a	3.0 ab	0.59
Christmas Bush (*Baccharis magellanica*)	3.1 ab	0.8 b	1.4 ab	3.4 a	0.61
Diddle-dee (*Empetrum rubrum*)	0.4	0	0.7	0.1	0.22
Diddle-dee berries	0.1	0.5	0	0	0.30

Forbs were consumed in higher proportions ($P<0.05$) in late spring and summer than during winter. The proportion of forbs in the diet was highest during late spring. Woody species contributed less ($P<0.05$) to the diet during late summer than all other periods. Christmas Bush and Mountain Berry were the most abundant woody species in the diets consumed by cattle. Diddle-dee berries were not consumed in any substantial quantities in any study period.

Table 4.34 Estimated seasonal diet of mature, non-pregnant cows grazing native pasture. *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Species	Late spring	Late summer	Early winter	Early spring	s.e.m.
White-grass and Cinnamon Grass	33.3 a^1	55.0 a^2	59.0 a^2	49.7 a^2	2.72
Fine grasses	31.8 a^1	32.8 b^1	11.8 bc^2	14.0 bc^2	1.99
Forbs	19.7 b^1	8.9 c^2	3.5 d^3	5.2 $d^{2,3}$	1.31
Ferns	3.7 $c^{1,2}$	1.1 d^3	1.9 $d^{2,3}$	4.6 d^1	0.56
Woody plants	5.6 c^1	1.5 d^2	6.5 cd^1	6.6 cd^1	0.86
Wavy Hair-grass and Native rush	5.8 c^2	0.3 d^2	17.3 b^1	20.0 b^1	1.75
Berries	0.1 $c^{1,2}$	0.5 d^1	0.0 d^2	0.0 d^2	0.14
s.e.m.	1.73	1.35	1.49	1.68	

Sheep *v.* Cattle

The diets consumed by the co-grazed sheep during the year were more similar between seasons than were those for weaner sheep (Table 4.35 *v.* 4.10). Winter and early spring diets were the most similar for both co-grazed shearling wethers and cattle. For co-grazed cattle, the diets with least similarity were early winter and late spring, however for co-grazed wethers were late summer and either early winter or early spring.

Table 4.35 Similarities between seasonal diets of co-grazed shearling wethers and mature, non-pregnant cows grazing native pasture

Seasons	Similarity index	
	Sheep	Cattle
Late summer v. Early winter	0.65	0.72
Late summer v. Early spring	0.65	0.72
Late summer v. Late spring	0.77	0.71
Early winter v. Early spring	0.80	0.86
Early winter v. Late spring	0.71	0.58
Early spring v. Late spring	0.74	0.66

Despite the relatively high similarity indices between seasons, the diet consumed by co-grazed wethers during late spring and late summer were more diverse ($P<0.05$) than that consumed in winter (Table 4.36). Diet diversity during early spring was similar to diversity in late spring and summer. Diets consumed by co-grazed cattle were more diverse ($P<0.05$) in late spring than all other periods. The co-grazed cattle diet during winter was less diverse ($P<0.05$) than all other periods. The diets consumed by co-grazed wethers was more diverse than that consumed by co-grazed cattle in three of the four study periods.

Table 4.36 Diversity indices for seasonal diets selected by co-grazed shearling wethers and mature, non-pregnant cows grazing native pasture. *Within columns, means with different letters differ significantly at P=0.05*

Season	Diversity		
	Sheep	Cattle	s.e.m.
Late spring	7.56 a	6.96 a	0.601
Late summer	7.59 a[1]	3.16 b[2]	0.460
Early winter	4.57 b[1]	2.70 b[2]	0.372
Early spring	5.99 ab[1]	3.75 c[2]	0.806
s.e.m.	0.707	0.426	

Faecal alkane concentrations

Sheep

Faecal concentrations of the dosed alkanes (C_{32} and C_{36}) varied between collection days during each of the four diet studies, however they showed no significant increasing or decreasing trends during the four five-day faecal collection periods (Fig. 4.13).

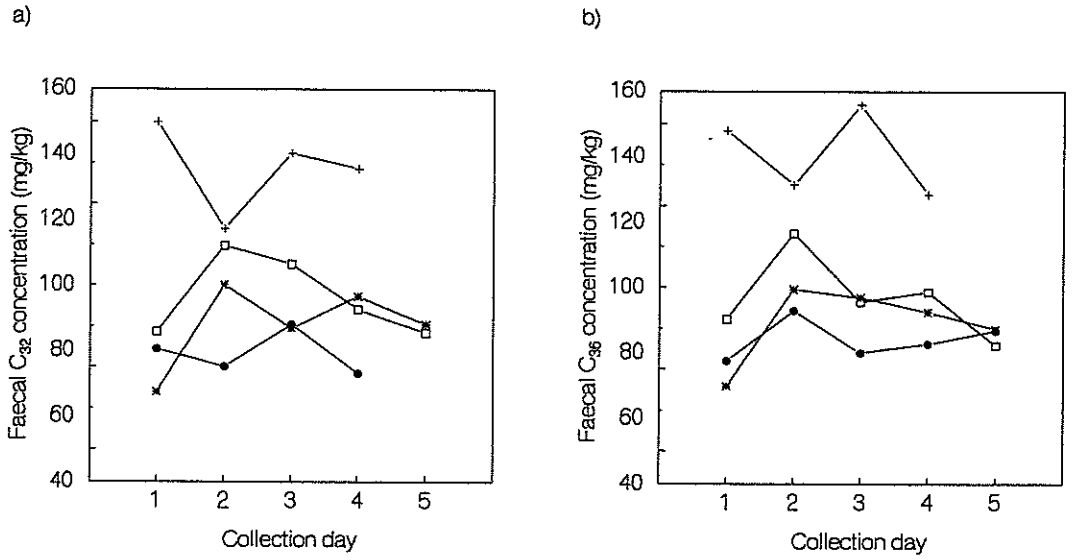

Figure 4.13 Mean faecal concentrations of (a) C_{32} and (b) C_{36} in shearling wethers consuming native pasture and dosed with Captec alkane capsules in late spring (●), early summer (✱), early winter (+) and early spring (□)

Cattle

Faecal concentrations of the dosed alkanes (C_{32} and C_{36}) varied between collection days during each of the four diet studies, however they showed no significant increasing or decreasing trends during the four five-day faecal collection periods (Fig. 4.14).

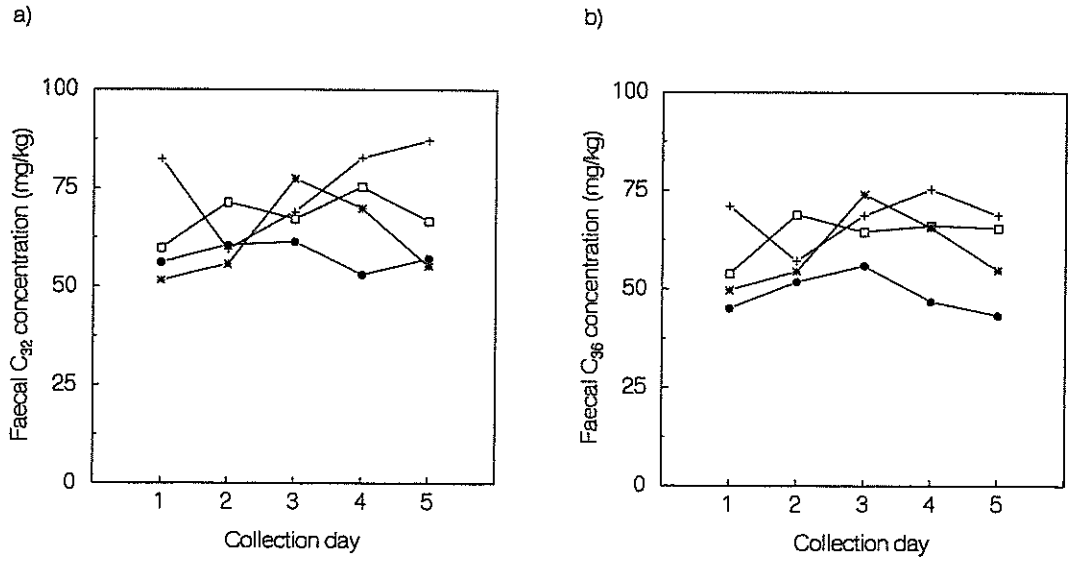

Figure 4.14 Mean faecal concentrations of (a) C_{32} and (b) C_{36} in co-grazed cattle consuming native pasture and dosed with Captec alkane capsules in late spring (●), early summer (✱), early winter (+) and early spring (□)

Liveweight change

The seasonal liveweight change of shearling wethers during the diet studies is shown in Fig 4.2, and the general mean liveweights were 45, 49, 40 and 39kg during late spring, late summer, early winter and early spring, respectively. Liveweight was only maintained during autumn, winter and early spring (March until October), and a period of rapid growth followed in late spring and summer (November to February). For co-grazed cows, average daily weight changes during the year were +417g/d from October to December, +50g/dy from December to May, and -357g/d from May to September. These periods do not coincide exactly with the experimental periods due to the mustering and weighing policies that were implemented to manage the National Beef Herd.

Diet quality

Sheep *v.* Cattle

CP_M, ME_M, NDF_M, P_M and Ca_M contents of native pasture diets selected by co-grazed sheep and cattle were implied from microhistology. For co-grazed sheep CP_M was highest in late spring and was

significantly higher than during early winter (Table 4.37). CP_M of co-grazed cattle diets was greater ($P<0.05$) in late spring and late summer than winter and early spring. CP_M was higher ($P<0.05$) for co-grazed sheep than cattle during winter and early spring. For both sheep and cattle, ME_M was higher ($P<0.05$) in late spring and summer than winter and early spring, and diets selected by sheep contained more ME_M ($P<0.05$) than those selected by cattle in all four periods.

NDF_M contents of the early winter and early spring diets consumed by co-grazed sheep were greater ($P<0.05$) than NDF_M in both summer diets. The same trend was evident for the cattle diets, however NDF_M of the late spring diet was also lower ($P<0.05$) than NDF_M for the late summer diet. Diets selected by cattle contained generally less P_M and Ca_M than those selected by sheep. For both nutrients, these differences were significant in late summer and early winter, and in early spring for P_M.

Table 4.37 Estimated nutritional value of diets consumed by shearling wethers and mature, non-pregnant cows using microhistological techniques. *Within rows, means with different letters, and for each data pair within columns, means with different numbers differ significantly at P=0.05*

Diet quality		Late spring	Late summer	Early winter	Early spring	s.e.m.
CP_M (%)						
	Sheep	10.6 b	9.9 ab	9.5 a^1	9.9 ab^1	0.18
	Cows	11.2 a	10.0 b	5.8 d^2	6.7 c^2	0.17
ME_M (MJ/kg)						
	Sheep	8.2 a^1	8.1 a^1	7.1 b^1	7.3 b^1	0.10
	Cattle	7.7 a^2	7.3 b^2	6.1 d^2	6.5 c^2	0.07
NDF_M (%)						
	Sheep	55.5 a	54.8 a^1	62.1 b^1	62.1 b^1	0.95
	Cattle	57.3 a	65.3 b^2	69.2 b^2	67.8 b^2	1.14
P_M (%)						
	Sheep	0.11 a^1	0.09 b^1	0.10 ab^1	0.11 ab^1	0.004
	Cattle	0.12 a^2	0.06 b^2	0.05 c^2	0.06 b^2	0.002
Ca_M (%)						
	Sheep	0.19 ab	0.17 a^1	0.23 b^1	0.16 a	0.010
	Cattle	0.18 a	0.12 b^2	0.14 b^2	0.13 b	0.007

Mean CP_M of diets consumed by sheep and cattle were significantly different over the four study periods, and were 10.8% and 8.4±0.09%, respectively ($P<0.01$). Significant differences ($P<0.01$) were also observed for ME_M, NDF_M, P_M, and Ca_M, and general means were 7.7% and 6.9±0.04MJ/kg, 58.6% and 64.9±0.53%, 0.10% and 0.07±0.002%, and 0.19% and 0.14±0.004% for sheep and cattle diets, respectively.

Intake and digestion

Sheep

Although DMI_A tended to be higher than DMI_M the estimated DMI's from both methods for each season's diet were not significantly different (Table 4.38). Both methods established that DMI was highest during the late spring and late summer periods. Moreover, DMI during late spring and summer was greater ($P<0.05$) than during early winter. DMI during winter was approximately half the quantity of DMI consumed during early and late summer.

Table 4.38 Estimated DMI for shearling wethers fed native pasture, derived by microhistological (DMI_M) or alkane (DMI_A) methods using the $C_{31:32}$ (DMI_{31}) and $C_{33:32}$ (DMI_{33}) pairs. *Within columns, means with different letters differ significantly at P=0.05*

Season	DMI_M	DMI_A			
		DMI_{31}	DMI_{33}	DMI_{ADJ}	s.e.m.
		kg/d			
Late spring	1.25 b	1.35 b	1.41 b	1.36 b	0.129
Late summer	1.16 b	1.51 b	1.50 b	1.51 b	0.213
Early winter	0.80 a	0.69 a	0.70 a	0.69 a	0.080
Early spring	0.91 ab	1.03 ab	1.08 ab	1.03 ab	0.069
s.e.m.	0.136	0.133	0.137	0.137	
		% of liveweight			
Late spring	2.8 b	3.0 b	3.1 b	3.0 b	0.29
Late summer	2.5 ab	3.3 b	3.3 b	3.3 b	0.33
Early winter	2.0 a	1.7 a	1.8 a	1.7 a	0.20
Early spring	2.4 ab	2.7 ab	2.8 ab	2.7 ab	0.22
s.e.m.	0.26	0.26	0.26	0.26	
		$g/kg^{0.75}$			
Late spring	71.6 b	77.5 b	80.9 b	78.0 b	7.41
Late summer	66.8 b	86.7 b	86.9 b	86.7 b	9.28
Early winter	47.5 a	43.5 a	44.2 a	43.6 a	5.06
Early spring	58.7 ab	66.5 ab	69.5 ab	66.7 ab	5.05
s.e.m.	6.84	6.64	6.77	6.83	

DMI during early spring tended to be greater than during winter and less than both summer periods but not significantly. DMI_A tended to be greater during late summer than early summer, however DMI_M tended to be higher during early summer compared to late summer. DMI_{31} was similar to DMI_{33}. DMI_{ADJ} was similar to the values estimated by both DMI_{31} and DMI_{33}.

DMI expressed in terms of liveweight, both as a percentage of liveweight and per kg of metabolic liveweight, exhibited the same trends as gross DMI. DMI increased ($P<0.05$) from 1.7% and 1.8% to 3.3% of bodyweight from winter to late summer based on alkane estimates of DMI. Similarly, DMI expressed in terms of metabolic liveweight increased almost two-fold from winter to late summer,

increasing from 43.5g/kg$^{0.75}$ to 86.7g/kg$^{0.75}$ when estimated by the $C_{31:32}$ alkane pair, and 44.2g/kg$^{0.75}$ to 86.9g/kg$^{0.75}$ for the $C_{33:32}$ pair.

DMD_M tended to be lower than DMD_A for each of the seasonal diets (Table 4.39). DMD_{AF} estimated by both alkane pairs was between 3.3 and 8.8 units, and 4.2 and 8.9 units higher for the $C_{31:32}$ and $C_{33:32}$ pairs, respectively. The difference in DMD's estimated by alkanes and microhistology were only significant for the late summer diet. DMD_{AF} estimated by the $C_{31:32}$ and $C_{33:32}$ pairs were similar for all four seasonal diets. DMD_{AF} and DMD_{AC} for the diet consumed in late summer was higher ($P<0.05$) than for early winter and early spring diets. DMD_M for both summer diets were greater ($P<0.05$) than the early winter and early spring diets. DMD_{AC} calculated from the dilution of alkanes (**Eq. 3.10**) were similar to DMD_{AF} calculated by difference from forage intake and faecal excretion (**Eq. 3.11**).

Table 4.39 Estimated DMD for shearling wethers fed native pasture, derived by microhistological (DMD_M) or alkane methods using the $C_{31:32}$ and $C_{33:32}$ pairs (DMD_{AF}, Eq. 8), or the dilution of herbage concentrations of C_{31} or C_{33} (DMD_{AC}, Eq. 9). *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMD_M	DMD_{AF}		DMD_{AC}		s.e.m.
		$C_{31:32}$	$C_{33:32}$	DMD_{31}	DMD_{33}	
Late spring	57.8 b	61.1 ab	62.0 ab	61.9 ab	62.3 ab	2.78
Late summer	57.3 b^1	66.1 b^2	66.2 b^2	65.6 b^2	65.6 b^2	0.87
Early winter	50.9 a^1	57.3 a^{12}	57.9 a^{12}	56.9 a^2	58.7 a^2	1.82
Early spring	52.0 a	57.1a	58.7 ab	56.1 a	57.8 a	2.90
s.e.m.	0.63	1.54	2.77	2.39	3.02	

DDMI and DOMI were greater ($P<0.05$) during late spring and summer than during early winter and early spring (Table 4.40). ME intake and CP intake was greater in late summer than winter ($P<0.05$). P_M intake was adequate for maintenance during early spring, late spring and late summer, but was below maintenance requirements (≥1.1 g/day for 40kg sheep, SCA 1990) during winter. P_M intake was lower ($P<0.05$) in winter and early spring than during late spring and summer. Ca_M intake was lower ($P<0.05$) during early spring than at all other times of the year, and was higher ($P<0.05$) in late summer than for all other periods. Ca_M consumed in the diets were adequate for growth rates up to 100g/d.

DMD_{ADJ} was similar to the mean of all alkane based DMD estimates, and were 61.2% *v.* 61.8%, 66.1% *v.* 65.9%, 57.5% *v.* 57.7% and 57.2% *v.* 57.4%, respectively for the late spring, late summer, early winter and early spring diets.

Table 4.40 Estimated DDMI, DOMI, ME intake, apparent N digestibility, and Ca and P intake from native pasture consumed by shearling wethers, based on DMI and DMD estimated by the $C_{33:32}$ alkane pair. *Within columns, means with different letters differ significantly at P=0.05*

Parameter	Late spring	Late summer	Early winter	Early spring	s.e.m.
DMD_{ADJ} (%)	61.2 ab	66.1 a	57.5 b	57.2 b	1.56
DDMI (g/d)	832 ab	990 a	399 c	595 bc	84.9
DOMI (g/d)	812 ab	970 a	389 c	582 bc	81.2
ME intake (MJ/d)	11.4 ab	13.8 a	5.7 c	8.0 bc	1.19
CP intake (g/d)	144.6 a	149.7 a	66.0 b	102.6 ab	14.49
P intake (g/d)	1.55 a	1.39 a	0.71 b	1.15 ab	0.136
Ca intake (g/d)	2.69 a	3.19 a	1.63 b	1.69 b	0.263

Cattle

DMI_M estimated by microhistological methods tended to be lower than all DMI_A estimates, however the differences were only significant for the late summer diet (Table 4.41).

DMI's during late spring and summer were more than double those estimated for the winter and early spring diets ($P<0.05$), regardless of the method used to estimate DMI.

Table 4.41 Estimated DMI for mature, non-pregnant cows fed native pasture, derived by microhistological (DMI_M) or alkane (DMI_A) methods using the $C_{31:32}$ (DMI_{31}) and $C_{33:32}$ (DMI_{33}) pairs. *Within columns, means with different letters, and within rows means with different numbers differ significantly at P=0.05*

Season	DMI_M	DMI_A			
		DMI_{31}	DMI_{33}	DMI_{ADJ}	s.e.m.
		kg/d			
Late spring	6.15 a	7.77 a	7.62 a	7.75 a	0.526
Late summer	5.73 a^1	7.41 a^2	6.95 a^2	7.37 a^2	0.262
Early winter	2.67 b	3.45 b	3.32 b	3.44 b	0.296
Early spring	2.74 b	3.21 b	3.02 b	3.19 b	0.320
s.e.m.	0.374	0.392	0.310	0.382	
		% of liveweight			
Late spring	1.4 a^1	1.8 a^2	1.7 a^2	1.8 a^2	0.08
Late summer	1.2 a^1	1.6 a^2	1.5 b^2	1.6 a^2	0.05
Early winter	0.7 b^1	0.9 b^2	0.8 c^2	0.8 b^2	0.04
Early spring	0.7 b	0.9 b	0.8 c	0.9 b	0.06
s.e.m.	0.06	0.06	0.05	0.06	
		$g/kg^{0.75}$			
Late spring	63.7 a^1	80.6 a^2	79.2 a^2	80.5 a^2	3.41
Late summer	56.8 a^1	73.6 a^2	69.0 b^2	73.2 a^2	2.34
Early winter	29.3 b^1	38.0 b^2	36.5 $c^{1,2}$	37.9 b^2	1.93
Early spring	32.4 b	38.0 b	35.7 c	37.8 b	2.80
s.e.m.	2.86	2.86	2.17	2.77	

When expressed in terms of liveweight and per kg of metabolic liveweight, DMI_M was less than DMI_A ($P<0.05$) during the late spring, late summer and early winter periods. DMI_M and DMI_A during late spring and late summer were higher ($P<0.05$) than during winter and early spring. In all cases DMI_{31}, DMI_{33} and DMI_{ADJ} provided estimates of DMI of similar magnitude.

In all four study periods, DMD_M estimates implied from the results of microhistological analysis of faeces were lower than the DMD_{AF} and DMD_{ADJ} estimates derived from alkane data (Table 4.42). DMD_M for late spring and late summer diets were higher ($P<0.05$) than for the early winter and early spring diets. In addition, DMDM for late spring was higher ($P<0.05$) than during late summer. The digestibilities of the late summer and late spring diets, estimated by $C_{31:32}$ and DMD_{ADJ} were also higher than those for the early winter and early spring diets ($P<0.05$). The DMD of the early spring diet was lower ($P<0.05$) than the DMD of the early winter diet when DMD_{AF} was estimated by $C_{33:32}$.

Table 4.42 Estimated DMD for mature, non-pregnant cows fed native pasture, derived by microhistological (DMD_M) or alkane methods using the $C_{31:32}$ and $C_{33:32}$ pairs (DMD_{AF}, Eq. 3.10), or the dilution of herbage concentrations of C_{31} or C_{33} (DMD_{AC}, Eq. 3.11). *Within columns, means with different letters, and within rows, means with different numbers differ significantly at P=0.05*

Season	DMD_M	DMD_{AF} $C_{31:32}$	DMD_{AF} $C_{33:32}$	DMD_{ADJ}	s.e.m.
Late spring	54.4 a^1	64.1 a^2	63.4 a^2	64.0 a^2	0.94
Late summer	52.0 b^1	62.9 a^2	60.4 ab^2	62.8 a^2	1.30
Early winter	44.6 c^1	57.1 b^2	55.3 bc^2	56.9 b^2	1.16
Early spring	46.8 c^1	54.8 b^2	52.0 c^2	54.5 b^2	1.26
s.e.m.	0.47	1.19	1.56	1.20	

DDMI and DOMI were greater ($P<0.05$) for the late spring and late summer periods than during early winter and early spring (Table 4.43). ME intake followed a similar pattern ($P<0.05$), and ME intake during late spring and late summer were 134% to 181% greater than during early winter and early spring.

Table 4.43 Estimated DDMI, DOMI, ME intake, apparent N digestibility, and Ca and P intake from native pasture consumed by mature, non-pregnant cows, based on DMI and DMD estimated by the $C_{33:32}$ alkane pair. *Within columns, means with different letters differ significantly at P=0.05*

Parameter	Late spring	Late summer	Early winter	Early spring	s.e.m.
DDMI (g/d)	4.95 a	4.62 a	1.96 b	1.74 b	0.226
DOMI (g/d)	4.78 a	4.47 a	1.91 b	1.70 b	0.219
ME intake (MJ/d)	71.2 a	66.4 a	27.9 b	24.5 b	3.24
CP intake (g/d)	865 a	735 a	200 b	215 b	35.0
P intake (g/d)	8.9 a	4.7 b	1.5 c	2.0 c	0.37
Ca intake (g/d)	13.6 a	9.0 b	4.8 c	4.3 c	0.79

CP intakes during late spring and late summer were up to four times greater ($P<0.05$) than during winter and early spring. P and Ca intake followed a seasonal pattern, and declined from the highest in late spring to lows in early spring. P and Ca intake in late spring was higher than during late summer ($P<0.05$), and intakes of both nutrients during late spring and late summer were higher ($P<0.05$) than during early winter and early spring.

Cattle *v.* Sheep

As a percentage of liveweight, co-grazed sheep consumed more native pasture (76% to 200%, $P<0.05$) than co-grazed sheep in each of the four study periods (Table 4.44). When DMI was expressed in terms of metabolic liveweight, DMI was similar for sheep and cattle during late spring, late summer and early winter. In late spring, sheep consumed more (77%, $P<0.05$) pasture per kg of metabolic liveweight than cattle. DMD and OMD of the diet consumed by sheep in late summer was higher than for cattle during late summer ($P<0.05$). For all other study periods, the DM and OM, respectively, of sheep and cattle diets were similarly digestible. Apparent digestibility of N was higher for co-grazed cattle than sheep during late spring and late summer, but was lower than sheep during the early winter study period. Apparent N digestibilities were similar for sheep and cattle during early spring.

Table 4.44 Estimated dry matter intake and digestibility of native pasture diets consumed by co-grazed sheep and cattle. *Within rows, means with different numbers, and for each pair of data within columns, means with different letters differ significantly at P=0.05*

Parameter		Late spring	Late summer	Early winter	Early spring	s.e.m.
DMI (% of liveweight)						
	Sheep	3.0 a[2]	3.3 a[2]	1.7 a[1]	2.7 a[1,2]	0.26
	Cattle	1.7 b[1]	1.6 b[1]	0.8 b[2]	0.9 b[2]	0.06
	s.e.m.	0.18	0.21	0.15	0.18	
DMI ($g/kg^{0.75}$)						
	Sheep	78.0 [2]	86.7 [2]	43.6 [1]	66.7 a[1,2]	7.41
	Cattle	80.5 [1]	73.2 [1]	37.9 [2]	37.8 b[2]	2.77
	s.e.m.	5.17	6.25	4.02	4.46	
DMD (%)						
	Sheep	61.2 [1,2]	66.1 a[1]	57.5 [2]	57.2 [2]	1.56
	Cattle	64.0 [1]	62.8 b[1]	56.9 [2]	54.5 [2]	1.20
	s.e.m.	1.04	1.07	1.08	2.07	
OMD (%)						
	Sheep	63.6 [1,2]	69.1 a[1]	59.6 [2]	59.6 [2]	1.78
	Cattle	65.7 [1]	64.5 b[1]	59.0 [2]	56.7 [2]	1.14
	s.e.m.	0.21	1.42	1.00	2.18	
Apparent N digestibility (%)						
	Sheep	51.0 a[1]	58.7 a[1,2]	65.9 a[2]	61.3 [1,2]	2.83
	Cattle	67.1 b[1]	68.5 b[1]	57.3 b[2]	61.9 [2]	1.40
	s.e.m.	2.27	3.06	1.88	0.94	

Sheep

Faecal concentrations of N, Ca and P followed similar, distinct seasonal patterns and reflected intake of the nutrients (Fig 4.15a). For all three nutrients, faecal concentrations declined ($P<0.05$) from summer to winter, and increased during the following spring. Peak concentrations during summer (±s.e.) were 2.2±0.17g/kg, 0.53±0.029g/kg and 0.43±0.023g/kg for N, Ca and P, respectively. Minimum concentrations recorded in winter were 1.2±0.04g/kg, 0.27±0.031g/kg and 0.16±0.043g/kg for N, Ca and P respectively. Faecal concentrations of N, P and Ca reflected the apparent intake of all three nutrients (Fig. 4.15b).

Cattle

Faecal concentrations of N, P and Ca followed similar seasonal patterns to those exhibited by co-grazed sheep (Fig. 4.16a). Concentrations of all three nutrients in the faeces fell significantly from late spring to early winter, and concentrations either stabilised or rose slightly in early spring. The faecal concentrations of P and N were correlated with dietary P and CP intake (Fig. 4.16b). The apparent rise in consumption of Ca during early winter and early spring, compared to late summer, was not reflected in faecal Ca concentration.

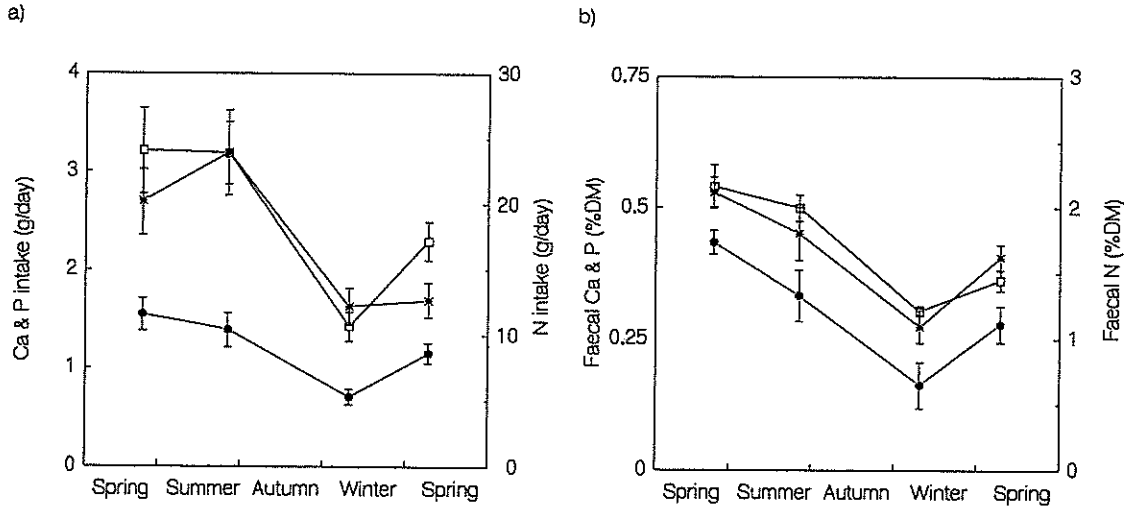

Figure 4.15 a) Calcium (✱), phosphorus (□) and nitrogen (○) intake (g/day), and b) faecal calcium (✱), phosphorus (□) and nitrogen (●) concentrations (%DM) for shearling wethers grazing native pasture

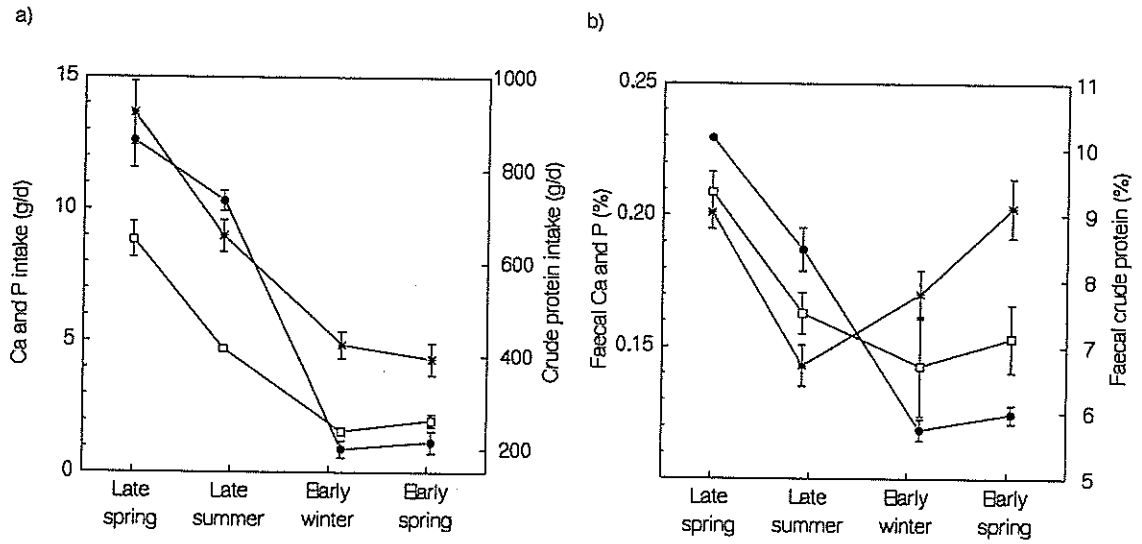

Figure 4.16 a) Calcium (✱), phosphorus (□) and crude protein (●) intake (g/day), and b) faecal calcium (✱), phosphorus (□) and nitrogen (●) concentrations (%DM) for mature, non-pregnant cows grazing native pasture

4.8 Empirical calculations

Predicting liveweight changes using alkane-derived estimates of DMI and DMD

DMI_{ADJ} and DMD_{ADJ} estimated by alkanes were used to estimate liveweight changes for lactating ewes, weaners, dry cattle, and co-grazed sheep and cattle and using SCA (1990) formulas (Table 4.45). The calculations used to predict liveweight change are listed in Miller (2002; Appendix 8). Predicted liveweight changes are presented both with and without an allocation for ME under conditions of cold stress.

For sheep, the predictions showed good agreement with observed changes. Liveweight change for the lactating ewes was estimated in conjunction with daily milk production, and the predicted liveweight change was also in good agreement with actual change. For the winter and early and late spring periods for both weaners and co-grazed sheep, predicted liveweight change more closely approximated actual liveweight change when the ME allocation for ECOLD was excluded from the calculation.

For both dry cattle and co-grazed cattle, when an allowance was made for ECOLD during late summer, early winter and early spring, predicted liveweight changes closely approximated observed values. During late spring, liveweight changes were better approximated when no allowance was made for ECOLD.

Table 4.45 Comparisons between observed liveweight changes for sheep and liveweight changes predicted by empirical formulae, with or without an ME allowance for cold stress (ECOLD)

Animals Season	Liveweight change (g/d) Observed	Predicted no allowance for ECOLD	 allowance for ECOLD
Lactating ewes			
Early summer	66	71	49
Weaners			
Winter	8	5	-23
Early spring	8	14	-12
Late spring	15	18	-3
Summer	90	109	62
Autumn	20	19	-4
Dry cattle			
Late spring	346	330	297
Late summer	75	178	40
Early winter	-342	-165	-342
Early spring	-435	-229	-391
Co-grazed sheep			
Late spring	50	50	33
Late summer	73	85	85
Early winter	-15	-22	-52
Early spring	15	12	-14
Co-grazed cattle			
Late spring	417	336	303
Late summer	50	222	88
Early winter	-300	-255	-432
Early spring	-350	-249	-413

Predicting protein requirements using alkane-derived estimates of DMI and DMD

The requirements for apparently digested protein leaving the stomach (ADPLS) for weaner sheep and lactating ewes (Table 4.46), co-grazed sheep (Table 4.47), and non-lactating cows (Table 4.48) and co-grazed cattle (Table 4.49) were estimated empirically (SCA 1990) from DMI_{ADJ}, DMD_{ADJ}, and CP_M and known liveweight changes (Table 4.45). In addition, the potential yield of microbial crude protein (MCP) to match ME intake, the apparent rumen degradability of CP, the potential yield of digestible undegraded protein (DUDP) and ADPLS supplied by the diet, and the apparent dietary supplies of RDP and ADPLS were estimated. The calculations used to derive these estimates are listed in Miller (2002; Appendix 9).

Sheep

Although the diets were potentially capable of supplying sufficient ADPLS to support the growth rates of the weaner sheep during each of the five study periods, ADPLS apparently supplied by the diet was less

than that required to sustain the observed body growth rates during early winter, spring and autumn (Table 4.46). Furthermore, RDP apparently supplied by the diet was substantially lower than the potential yield of MCP predicted by the intake of ME. Low rumen degradability of CP and low degradability of UDP apparently contributed to the ADPLS deficit during winter, spring and autumn.

To support the ADPLS requirements for observed growth, the CP concentration of the diets were required to be at least 10.2%, 10.1%, 10.1%, and 10.2% for the winter, early spring, late spring and autumn diets, respectively. Since the mathematical estimate of the rumen degradability of CP (d_g) is partially derived from dietary CP concentration (SCA 1990), the higher CP contents of the diets resulted in d_g estimates being revised upwards to 0.54, 0.57, 0.57, and 0.58 for the early winter, early spring, late spring and autumn diets, respectively. Raising CP concentration of the diets to these levels still failed to supply RDP to match potential MCP yield.

Table 4.46 Empirical estimates of potential microbial crude protein (MCP) yield, digestible undegraded protein (DUDP), and apparently digestible protein leaving the stomach (ADPLS) potentially supplied by native pasture, compared to ADPLS required to meet observed growth rates, and the quantity of rumen degraded protein (RDP) and ADPLS apparently supplied by native pasture to weaner sheep and lactating ewes

Parameter	Ewes	Weaner sheep				
	Early Summer	Early winter	Early spring	Late spring	Summer	Autumn
Implied CP_M concentration of the diet (%)	12.0	8.6	7.9	9.0	10.5	9.5
ADPLS required for observed growth rates (g/d)	90.3	35.9	37.1	40.7	63.6	49.3
ADPLS potentially supplied by the diet (g/d)	167.6	38.9	40.2	46.2	95.1	55.7
ADPLS apparently supplied by the diet (g/d)	130.4	26.5	23.9	33.5	65.7	43.7
Apparent rumen degradability of CP	0.74	0.46	0.45	0.52	0.69	0.55
Potential MCP yield from the diet (g/d)	253.9	53.5	58.1	64.2	145.4	76.2
RDP apparently supplied by the diet (g/d)	187.3	31.2	29.0	41.6	93.0	54.7
Apparent degradability of UDP	0.38	0.24	0.21	0.26	0.33	0.29
DUDP potentially supplied by the diet (g/d)	25.5	9.0	7.6	10.2	13.6	13.0

ADPLS apparently supplied by the diets was sufficient to meet the observed growth rates of lactating ewes during early summer and co-grazed sheep during spring (Table 4.46 and 4.47). However, ADPLS apparently supplied by the diet to shearlings wethers during early winter and late summer was slightly less than required to support the observed growth rates. In addition, none of the diets appeared to supply sufficient RDP to meet the potential yield of MCP, determined by the intake of ME. Consequently, where ADPLS requirements were met, the additional protein was provided by DUDP. To satisfy the ADPLS requirement for the growth rates observed for shearling wethers during early winter and late summer, dietary CP concentrations of 9.7% and 10.1%, respectively, were required, and d_g's were subsequently recalculated to be 0.53 and 0.63, respectively.

Table 4.47 Empirical estimates of potential microbial crude protein (MCP) yield, digestible undegraded protein (DUDP), and apparently digestible protein leaving the stomach (ADPLS) potentially supplied by native pasture, compared to ADPLS required to meet observed growth rates, and the quantity of rumen degraded protein (RDP) and ADPLS apparently supplied by native pasture to co-grazed shearling sheep

Parameter	Co-grazed sheep			
	Early winter	Early spring	Late spring	Late Summer
Implied CP_M concentration of the diet (%)	9.5	9.9	10.6	9.9
ADPLS required for observed growth rates (g/d)	29.3	42.9	59.8	71.7
ADPLS potentially supplied by the diet (g/d)	35.8	51.8	72.8	102.0
ADPLS apparently supplied by the diet (g/d)	28.2	45.2	67.6	69.1
Apparent rumen degradability of CP	0.52	0.54	0.60	0.62
Potential MCP yield from the diet (g/d)	47.6	67.2	125.4	151.8
RDP apparently supplied by the diet (g/d)	34.0	55.5	86.5	93.1
Apparent degradability of UDP	0.29	0.30	0.34	0.30
DUDP potentially supplied by the diet (g/d)	9.1	14.1	19.2	17.3

Cattle

ADPLS required to support the observed liveweight changes were apparently matched by that supplied by the diet for non-lactating cows during late spring and late summer. Apparent supply of ADPLS during early winter and early spring was underestimated by the calculations based on DMI_{ADJ}, DMD_{ADJ} and CP_M. For apparent supplies of ADPLS to meet the requirements of the observed liveweight changes, CP_M and rumen dg early winter and early spring were adjusted to 8.8% and 0.47, and 9.0% and 0.43, respectively.

Table 4.48 Empirical estimates of potential microbial crude protein (MCP) yield, digestible undegraded protein (DUDP), and apparently digestible protein leaving the stomach (ADPLS) potentially supplied by native pasture, compared to ADPLS required to meet observed growth rates, and the quantity of rumen degraded protein (RDP) and ADPLS apparently supplied by native pasture to non-lactating, mature cows

Parameter	Non-lactating cattle			
	Late spring	Late summer	Early winter	Early spring
Implied CP_M concentration of the diet (%)	8.7	11.4	8.5	8.7
ADPLS required for observed growth rates (g/d)	269	233	154	133
ADPLS potentially supplied by the diet (g/d)	383	365	216	222
ADPLS apparently supplied by the diet (g/d)	263	353	144	125
Apparent rumen degradability of CP	0.56	0.68	0.45	0.42
Potential MCP yield from the diet (g/d)	564	500	296	310
RDP apparently supplied by the diet (g/d)	350	478	167	138
Apparent degradability of UDP	0.25	0.37	0.24	0.25
DUDP potentially supplied by the diet (g/d)	68	85	50	48

The apparent quantity of RDP supplied by the native pasture only approached the potential MCP yield commensurate with ME intake during late summer. At all other times of the year, RDP supplied by the diet represented only 45% to 62% of the expected yield of MCP predicted by ME intake. Even after the upwards adjustment of dietary CP_M to 8.8% and 9.0% during early winter and early spring, RDP supplied remained less than potential MCP yield (61% and 48%, respectively).

Similar trends were evident for co-grazed cattle (Table 4.49). ADPLS apparently supplied by the native pasture met the estimated ADPLS requirements for observed liveweight changes during late spring and late summer. However, RDP apparently supplied by the diet remained less than the potential MCP yield predicted from ME intake, and were 94% and 79% for the late spring and late summer periods, respectively.

For the early winter and early spring periods, ADPLS apparently supplied by the diet was substantially lower than that required to meet the observed liveweight changes. For the diet to meet these requirements, CPM was required to be revised to 8.9% for both periods, and rumen dg's were recalculated as 0.47 and 0.45 for early winter and early spring, respectively. After revision of CP_M, apparent RDP supplied by the diet during early winter and early spring remained less than the potential MCP yield, and were 62% and 47% of potential MCP yield, respectively.

Table 4.49 Empirical estimates of potential microbial crude protein (MCP) yield, digestible undegraded protein (DUDP), and apparently digestible protein leaving the stomach (ADPLS) potentially supplied by native pasture, compared to ADPLS required to meet observed growth rates, and the quantity of rumen degraded protein (RDP) and ADPLS apparently supplied by native pasture to co-grazed cattle

Parameter	Co-grazed cattle			
	Late spring	Late summer	Early winter	Early spring
Implied CP_M concentration of the diet (%)	11.2	10.0	5.8	6.7
ADPLS required for observed growth rates (g/d)	284	266	122	112
ADPLS potentially supplied by the diet (g/d)	446	405	150	176
ADPLS apparently supplied by the diet (g/d)	426	338	41	57
Apparent rumen degradability of CP	0.65	0.59	0.20	0.27
Potential MCP yield from the diet (g/d)	600	558	233	206
RDP apparently supplied by the diet (g/d)	563	438	39	57
Apparent degradability of UDP	0.36	0.31	0.12	0.13
DUDP potentially supplied by the diet (g/d)	111	92	19	25

For sheep, apparent rumen degradabilities of CP_M were negatively correlated with NDF_M concentrations of the diets (correlation = -0.82), and were estimated by;

$$degradability = -0.0111 * NDF + 1.1912 \quad (R^2=0.677, P<0.01) \qquad (4.2)$$

For cattle, apparent rumen degradabilities of CP_M were negatively correlated with NDF_M concentrations of the diets (correlation = -0.77), and were estimated by;

$$degradability = -0.0296 * NDF + 2.367 \quad (R^2=0.591, P<0.01) \tag{4.3}$$

When sheep and cattle data were combined, apparent rumen degradabilities of CP_M were negatively correlated with NDF_M concentrations of the diets (correlation = -0.74), and were estimated by;

$$degradability = -0.0178 * NDF + 1.5897 \quad (R^2=0.543, P<0.01) \tag{4.4}$$

4.9 Intake of zearalenone by sheep and cattle

The fungal toxin zearalenone is associated with low fertility of ruminants. In response to low fertility rates in Falkland Islands' cattle, the concentration of zearalenone in Falklands' plants was determined to evaluate the likely incidence of zearalenone-induced infertility in cattle and sheep. Zearalenone was present in plant samples collected during the diet studies, and concentrations appeared to vary seasonally (Table 4.50).

Table 4.50 Seasonal concentrations of zearalenone (μg/g of DM) in selected Falkland Islands' plants and sheep and cattle faeces

	Zearalenone concentration (μg/g)				
Species	Feb	Mar	Jul	Sep	Nov
Grasses					
Agrostis capillaris	0.102	0.035	0.068	0.059	0.106
Poa pratensis	-*	-	0.085	-	0.100
Poa annua	0.039	0.037	0.051	-	0.042
Deschampsia flexuosa	-	1.034	-	-	-
Cortaderia pilosa	-	0.066	0.086	0.113	0.067
Heirocholë redolens	0.048	-	-	0.117	0.107
Aira praecox	-	-	0.292	-	0.769
Trisetum spicatum	-	0.064	-	-	0.154
Luzula alopecuris	-	0.144	-	0.203	0.310
Poa flabellata	-	-	-	0.095	-
Shrubs					
Empetrum rubrum	-	1.101	0.235	0.809	0.238
Forbs					
Gunnera magellanica	-	-	0.251	1.242	0.500
Blechnum penna-marina	-	-	1.166	1.104	0.154
Sisyrinchium filifolium	-	-	-	-	0.227
Sheep faeces	-	-	-	-	0.16
Cattle faeces	0.11	-	-	-	-

* - Not measured on that date

Diets containing greater than 1μg/g of DM are associated with infertility, and prolonged daily consumption of 0.5μg/g to 1.0μg/g may also induce mild infertility (J. Sprosen[2] Pers. comm.). Few Falklands' plants contained zearalenone levels sufficient enough to generate a diet containing 0.5μg/g of the toxin for either sheep or cattle. Zearalenone was detected in faeces from sheep sampled in November and cattle sampled in February.

5.0 DISCUSSION

Prediction of intake and digestibility

Before any meaningful conclusions could be drawn from the diet studies about the nutritional value of Falklands' native pasture for sheep and cattle, it was necessary to consider if the data were credible? To answer this question, DMI and DMD estimates were initially compared to historical data. Unfortunately, data on the intake and digestion of native pasture in the Falklands is scarce as only one previous study attempted to measure DMI and DMD for sheep (Table 1.5, G. Hoppé unpublished data), and no studies have been conducted with cattle. In the sheep study, Hoppé used wethers, presumably during summer, and neither the liveweight nor the ages of the sheep used in the study are known. However DMI and DMD for the sheep consuming the White-grass pasture maintained at 8cm were very similar to alkane-derived DMI and DMD estimates for the co-grazed wethers grazing native pasture during late spring and late summer in the present studies (Table 4.38 & 4.39).

A more robust test of the credibility of the DMI and DMD estimates was provided when the data were applied in empirical formulae, and the liveweight responses of sheep and cattle were predicted for each of the study periods and compared to actual liveweight changes for these animals. In general there were close agreements between the observed and predicted values for both animal species (Table 4.45). This outcome suggested that the ME intakes predicted from the alkane estimates of DMI and DMD were within expected ranges, and hence provided confidence in both the absolute values, and the methods used to derive them. Consequently, these techniques may have the potential to be used more widely to study the diets of ruminants grazing rangelands.

Inclusion of an ME allowance for cold stress (ECOLD) during winter and early spring for the weaner sheep and co-grazed wethers led to poorer predictions of liveweight change than when no ECOLD allowance was made. Although this may be related to imperfections in the DMI_{ADJ} and DMD_{ADJ} estimates or errors in liveweight measurement, it is also likely that the ECOLD allowance was overestimated. Calculation of this entity requires the use of estimates of the environmental conditions actually experienced by the animals during the measurement period. In performing the calculations for ECOLD, mean monthly wind speed and air temperature were assumed from historical data and it is likely that these values did not adequately reflect the conditions experienced by the sheep in the studies. This was particularly important for wind speed as this variable has a large effect on the values for total thermal

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insulation (I_e+I_t) and lower critical temperature (T_{lc}), and consequently the ME allowance for ECOLD. Wind speed is frequently measured at heights several metres above ground level and it is unlikely that grazing sheep experience these wind velocities due to their smaller stature and use of terrain and taller vegetation as shelter against high winds. Consequently, without better data for the conditions actually experienced by sheep for these two study periods, the liveweight predictions derived without an allowance for ECOLD may be accepted to provide further validation of DMI_{ADJ} and DMD_{ADJ}.

In contrast, liveweight changes were better predicted for cattle when ME allowances for ECOLD were included in the calculations. This anomaly may be explained by relative differences in size of the sheep and cattle. There are no trees in the grazed Falklands landscape, and cattle stand well above the top strata of the White-grass sward. Consequently, as larger animals the cattle face more difficulty finding natural shelter whilst grazing and are naturally more exposed to wind and hence wind-chill. Some relief may be gained by using the topography of the landscape to evade high winds, however it is likely that cattle experience environmental conditions that more closely reflect those recorded for meteorological purposes. Hence, the ME allowance for ECOLD derived from such data may be more relevant for cattle than sheep in the Falklands.

The differences between DMI estimated by $C_{31:32}$ and $C_{33:32}$ pairs for weaner, shearling and ewe diets (2.9%, 2.6% and 9.3%, respectively) closely matched the differences in faecal recovery of these alkanes (3.3%, 2.6% and 8.0%, respectively). To validate the estimates of DMI and DMD generated by the alkane methods, DMI_{ADJ} and DMD_{ADJ} were chosen as the preferred data. This decision was made on the basis that there is no general agreement on whether any alkane pair is more accurate than another to predict intake and DMD. Whilst some studies suggest that actual intake is more closely reflected when estimated by the $C_{33:32}$ pair (Mayes *et al.* 1986, Stakelum and Dillon 1990, Reeves *et al.* 1996), other studies show better agreement with DMI estimated by the $C_{31:32}$ pair (Dove and Olivan 1998). Herd *et al.* (1998) proposed that these differences are caused by the small differences in recoveries of the respective alkane pairs, and that applying corrections for incomplete faecal recovery, and using the ratio of the mean of adjusted C_{31} and C_{33} concentrations to adjusted C_{32} may allow discrepancies for imperfect adjustment of faecal recovery to be corrected. This approach was used to generate DMI_{ADJ} and DMD_{ADJ} in these Falklands' studies.

For sheep, DMI and DMD estimates derived from microhistological data were substantially lower than alkane estimates and their use in empirical formulae would have produced incorrect estimates of liveweight change. This large discrepancy between microhistological and alkane estimates of diet quality, and hence DMI, is consistent with reports that microhistology frequently misrepresents actual diets consumed by animals (Dearden *et al.* 1975, Vavra and Holechek 1980, Holechek *et al.* 1982, Norbury 1988). Moreover, it highlights the ability of animals to select diets of substantially higher quality to those sampled by hand (Langlands 1974, Vulich *et al.* 1993). Consequently, implied DMD estimates that are calculated by summing the proportional contribution of each species to the diet are unlikely to adequately describe the true nutritive value of the diet to the animal.

For cattle however, the differences between DMD_M and DMD_A, and DMI_M and DMI_A were substantially less than those for sheep, and the differences between the data derived by microhistological methods and alkane methods were not generally significant. It is likely that the cause of this discrepancy lies in the eating characteristics of sheep and cattle. Sheep are more easily able to select individual plants and plant parts than cattle due to the anatomy of their mouth parts. The more dextrous lips of sheep enable them to be more selective than cattle, and in doing so are acknowledged to select diets of higher nutritional value than those harvested by hand. Since the microhistological methods relied upon summing the results of chemical analyses of plants collected by hand, and using those results to imply diet quality and subsequently DMI, this is likely to have led to quantitative underestimates of diet quality for sheep. As less discriminant grazers, the cows may have harvested pasture in a manner more closely approximating the hand collection methods, hence the difference between implied and actual diet quality were likely to be much smaller than observed with sheep.

Diet quality

It is clear that diets consumed by both sheep and cattle grazing native pasture in the Falklands exhibit a marked seasonal pattern of digestibility, and hence energy supply, and protein, P and Ca supply. Whilst acknowledging the limitations in combining data from different age groups and paddocks, when DMD and DMI estimates for native pasture consumed by sheep are combined, a seasonal pattern of nutrition emerges (Fig. 5.1).

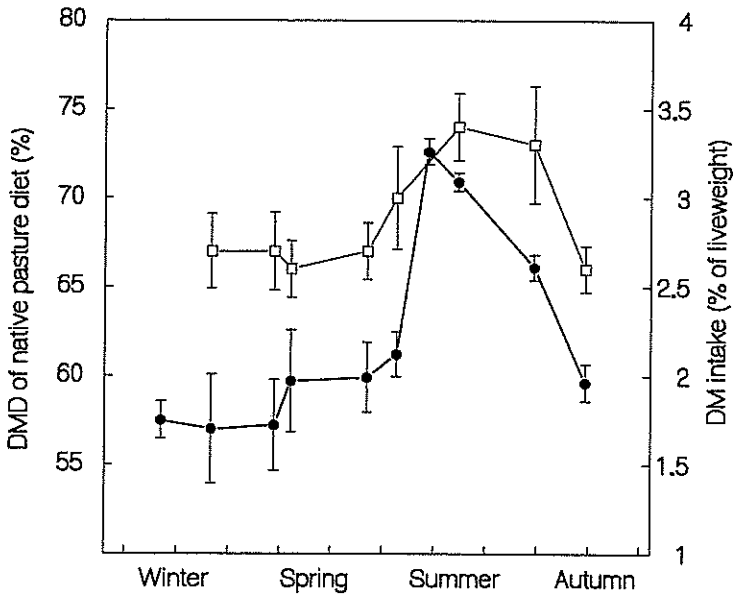


Figure 5.1 Seasonal DMD (●) and DMI (% of liveweight, □) of native pasture by sheep in the Falkland Islands

For much of the year the sheep appeared to consume a maintenance diet. The rapid rise in diet quality during summer coincided with a period of rapid growth by sheep. This rise also coincided with warmer

summer temperatures and growth of pastures, particularly the fine grass and forbs component of the pasture. These species appear to drive sheep productivity. Specifically, Smooth-stalked Meadow-grass and Native Fescue are particularly important contributing up to 40% of the diet during summer. Consequently, pasture management criteria that maintain or promote the abundance and growth of these species would benefit sheep growth and productivity. These two species would therefore be suited for use as indicators to assess the apparent quality of the pasture for sheep. Unfortunately, the large difference between winter, spring, and autumn diets, and that consumed during summer (up to 15 DMD units), suggests that substantial destocking would need to occur during the summer pasture growth period in order to produce sufficient carry-over DM of the better quality fine grasses and forbs for grazing during the following autumn and winter, and to maintain substantially faster growth rates of sheep than are currently achieved. Presently, this is the only method available to farmers to capitalise upon the summer pasture growth phase, since the opportunity to mechanically conserve these forages is limited by the heterogenous nature of the pastures, and the sparse occurrence of easily harvestable, high feed quality areas.

The similar DMI and DMD of pastures consumed by set-stocked, co-grazed cattle, and rotationally grazed non-lactating cows in all four study periods (Fig. 5.2 and 5.3) may imply that opportunities to manipulate the quality of the diet available to cattle, by using alternate grazing strategies, are limited. The predominance of poorly digestible, protein-poor pasture species for much of the year, and the inability of cattle to select the less abundant, higher quality plants lead to this conclusion. This may be particularly important where sheep are co-grazed with cattle and the competing grazing behaviour of the two animal species impact on the quality of the diets that both animals consume.

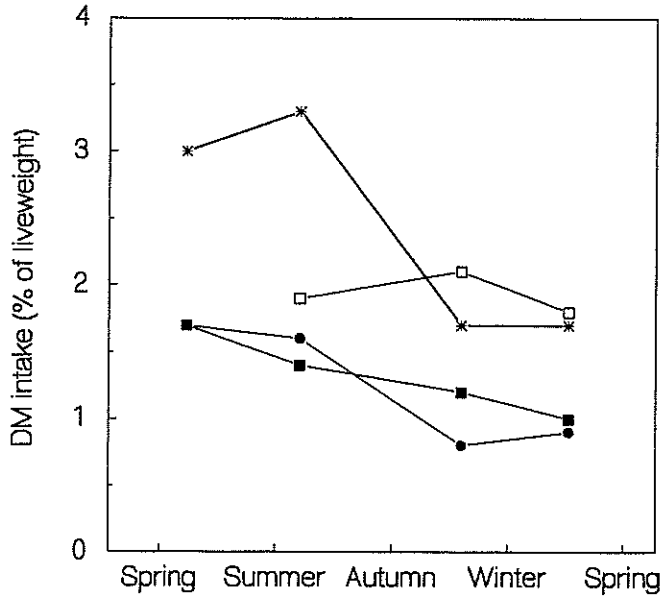


Figure 5.2 Seasonal DMI of native pasture, expressed as a percentage of liveweight, by co-grazed sheep (✱) and cattle (●), and non-lactating (■) and lactating (□) cows in the Falkland Islands

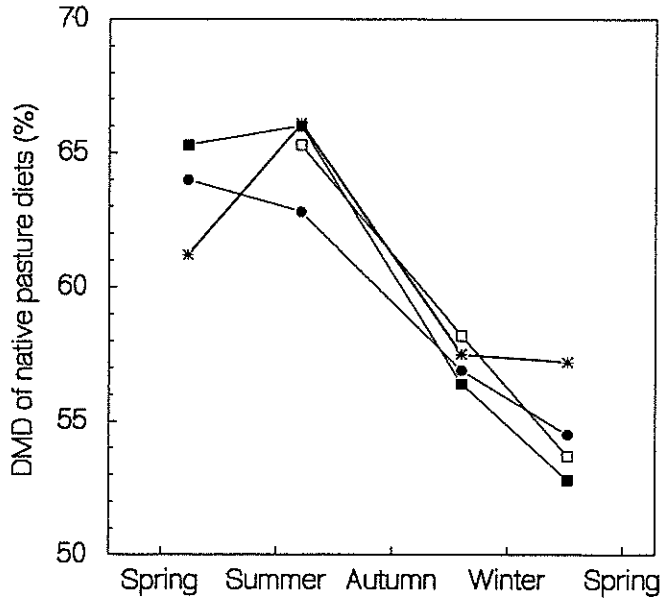


Figure 5.3 Seasonal DMD of native pasture consumed by co-grazed sheep (✱) and cattle (●), and non-lactating (■) and lactating (□) cows in the Falkland Islands

In light of the different grazing abilities of sheep and cattle to select plants, it was perhaps surprising to only detect differences in the digestibility of the respective animals' diets during late summer. The higher digestibility of the diet consumed by sheep during late summer was probably related to the high incidence of Diddle-dee berries in sheep diets, and the dominance of White-grass in the diet of cattle. In each of the other 3 study periods, DMD was similar for sheep and cattle.

The substantially higher nutrient requirement of lactating cows was well demonstrated in the three periods that their diets were compared to no-lactating cows (Fig. 5.2). Whilst the relative quantity of feed consumed by both groups of cattle were similar throughout, expression of intake in terms of body weight demonstrated the reliance upon body reserves of lactating cows to maintain milk production during a period when diet quality was particularly poor, and insufficient to maintain maternal body weight during lactation. These differential demands resulted in a significant weight difference between lactating and non-lactating cows by the early spring, and may help explain the biennial calving system traditionally practiced by local farmers. Without calving, the pattern of nutrition provided by native pasture apparently allows cows to maintain annual bodyweight, and this is achieved by weight gain during late spring and summer, and weight loss during autumn, winter and early spring. The large weight loss experienced by calving cows in these studies must be regained over the subsequent 18 months, and is probably contributed to by compensatory growth mechanisms in the spring and summer period in the year after calving. If a cattle industry is to become a viable diversification option for Falklands' farmers, systems that limit the substantial loss of body weight in the winter following calving, and the subsequent effects that liveweight loss confers on fertility, must be identified and implemented as a priority. It is doubtful that native pastures dominated by White-grass will provide forage of sufficient quality to meet this

requirement. Improved legume pastures and winter forage crops currently under investigation by farmers and the Department of Agriculture appear ideally suited to fill this void.

An immediate outcome from these studies would be to recommend that calves are weaned from cows before the onset of winter and pasture quality begins to rapidly decline. Clearly, calves gain little from suckling after May, and both the mother and offspring suffer growth restrictions when the relationship is sustained through winter (Fig. 4.8).

Nitrogen supplied by native pasture

The inability of the diet to supply sufficient N to weaner sheep and non-lactating cattle was demonstrated by both plasma urea and rumen ammonia concentrations during the year. The minimum concentration of NH_3-N for maximum rates of rumen fermentation is accepted as 5mg/100ml (Satter and Slyter 1974, Satter and Roffler 1976). However, it is suggested that higher rates than this are required to maximise ruminal fermentation and microbial synthesis (Satter and Slyter 1974, Allen and Miller 1976, Mehrez *et al.* 1977, Boniface *et al.* 1986), and SCA (1990) recommends a minimum range of 6mg/100ml to 8mg/100ml (Pisulewski *et al.* 1981). The low concentrations of rumen ammonia measured from weaner sheep between late autumn, winter, spring and early summer (4.0mg to 4.5mg/100ml), and non-lactating cows during the same period (3.8mg to 4.4mg/100ml) in the current study suggested that availability of fermentable N, and hence RDP, was limiting animal productivity.

Using the values for DMI_{ADJ}, DMD_{ADJ}, and implied CP_M concentration of diets to estimate the protein requirements of the sheep and the dietary supply of protein, two conclusions became apparent. Firstly, the implied dietary CP concentrations were not reliable to generally estimate CP intake by the sheep. This was clearly shown for weaner wethers for four of the study periods, and for shearling wethers during winter, wherein the ADPLS requirements to support the observed growth rates were unmatched by the ADPLS apparently supplied by the diets. For these study periods it would appear that either the CP concentrations of the diets were underestimated by CP_M, or that the rumen d_g of CP was underestimated, since ADPLS potentially supplied by the diets appeared to satisfy the ADPLS requirements. The rumen d_g of protein was not measured during these studies, rather it was calculated. This calculation was dependant on the calculation of MADF from the ME content of the diet (SCA 1990, Eq. 1.14), and ME was in turn calculated from DMD_{ADJ} (Freer *et al.* 1997, **Eq. 3.3**). This series of calculations undoubtedly introduces a degree of error in the resultant estimate of d_g. Furthermore, d_g is directly related to CP concentration of the diet (SCA 1990, Eq. 2.13), hence a further source of error arises if dietary CP concentration is inaccurately determined. Consequently, a combination of these sources of error has probably influenced the estimates of ADPLS apparently supplied by these native pasture diets. Since sheep are known to select diets of higher quality than that apparently on offer, and it is probable that the CP_M concentration of the diet implied by botanical composition underestimated actual protein concentration of the diet, an attempt was made to compensate for these errors, and CP concentrations of the diets were increased to allow ADPLS requirements to be met. For weaners during winter, early and late spring, and autumn, and shearlings during early winter, these recalculations suggested that the diets

selected by sheep needed to contain more than 10.1% CP, and that implied CP_M may have underestimated apparent dietary CP by as much as 20%.

The second conclusion was that year-round, the quantity of RDP apparently supplied by the diets failed to meet the potential MCP yield predicted from ME intake. Whilst this conclusion was consistent with the observation that rumen NH_3-N concentrations for weaner wethers were sub-optimal for rumen fermentation during winter, spring and autumn, rumen NH_3-N was apparently sufficient during summer (≥8mg/100ml) and suggested that the MCP requirement for this period was met by dietary RDP. This was not evident from the predicted values since RDP apparently supplied by the diet (102g/d) was substantially less than the potential yield of MCP (145g/d, Table 29). For the summer diet to provide sufficient RDP to meet the potential yield of MCP, as suggested by both rumen NH_3-N and plasma urea concentrations, a dietary CP concentration of 13.9% was required and was 32% higher than implied dietary CP_M. This observation provides further support to the conclusion that implied dietary CP_M concentrations were substantially underestimated during the studies, and that other measures to determine the adequacy of dietary N, for example rumen NH_3-N and plasma urea, are more valuable determinants of the protein status of ruminants than implied estimates of forage CP (Weston and Hogan 1968, McMeniman 1981, Hennessy and Nolan 1988).

These two conclusions generally held for cattle grazing native pastures also. Firstly, a reliance on CP_M tended to underestimate CP intake by cattle during winter and early spring, however the underestimates were not as large as those that existed for weaner sheep particularly. This is also likely to have been due to the different grazing abilities of sheep cattle, and the cattle consumed diets that more closely approximated the nutritional quality of the pasture samples collected by hand. Secondly, and in agreement with the sheep studies, cattle rarely consumed sufficient RDP to match the potential MCP yield predicted by ME intake. This was confirmed by the rumen NH_3-N samples collected from non-lactating cows during the study periods, and was reflected in a distinct seasonal variations in plasma urea concentrations.

The principal conclusion from these results is that during autumn, winter and early spring both sheep and cattle apparently suffered RDP deficiencies that failed to satisfy the MCP requirement for the ME consumed. This conclusion would suggest that RDP is the first limiting nutrient for both animal species during this period. Higher growth rates, more efficient rumen fermentation and increased DMI would be likely to occur if an RDP supplement were provided to these animals. Thereafter, ME would limit further increments in productivity.

The significant rise in plasma creatinine observed for weaners during winter and the subsequent fall during spring and summer is further evidence of poor nutrition during autumn and winter. This trend was also mimicked in plasma samples collected from non-lactating cows. Phosphocreatine stored in muscle is converted to creatinine, releasing energy in the reaction. The elevated level of the decomposition product, creatinine, in plasma during winter is indicative of an increased reliance on stored muscle energy for maintenance (Finco 1989, Beitz 1993). With increased energy consumption in summer, creatinine levels were significantly lower.

Phosphorus and calcium intake

Sheep

The seasonality of P and Ca consumption was well illustrated for both the weaner and shearling sheep. Apparent P intake during winter and spring was below recommended levels for maintenance for both weaners and shearlings, and was reflected in plasma inorganic P levels from weaner sheep. Whilst this data provides further support for the accuracy of DMI estimates derived from the alkane data, it also has implications for sheep productivity. Although no clear demonstration of a P deficiency in grazing sheep exists (McDonald 1968) P is widely acknowledged to play a role in reducing feed intake (Ternouth and Sevilla 1984), and sheep consuming low P diets have responded to P supplements through improved digestibility and forage intake (McMeniman 1976). P deficiencies have been previously identified in weaner sheep in the Falklands (Miller *et al.* 1998), consequently young sheep in the Islands may be subjected to widespread, seasonal P deficiencies. Further studies would therefore be warranted to examine the likelihood for these animals responding to strategic P supplements under grazing conditions.

Whilst Ca intake did not appear to fall below maintenance requirements for either weaners or shearlings, intake was just sufficient to meet the maximum 90g/day growth rates for weaners during summer (SCA 1990). Similarly, the maximum growth rate supported by Ca intake for shearlings was 100g/day during summer, hence Ca availability was not limiting for these animals. Intake of Ca during winter and spring was associated with the proportion of Mountain Berry in diets of weaner sheep, and consumption of the plant during winter ensured Ca supplies were maintained at or slightly above maintenance requirements. This is important in the Falklands where interactions between Ca, P and vitamin D may be critical. It has been previously shown that weaner sheep can be subject to seasonal Ca and P deficiencies (Miller *et al.* 1998, Clelland 2002), and weaner sheep have exhibited increased growth rates when supplemented with injections of vitamin D_3. Plasma concentrations of 25-OHD_3 below 25nmol/L are considered deficient (Puls 1994), and the evidence provided in this thesis for vitamin D deficiency between March and October in young sheep grazing in the Falklands is consistent with similar findings for young sheep during autumn, winter and spring at similar latitudes in the northern hemisphere (Smith and Wright 1984). During autumn, winter and early spring the far southern latitude of the Islands (51° to 53°) means that the sun falls below the 35° elevation required for ultraviolet light to pass through the atmosphere in sufficient quantities to effectively synthesise vitamin D_3 in the skin of animals (Underwood 1981). Consequently, weaner sheep must rely upon supplies of vitamin D_3 obtained from the mother across the placenta (Fraser 1995), *de novo* synthesis prior to autumn, and consumption of vitamin D_2 from forage (Horst *et al.* 1981) to generate stores of the vitamin for subsequent use during autumn, winter and early spring. The steroid activity of vitamin D controls the absorption of Ca and P (Fraser 1994), and since low Ca intake can accelerate the development of vitamin D deficiencies (Fraser 1995), and sheep are susceptible to osteomalacia when P and vitamin D are deficient (Radostits *et al.* 2000), the interactions between these nutrients in young sheep in the Falklands requires further study, particularly in light of the seasonal P deficiency identified in the present study. The syndrome of most importance in the Falklands may be the hypophosphatemia that develops conjointly as a result of vitamin D deficiency and low P

intake, and the negative effects that P deficiencies confer on feed intake, nutrient utilisation and reproduction (Radostits *et al.* 2000). Hypocalcaemia occurs in the latter stages of a vitamin D deficiency, typically some months after the onset of hypophosphatemia (Radostits *et al.* 2000), and evidence for this in the Falklands includes an apparent hypocalcaemia syndrome. This syndrome involves muscle weakness and paralysis, and is triggered by the movement of sheep during mustering prior to shearing in early summer. The increased Ca demand by muscles that is associated with walking during mustering is unable to be satisfied by the endocrine system of the vitamin D-deficient animal. This syndrome is treated locally with intravenous calcium gluconate (Bikle 1998). The lack of widespread bone disorders in the Falklands is probably linked to consumption of relatively Ca-rich shrubs during autumn, winter and spring where they are available, and restricted ME and CP intake which limit body growth rates and hence P and Ca requirement during this period.

Cattle

Both P and Ca intake were estimated using implied concentrations of P and Ca in native pasture, and DMI_{ADJ}. These estimates suggested that intake of both nutrients was insufficient to meet animal requirements during all four study periods. In winter and early spring particularly, intake was less than 50% of the maintenance requirements for P (11.4g/d) and Ca (10.7g/d) by 400kg non-lactating cows (SCA 1990). Although some allowance should be made for underestimating P and Ca intake, by virtue of the animals selecting more nutrient-rich pasture than that harvested by hand, the very low apparent P and Ca intakes during winter and spring should be a general concern in the practical management of these cattle. Generally, these trends were not evident in plasma concentrations of these nutrients, as neither nutrient entered a 'deficient' range during the studies. However, faecal concentrations of P fell well below the 2g/kg recognised as an indicator of dietary P deficiency (Belonje 1978, Belonje and Van der Berg 1980, Masters and White 1996). Across the Islands, cattle can be observed exhibiting pica such as bone chewing. This is commonly associated with P deficiencies elsewhere (Underwood 1981), and adds further weight to the likelihood of seasonal P deficiencies in cattle grazing native pastures.

Botanical composition of diets

Sheep

The high proportion of fine grasses in the diets of sheep during late spring and summer particularly, is a key finding in these studies. The relatively high occurrence in the diet compared to their distribution in the pastures consumed (data not shown) suggests that the sheep seek out these species in preference to White-grass and shrubs when the finer grasses become more widely available during the warmer months. White-grass and Diddle-dee are the two most abundant species in the Islands (Davies 1988, McAdam 1992), and their apparent low preference to sheep when more nutritious species are available implies that a greater understanding of ways to manipulate pasture management to promote and conserve the growth of the fine grasses is required if sheep productivity is to be substantially improved. However, the large differential between pasture quality in summer and the remainder of the year (Fig. 5.1) will preclude

substantial increases in animal productivity without substantial changes in pasture composition. Changes of this magnitude will not occur without a large input of fertility (Davies 1988).

The pattern of consumption of fine grasses and forbs followed that which has been reported for the growth of these species in the Islands. Much of the contribution made to pastures by these species is achieved during the period from November to March (late spring and summer), thereafter growth of these species slows and they become dormant during late autumn, winter and early spring. From August to mid-November, growth rate of pasture from greens peaks at 13kg/ha/day (R. Thompson[3] unpublished data). The forb fraction of White-grass swards increases in biomass by 70% during Jan to April (McAdam 1986), and greens produce up to 6 times more DM than White-grass, and up to 28 times more ME/ha during spring and summer than White-grass (McAdam 1986, Kerr 1995). White-grass displays a similar spring and summer growth pattern. McAdam (1986) reported peak growth rates for White-grass of approx 19kg/ha/day during early January, rising from 2kg/ha in late November and returning to 4kg/ha by the end of February (1,440kg/ha). However the low DMD of the species appears to limit intake of this plant during summer compared to the more nutrient rich fine grasses. The shift away from White-grass and woody species during late spring, summer and autumn is consistent with animals actively seeking more nutritious species. Sheep apparently consumed fine grasses at times when they were in abundance, and during periods of poor abundance substituted White-grass, Mountain Berry, and to a lesser extent Wavy Hair-grass. The apparent ability of Smooth-stalked Meadow-grass and Native Fescue particularly, to persist under selective grazing may make these plants ideal candidates to use in a plant selection and introduction programmes for pasture improvement.

Davies (1988) suggested that Annual Meadow-grass was likely to only play a minor dietary role in sheep diets. This view is contrary to popular belief amongst farmers as Annual Meadow-grass is widely distributed within coastal greens and beside creeks and ditches. The data from the studies in this thesis suggest that Davies was correct, and that although Annual Meadow-grass is consumed, other fine grasses are quantitatively more important. The cause of this disparity is probably multifactorial, including the early flowering habit and low yield of Annual Meadow-grass (R. Thompson unpublished data), and preferential grazing by native Upland Geese (*Chloëphaga picta*). Preferential grazing by populations of the native Upland Goose on greens contributes to keep those pastures very short throughout the year (7mm to 13mm, Summers and Grieve 1982). Consequently, competition between geese and sheep probably limits the ability of sheep to consume this species in significantly greater quantities. By contrast Smooth-stalked Meadow-grass and Native Fescue are more widely distributed than Annual Meadow-grass (Davies 1988), particularly in White-grass pastures, and sheep may be offered a greater chance to consume these plants since geese do not typically graze White-grass pastures.

Geese apparently consume a very similar diet to that consumed by sheep during summer in these studies, during which sheep selected fine grasses in preference to White-grass and woody species. Geese display a preference for fine grasses, and *Poa* sp. contribute 33% to 100% of the diet during the year, and Early Hair-grass and Native Wood Rush are also preferred (Summers and Grieve 1982). The large population

[3] R. Thompson, Department of Primary Industries, Water and Environment, Tasmania

of geese in the Islands and their concentration on the more productive pastures presents a competitive grazing threat to sheep. When considering the goose's characteristic preference for greens and almost absence from White-grass pasture, competition between geese and sheep for the herbage available to be consumed from greens is probably substantial.

There is anecdotal evidence in the Falklands that sheep readily consume goose faeces, particularly during winter, and this phenomenon has been observed elsewhere with reindeer (Van der Wal and Loonen 1998). Although this aspect of forage intake was not specifically examined in the present study, goose faeces may represent a useful food resource for sheep when preferred forages are scarce, as OMD and CP of goose faeces are in the ranges 59% to 72% and 8.0% to 10.8%, respectively (Summers and Grieve 1982, Appendix 3).

The importance of *Poa* sp. and *Festuca* sp. in sheep diets in the Falklands concurs with data for ruminants grazing analogous pastures in Tierra del Fuego (Raedeke 1980, Posse *et al.* 1996) and South Georgia (Leader-Williams *et al.* 1981). Moreover, a similar increase in diet diversity during summer was observed for sheep in the Falklands in the present studies, and for sheep in Tierra del Fuego (Posse *et al.* 1996) and reindeer in South Georgia (Leader-Williams *et al.* 1981).

The reliance upon White-grass for much of the year has substantial implications for many areas on West Falkland in particular, where White-grass is often not abundant and pastures are dominated by Diddle-dee. Since sheep did not apparently consume Diddle-dee preferentially in these studies, it poses the question what are the important species for sheep in these areas? It is likely that a greater reliance is placed upon species such as Smooth-stalked meadow grass, Mountain Bluegrass, and Native Fescue. Since these species are less abundant during autumn and winter, sheep are also likely to suffer lower growth rates than observed in these studies, and some confirmation for this is seen in the lower liveweights achieved by sheep in these areas when compared to sheep from White-grass pastures at the same age (Makin-Taylor 1991, Baughan *et al.* 1993).

The contribution of White-grass to weaner sheep diets in late spring was similar to that estimated by Davies (1988) for sheep grazing White-grass swards from October to December (Table 1.1). However, Buckingham (1987) and Davies (1988) estimated that White-grass contributed up to 85% of the diet by occurrence, and 76% of the diet by dry weight for wethers from February to April (Table 1.2 & 1.3). This is much higher than the 42% DM contributed by White-grass to weaner and shearling diets in the present studies. The difference between these results may lie in both the methods used by Davies to estimate intake, and the fact that groups of sheep were confined to small White-grass dominant areas offering sheep much less opportunity to select other species than may have been the case in the present studies. Weaner sheep in these studies selected fewer forbs than recorded by Davies for mature wethers; however, the shearling wethers in the present studies selected a similar proportion of forbs in late spring as wethers during October to December (Table 1.1). Unlike Davies (1988), the sheep in the present studies showed no obvious preference for Christmas Bush, however the pattern of Christmas Bush consumption by wethers in Davies' study was similar to the consumption of Mountain Berry by weaner sheep in the

present study, confirming the role shrubs play during winter and spring when the availability of other more preferred species is apparently less.

In agreement with the Diddle-dee studies with goats and sheep (Table 1.4), the present studies failed to demonstrate that Diddle-dee is preferred forage for young sheep. The highest intake of Diddle-dee was recorded for shearling wethers during late summer when they were also consuming a substantial quantity of Diddle-dee berries, consequently, accidental consumption of the leaves may explain this peak intake of leaf material.

There was an apparent difference in the quantity of fine grasses consumed by shearlings and weaners during summer and winter, with shearlings tending to consume proportionally more fine grasses during winter and less fine grass during summer than weaners. It is likely that the discrepancy during summer lies in both differences in species abundance between the two areas studied, and the timing of the diet studies. The late spring collection period for shearlings was similarly timed to the late spring period for weaners, however the late summer collection period was 6 weeks later than the summer collection period for weaners. Consequently, it is possible that the late summer period was too late to identify the summer 'spike' in feed quality and abundance of fine grasses. The high presence of Diddle-dee berries in the shearling diets at this time supports this conclusion as Diddle-dee berries were not present during the summer collection period for weaners, and the failure of White-grass to fall below the proportion consumed in late spring (24%), before fine grasses became abundant, suggests that the berries were not simply substituted for fine grasses. It would have been expected that the poorer quality White-grass would have been substituted by Diddle-dee berries if high quality fine grasses were more abundant. This observation adds further weight to the conclusion that diet quality is high for just a short period over summer, and that animals must capitalise on this peak in nutrient availability in order to survive, produce and reproduce under Falklands' conditions.

Cattle

Lactating and non-lactating cows consumed similar diets throughout the studies, hence the data for botanical composition were pooled for analysis. In agreement with the weaner sheep studies, White-grass was consumed by cattle in greater quantities during winter and early spring than during summer. Moreover, White-grass was apparently substituted for fine grasses during the warmer months in a similar manner as seen with weaner sheep. Consequently, it is likely that the preference for these finer species and the higher nutrient content of the fine grasses are responsible for the liveweight gains achieved by cows during late spring and summer. The rotationally grazed cattle tended to consume less White-grass in their diets for most of the year than did weaner sheep. However during summer, cattle consumed substantially more White-grass than sheep. These differences may be related to the different abilities of sheep and cattle to graze selectively. As White-grass is composed of both green and senescent material in a ratio often exceeding 30:70, it is likely that sheep are more efficient at selecting the green leaf than are cattle. The higher proportion of Small fern in the sheep diets supports this conclusion. Small fern grows deep within the White-grass bogs, within the stratum that green White-grass leaf is more abundant.

Accidental consumption of fern leaves by sheep whilst the sheep actively seek green leaf would account for their increased presence in sheep diets, whilst cattle are restricted to consuming the longer, senescent White-grass leaves that contain substantially less fern. In addition, cattle may be restricted in their ability to consume fine grasses during the summer period due to the competition with other grazing animals for this resource. Sheep and geese graze these species close to the ground. This could also account for the higher contribution of White-grass to cattle diets during summer compared to sheep, and the higher incidence of apparently less palatable species in cattle diets, such as Early Hair-grass, Native Rush and Wavy Hair-grass, as other animals preferentially graze the meadow grasses and leave the less palatable species. This assertion is supported by the predominance of Native rushes and Hair-grasses in cattle diets that was not generally reflected by sheep, however in both animal's diets these plants exhibited similar seasonal trends and a degree of substitution during late summer particularly, when fine grasses contributed their most, and the Native rushes and Wavy Hair-grass were only a minor contributor to the diets.

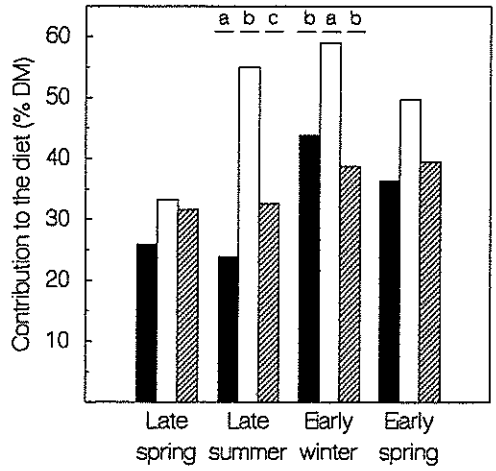
Forbs contributed similar contributions to cattle diets as those observed with weaner sheep with the exception that during late summer the abundance of forbs in cattle diets was almost twice that for sheep, and Pig Vine was a noticeable component of this group of plants. This species was largely uneaten by sheep at any time during the year.

Co-grazed sheep and cattle

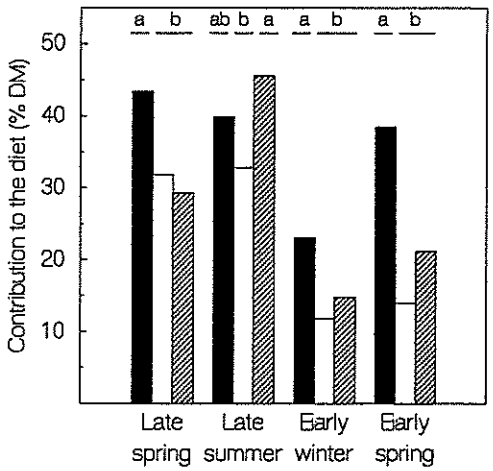
Superficially, it is possible to compare the diets of sheep and cattle grazing similar pastures but under different grazing management regimes, however the data are limited by many uncontrolled factors. A true test of diet complementarity and competition can only be performed when sheep and cattle are grazed together. This was done during the course of these studies, and sheep and cattle were grazed together in a paddock set stocked for 12 months at a stocking rate in the mid-range of those generally set for sheep in the Falklands. In our studies, both sheep and cattle in a ratio of approximately 10 sheep to 1 cow contributed to the total stocking rate. This ratio is generally accepted as optimal for co-grazing these species (Nolan and Connolly 1988).

When co-grazed, sheep and cattle consumed similar quantities of White-grass during both spring periods, however cattle relied more heavily upon White-grass during late summer and winter (Fig. 5.4). This was anticipated since it is likely that as pasture growth slows and the finer, more nutritious grasses become less prevalent in the pasture, sheep would preferentially graze these species and cattle would be forced to consume species with greater bulk within the remaining sward. The results generally upheld this hypothesis.

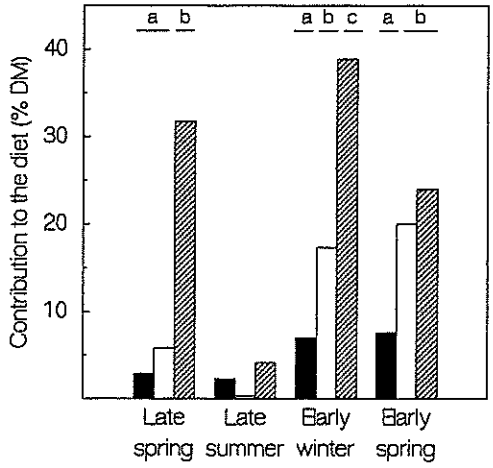
a)


Contribution to the diet (% DM)
60
50
40
30
20
10
a b c b a b
Late spring
Late summer
Early winter
Early spring

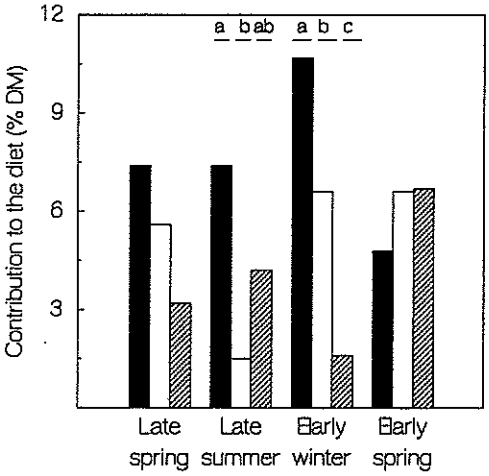
b)


Contribution to the diet (% DM)
50
40
30
20
10
a b ab b a a b a b
Late spring
Late summer
Early winter
Early spring

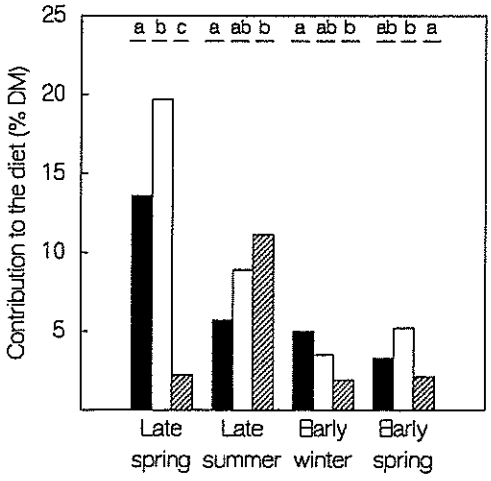
c)


Contribution to the diet (% DM)
40
30
20
10
a b a b c a b
Late spring
Late summer
Early winter
Early spring

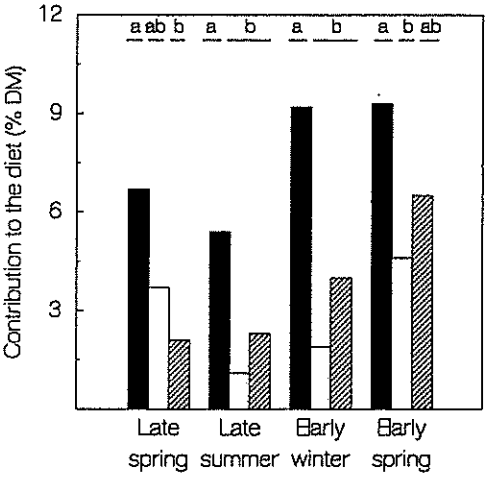
d)


Contribution to the diet (% DM)
12
9
6
3
a b ab a b c
Late spring
Late summer
Early winter
Early spring

e)


Contribution to the diet (% DM)
25
20
15
10
5
a b c a ab b a ab b ab b a
Late spring
Late summer
Early winter
Early spring

f)


Contribution to the diet (% DM)
12
9
6
3
a ab b a b a b a b ab
Late spring
Late summer
Early winter
Early spring

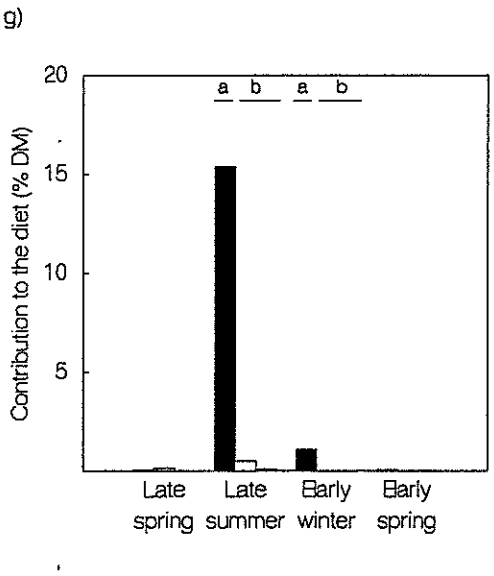


Figure 5.4 Comparative intake of pasture species by co-grazed sheep and cattle, and cattle grazing similar pastures in a rotational grazing system; a) White-grass, b) fine grasses, c) Wavy Hair-grass and Native rush, d) woody species, e) forbs, f) ferns, and g) Diddle-dee berries

The effect of alternate grazing management strategies on the inclusion of White-grass in cattle diets was also highlighted during the co-grazed diet study. During all four study periods, rotationally grazed cattle consumed similar dietary proportions of White-grass to co-grazed sheep and significantly less than co-grazed cattle during winter and summer, suggesting that as competition for pasture between sheep and cattle increases, sheep are able to maintain greater dietary diversity and nutrient intake than cattle that are unable to compete for the shorter, more nutritious pasture species and are forced to consume more White-grass. Although the DMD differences between co-grazed sheep and cattle diets were not significant, cattle consistently consumed a diet of lower DMD during summer, winter and early spring, and provided support for this hypothesis. Longer rumen retention times of forage are generally associated with lower DMD. For cattle in these studies longer retention times may result from the high intake of White-grass relative to sheep, and could explain the significantly higher apparent N digestibility by cows compared to sheep during late spring and summer since longer rumen retention times have also been linked to increased N digestibility (Amaning-Kwarteng *et al.* 1986). It is also probable however, that the differences in apparent N digestibility between sheep and cattle during late spring, late summer and early winter were artefacts of the methods used to estimate N intake. Since N intake was estimated as the product of DMI and the implied concentration of CP in the diet, and the empirical calculations of protein requirements and supply identified discrepancies between potential and apparent CP supplies (section 4.8), these errors may have contributed to the digestibility differences. Consequently, care should be taken when interpreting this data and more specific identification methods should be employed in the future if more sensitive information is required to evaluate protein kinetics in Falklands' sheep and cattle.

The high inclusion of Diddle-dee berries in sheep diets during late summer, and almost no consumption of berries by cattle was initially surprising since they represent a highly digestible source of carbohydrates for the animals. However, their small size and the general refusal by both groups of animals to consume

Diddle-dee leaves may prevent the cattle from attempting to select the berries at the cost of ingesting Diddle-dee leaves as a substantive 'anti-feedant'. Farmers have provided anecdotal evidence to suggest that cattle occasionally consume Diddle-dee, particularly when they are being moved from place to place. However this may not necessarily be associated with feeding, but rather may have some behavioural origins.

Diddle-dee probably contains condensed or hydrolysable tannins. Whilst no chemical analyses have been conducted to confirm this, Diddle-dee emits ethylene after it has been mechanically stressed, and ethylene has been noted as a plant messenger that initiates a rise in condensed tannin concentrations in *Acacia* sp. leaves in response to grazing. Furthermore, tannins offer ruminal bypass protection for dietary protein. Ingested tannins bind dietary protein in the neutral environment of the rumen and prevent its degradation at that site. Tannin-bound protein can then be released in the acid stomach for absorption in the gastrointestinal tract. If cattle consume any Diddle-dee, as anecdotes suggest, it may therefore be that the animals exercise a degree of 'educated grazing' that enables them to use the protein by-pass properties of tannins to improve their total nutrition. Confirmation of this hypothesis needs further specific study.

An assuring sign for rotational grazing systems was the observation that rotationally grazed cattle were able to consume substantial proportions of fine grasses during late summer, and although the differences were not significant, rotationally grazed cattle consumed a diet of higher digestibility (+3.6 DMD units). Set-stocked, co-grazed cattle exhibited peak consumption of fine grasses approximately three months earlier in late spring, thus despite the relatively short growing period for the more nutritious Falklands' plants, it appears possible to save pasture for delayed grazing by animals provided that sufficient areas of land can be set aside for the purpose of 'stockpiling feed' for use later in the summer and early autumn. The extent to which these pasture savings can be accumulated and used in practice remain to be quantified.

Can we therefore conclude whether sheep and cattle are competitors or complementary grazers on Falklands' native pastures? Although the studies were not designed to compare the productivity of co-grazed sheep and cattle compared to single-species grazing, the data probably suggest that there are elements of both competition and complementarity. Competition appears to be evident for the fine grasses, and the much lower consumption of White-grass by rotationally grazed cattle compared to co-grazed cattle bears this out. And complementarity tends to be confirmed by the similar digestibilities of the diets consumed by co-grazed sheep and cattle. Consequently, although higher growth rates are probably achievable by both sheep and cattle in the absence of the other species, total annual animal productivity per ha is likely to be maximised when the two groups of animals are used to graze the same pasture. Separate grazing strategies would be particularly important for weaner sheep and cattle, and breeding ewes and cows that have high nutrient requirements. However wethers and non-breeding ewes and cows that require only moderate growth rates would be well suited to co-grazing. This may not necessarily require that the animals be co-grazed simultaneously, but they may be used in rotation to graze a pasture. An added benefit of this approach would be to assist to control the build-up of gastrointestinal nematode larvae in pastures.

Solving botanical composition

In these studies it was initially planned to use faecal microhistology to identify the species contributing to the diets of sheep and cattle, and subsequently use faecal alkane patterns and EatWhat to provide a second estimate of botanical composition. Given that microhistology has been criticised for often not accurately representing the proportional composition of diets as a result of differential digestion rates of plants (Dearden *et al.* 1975, Vavra and Holechek 1980, Holechek *et al.* 1982, Norbury 1988), this approach was seen as a more robust method to estimate the actual diet selected by sheep and cattle. The potential to use alkanes to assist with the measurement of complex rangelands diets has been reported (Salt *et al.* 1992, 1994) but is not in widespread use. A key difficulty is establishing herbage concentrations of alkanes in order to calculate DMI (**Eq. 3.9**). Hand plucking to obtain a 'representative pasture' is unlikely to be effective for spatially heterogeneous pastures, and in the Falklands particularly, using OF sheep to obtain a pasture sample was impractical. A practical solution was to estimate the botanical composition of the diet first, and then use the known alkane concentrations of each species to mathematically imply 'diet' concentrations of the various alkanes (Dove 1998).

Dove and Mayes (1996) predicted that alkanes may be used to discriminate up to 15 species in a diet provided that at least this many alkanes are used in least squares calculations. However, it was also suggested that the reliability of the predicted diets would decline due to the increasing potential for combinations of alkanes to exhibit similar patterns to those of other diet components as the number of components increases. This was probably why EatWhat was unable to predict 'sensible' diets during the studies in this thesis. It is impossible to force EatWhat to include plants in a solution. For simple diets this is not likely to be a difficulty, however for the complex diets resolved with the aid of microscopy in the present studies, EatWhat did not produce solutions that included plants that were known to be present in the diet.

An alternative to EatWhat was to use the Solver routine in Microsoft Excel to estimate botanical composition. It is possible to constrain the calculations in this approach, forcing the model to include 'known' species, and even specify the range of DMD for the diet to meet. This approach was briefly examined during the studies, however an alternative approach proved to be at least as advantageous as this mathematical approach. Using implied herbage alkane concentrations, derived from the microhistological estimates of diet composition, the estimates of DMI and DMD subsequently generated were within the range expected on the basis of known growth rates and patterns of growth of sheep and cattle in the Falklands. Consequently, no further effort was expended experimenting with EatWhat and Solver to estimate botanical composition and implied herbage alkane concentrations.

Although the apparent complexity of the diets selected by sheep and cattle in the Islands limited the opportunity to use alkanes to estimate botanical composition, the ratio of natural and dosed alkanes in herbage and faeces (**Eq. 3.9**) and the dilution of herbage alkanes in the faeces (**Eq. 3.11**) were well suited to estimate intake and digestibility when used in conjunction with the botanical compositions estimated by faecal microhistology. This multiple technique approach can thus be recommended for complex,

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70°C. Dove and Mayes (1991) reported that drying at 70°C affected the alkane concentrations in Lucerne, compared to freeze drying, and these effects increased in magnitude with increasing alkane carbon chain length (Fig. 5.5).

The magnitude of differences between faecal recoveries measured in these Falklands' studies and those reported in the literature were almost identical to the range of differences reported for alkanes extracted from oven dried compared to freeze dried Lucerne. Although it was not possible to confirm an effect of drying on the extraction of alkanes from faeces in the Falklands, in agreement with Dove and Mayes (1991), further studies are warranted to determine the effects of oven drying if this method is to be used more widely. Furthermore, in at least one of the published studies reporting lower faecal alkane recoveries (Ordakowski *et al.* 2001) oven drying was used to prepare plant and faecal samples. Consequently, the assumption that faecal alkane recovery for horses differs to ruminants should be further investigated with freeze-dried faecal samples. The agreement shown between observed liveweight responses and those predicted using the intake and digestibility data that was derived from alkanes using the faecal recoveries listed in Table 4.1 suggests that it was valid to apply these lower recoveries in the studies reported here.

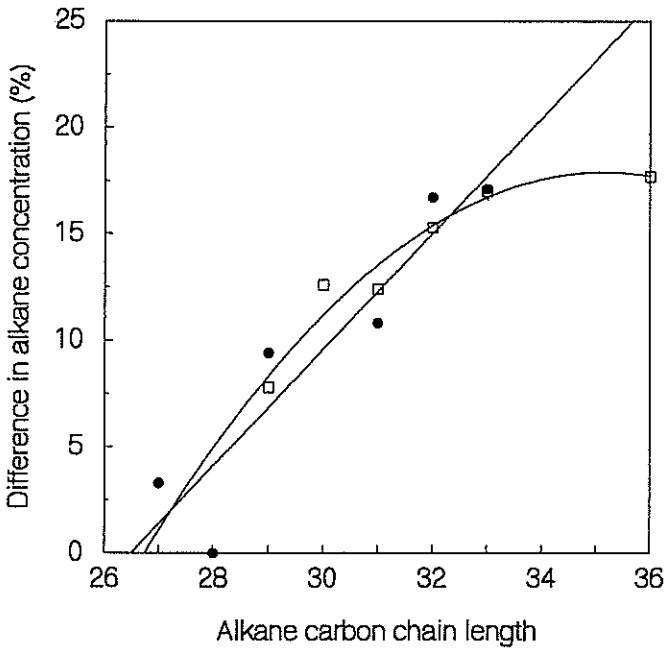

Figure 5.5 Comparison between differences in alkane concentrations for freeze-dried or oven dried (70°C) Lucerne samples (●, R^2=0.87, Dove and Mayes 1991), and differences between faecal recoveries in these Falklands' studies and published recoveries for sheep (□, R^2=0.95, Dove and Olivan 1998)

When faecal recoveries across the range C_{29} to C_{35} were subsequently calculated, it was apparent that these values were also lower than reported for sheep in most other recent studies (Mayes *et al.* 1986, Dove and Mayes 1996, Dove and Olivan 1998). However, in agreement with these recent studies faecal recovery tended to be less complete with decreasing carbon chain length.

Zearalenone

Low fertility is a common feature of cattle in the Falklands and the causes remain unconfirmed. Whilst the origins may now be somewhat clearer in light of the protein and phosphorus deficiencies identified in the studies reported here, concern was also expressed that a fungal toxin may be involved in the general infertility of cattle grazing native pastures. Zearalenone is widely acknowledged to induce infertility in ruminants, and an opportunistic study was conducted to evaluate its occurrence in the Falklands and its possible involvement in infertility in Falklands' cattle. Faecal samples from both sheep and cattle contained zearalenone indicating that the toxin is consumed during the year. Relationships between faecal concentrations of the toxin and infertility have not been established, however consumption of 1μg of zearalenone per g of forage DM per day is associated with infertility, and prolonged consumption of >0.5μg of zearalenone per g of DM may also lower fertility rates. The low concentrations of zearalenone in most of the Falklands' plants sampled suggest that it is unlikely that sheep and cattle consume diets with zearalenone concentrations approaching 0.5μg/g. Whilst an exhaustive analysis of all Falklands' plants that contribute to sheep and cattle diets was not undertaken, caution must be exercised in extrapolating these results further and a watching brief would be recommended should alternate strategies to improve fertility, for example protein and P supplementation, prove unsuccessful.

Conclusions

The success of the preliminary study with lactating ewes to estimate the botanical composition and nutritive value of native pasture consumed allowed the studies with young sheep, lactating and non-lactating cattle, and co-grazed sheep and cattle to proceed. From the subsequent studies with young sheep it was apparent that young sheep grazing native pasture suffered nutritional restrictions for as many as 9 months of the year, and they were forced to capitalise upon the short period of high quality pasture to accumulate body reserves. This 'feast or famine' environment places high stress on the animal's physiology and undoubtedly contributes to their high mortality and low annual and lifetime productivity. Similar seasonal nutritional variations were identified with cattle, and the demands of lactation on animal productivity were quantified in terms of forage intake and diet quality. The nutritional restrictions imposed on sheep and cattle were evident between March and October and for both animal species were due principally to a RDP deficiency, low ME intake, and an apparent P deficiency. Improved nutrition must be supplied and maintained during this period if substantially improved growth rates are to be achieved, and although rotational grazing may offer some potential to extend the length of time that better quality feed is available for grazing, it is doubtful that native pasture can be satisfactorily manipulated to meet this requirement. Consequently, alternate feeding practices that integrate summer grazing of native pasture with forages of substantially higher quality than winter native pastures should be investigated as a priority.

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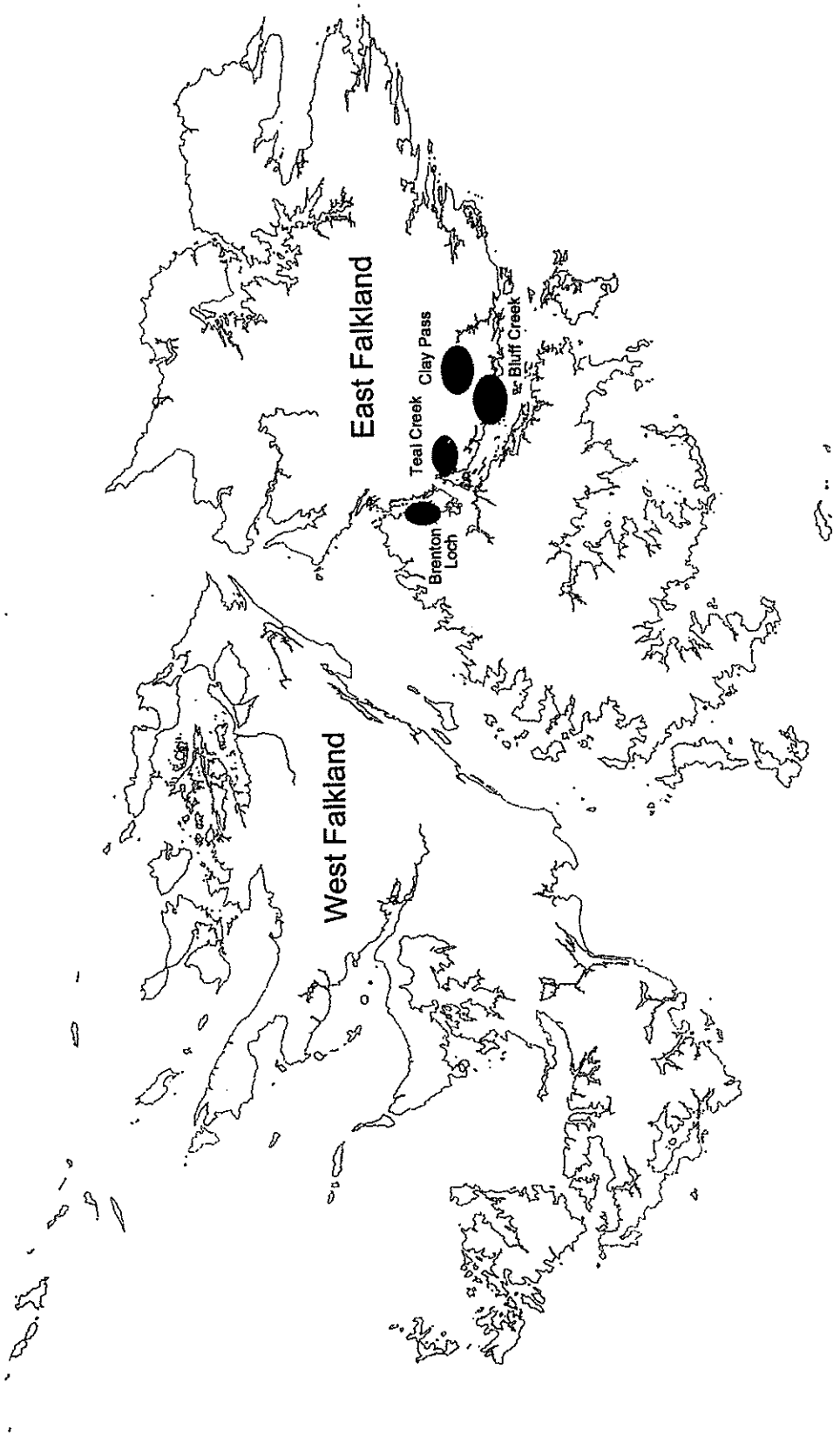
APPENDIX 1

LOCATIONS OF STUDY SITES



APPENDIX 2

GENERAL METHODS

A2.1 PREPARATION OF PLANT AND FAECAL SAMPLES

All plant and faecal samples were oven dried at 70°C to constant weight (48 hours). Dried samples were then milled in a small, bench-top hammermill (Culatti, Italy) through a 1mm screen. During the diet studies sub-samples (10g) were collected from each day's faecal output for each animal, and alkane analyses were performed on each of these daily samples. For each animal, daily faecal output was calculated from the dilution of C_{36} in the five daily faecal samples collected in each study period.

A2.2 COLLECTION OF BLOOD SAMPLES

Blood samples (10ml) were collected into evacuated tubes infused with heparin (Vacutainer, Becton Dickson, UK). Samples were centrifuged at 2,000 rpm for 10 minutes, and plasma was aspirated from the sample and frozen at -20°C until analyses could be performed. All analyses were performed on a Pye Unicam 8630 kinetics spectrophotometer.

A2.3 BLOOD CHEMISTRY

A2.3.1 Calcium

Commercial kits were used to determine plasma Ca concentrations (Catalogue # CA 590, Crumlin, Northern Ireland). The principle for measurement of plasma Ca ions is based on the quantitative binding of calcium to O-cresollphthalein complexone in an alkaline medium.

A2.3.2 Inorganic phosphorus

Commercial kits were used to determine plasma inorganic P concentrations (Catalogue # PH1016, Randox, Crumlin, Northern Ireland). The principle for measurement of plasma inorganic P is the reaction with ammonium molybdate in the presence of sulphuric acid to form a phosphomolybdate complex.

A2.3.3 Urea

Commercial kits were used to determine plasma urea concentrations (Catalogue # UR 445, Randox, Crumlin, Northern Ireland). Urea is hydrolysed in the presence of water and urease to produce ammonia and carbon dioxide. The ammonia produced in the first reaction combines with α-oxoglutarate and NADH in the presence of glutamate dehydrogenase to yield glutamate, water and NAD+.

A2.3.4 Creatinine

Commercial kits were used to determine plasma creatinine concentrations (Catalogue # CR 510, Randox, Crumlin, Northern Ireland). Plasma creatinine in an alkaline solution reacts with picric acid to form a coloured complex. The amount of complex formed is directly proportional to the creatinine concentration.

A2.3.5 25-hydroxyvitamin D_3

Plasma concentrations of 25-hydroxyvitamin D_3 (25-OHD) were determined using a modified competitive-binding assay. Full details of the assay are provided in Miller (2002).

A2.4 N-ALKANE ANALYSES

The concentration of n-alkanes in oven dried faeces and plants were determined by gas chromatography (Mayes *et al.* 1986).

A2.5 COLLECTION OF RUMEN FLUID SAMPLES

Rumen fluid was collected from sheep and cattle with the aid of a stomach tube. The fluid was immediately filtered through gauze to remove particulate matter, and an equal volume of 0.2M HCl was added to the samples. Samples were sealed in plastic vials and stored at room temperature until analysed.

A2.6 RUMEN AMMONIA

Rumen ammonia concentrations were determined by a colorimetric method. Samples were read in a Pye Unicam 8630 kinetics spectrophotometer. A full description of the method is provided in Miller (2002).

A2.7 NITROGEN

N concentrations in faeces were determined by Kjeldahl digestion (MAFF-48 1986). The acid digests were analysed using a Tecator auto N analyser (1030 Kjeltec auto analyser). This eliminated the need to carry out distillation and titration of the flasks.

N concentrations in plant samples were determined using both near-infrared (NIR) spectroscopy (operated by Agriculture Victoria's FEEDTEST service) and by titration following Kjeldahl digestion. Those samples analysed by NIR are identified in Appendix 3. Crude protein was calculated as the concentration of N (%) multiplied by 6.25.

A2.8 DRY MATTER DIGESTIBILITY

Unless otherwise stated, dry matter digestibility (DMD) was determined by NIR spectroscopy (operated by Agriculture Victoria's FEEDTEST service). DMD was determined for a number of samples by the two-stage digestion process described by Tilley and Terry (1963). These samples are identified in Appendix 3.

A2.9 METABOLISABLE ENERGY

In all instances, ME was calculated from DMD using the following formula (Freer *et al.* 1997);

$$ME = 0.168[\{(0.95 * DMD) - 0.9\} + EE] - 1.19 \qquad \text{(A2.1)}$$

EE=fat and was assumed to be 2.0 for pasture

A2.10 FEEDTEST

The FEEDTEST service operated by Agriculture Victoria at the Pastoral and Veterinary Institute, Hamilton, uses NIR to estimate forage quality. A FOSS-NIR Systems Model 5000 spectrophotometer is used for scanning samples. Calibration equations for determining feed quality have been derived from, and are continuously monitored using data from traditional wet chemistry methods. These methods are outlined below.

- Crude Protein - Kjeldahl digestion and titration (AOAC-984.13 1990)
- Neutral Detergent Fibre - standard Van Soest detergent system (Van Soest *et al.* 1991) method but using Ankom equipment
- Digestibility - pepsin-cellulase dry matter disappearance (Tilley and Terry 1963). The pepsin-cellulase method was calibrated against standard hays on which *in vivo* digestibility has been measured using sheep
- Water soluble cabohydrates (WSC) - forage crop leaves were dried at 60°C and ground through a 1mm screen. WSC was determined using the method reported in MAFF-14 (1986).
- Starch - forage crop roots were dried at 60°C and ground through a 1mm screen. Starch content was determined by the method of Hattey *et al.* (1994).
- Metabolisable Energy - calculated as per **Eq. A2.1**

A2.11 CALCIUM

Calcium in faeces and plant material was determined according to the method MAFF-3 (1986). Following preparation by dry combustion, analysis of the final extract was done by atomic absorption (MAFF-12 1986).

A2.12 PHOSPHORUS

Determination of phosphorus in faeces and plant material was performed using the method outlined in MAFF-58 (1986).

A2.13 ORGANIC MATTER

Plant and faecal samples were dried to a constant weight at 70°C for 48 hours. Dried samples were then ashed in a muffle furnace at 550°C for 3 hours and the ash remaining after incineration was weighed. Organic matter (OM) in the samples was then determined as;

$$Organic\ matter\ (\%) = \left(\frac{weight\ of\ dry\ sample - weight\ of\ ash}{weight\ of\ dry\ sample} \right) * 100 \qquad \text{(A2.2)}$$

APPENDIX 3

NUTRIENT CONTENT OF SELECTED PLANT SPECIES IN THE FALKLAND ISLANDS

Species		Collection date					
		Autumn	Winter	Early spring	Late spring	Early summer	Late summer
Grasses							
Bent	CP (%)	6.4	13.7	10.1	14.5	17.3	9.3
(*Agrostis capillaris*)	DMD (%)	54.9	46.3	52.6	58.1	64.1	57.6
	ME (MJ/kg)	7.8	6.4	7.4	8.3	9.2	8.2
	NDF (%)	63.7	62.6	67.3	63.2	56.9	61.8
	P (%)	0.12	0.13	0.10	0.11	0.15	0.14
	Ca (%)	0.18	0.17	0.15	0.19	0.22	0.19
Annual Meadow-grass	CP (%)	10.8	16.7	12.5	12.3	10.6	8.4
(*Poa annua*)	DMD (%)	55.8	74.4	65.5	66.0	70.3	64.0
	ME (MJ/kg)	7.9	10.9	9.5	9.5	10.2	9.2
	NDF (%)	56.3	49.2	48.5	52.7	53.6	58.2
	P (%)	0.23	0.31	0.20	0.15	0.19	0.19
	Ca (%)	0.22	0.12	0.15	0.18	0.19	0.26
Smooth-stalked	CP (%)	7.2	8.5	12.5	12.0	13.6	12.2
Meadow-grass	DMD (%)	43.8	48.2	61.0	65.9	69.2	62.5
(*Poa pratensis*)	ME (MJ/kg)	6.0	6.7	8.7	9.5	10.0	9.0
	NDF (%)	77.4	63.0	62.3	60.1	53.6	61.1
	P (%)	0.10	0.23	0.10	0.12	0.08	0.09
	Ca (%)	0.13	0.12	0.11	0.13	0.13	0.13
Early Hair-grass	CP (%)	13.5	13.5	9.2	11.5	8.5	14.5
(*Aira praecox*)	DMD (%)	59.5	51.8	47.1	55.3	50.8	58.3
	ME (MJ/kg)	8.5	7.3	6.5	7.8	7.1	8.3
	NDF (%)	59.6	62.2	63.2	65.3	72.6	59.6
	P (%)	0.18	0.18	0.16	0.14	0.19	0.12
	Ca (%)	0.20	0.21	0.09	0.15	0.16	0.13
Wavy Hair-grass	CP (%)	4.0	7.2	6.1	6.5	6.8	6.9
(*Deschampsia flexuosa*)	DMD (%)	47.1	52.3	56.8	57.9	55.5	58.7
	ME (MJ/kg)	6.5	7.3	8.0	8.2	7.9	8.4
	NDF (%)	75.2	70.2	71.6	68.3	67.5	69.0
	P (%)	0.15	0.16	0.14	0.18	0.19	0.13
	Ca (%)	0.20	0.11	0.15	0.13	0.15	0.14
Native fescue	CP (%)	6.3	7.1	11.9	11.5	12.4	12.5
(*Festuca magellanica*)	DMD (%)	65.8	60.5	52.8	59.8	57.5	66.1
	ME (MJ/kg)	9.5	8.7	7.4	8.5	8.2	9.5
	NDF (%)	58.2	57.4	59.0	59.5	57.1	55.2
	P (%)	0.06	0.08	0.11	0.12	0.12	0.11
	Ca (%)	0.11	0.18	0.14	0.14	0.14	0.18
Native Fog Grass	CP (%)	8.3	13.1	8.6	10.7	9.3	8.6
(*Trisetum spicatum*)	DMD (%)	57.3	53.9	58.2	57.1	60.6	52.7
	ME (MJ/kg)	8.1	7.6	8.3	8.1	8.7	7.4
	NDF (%)	64.8	61.4	61.1	61.9	62.7	65.0
	P (%)	0.15	0.15	0.14	0.14	0.13	0.15
	Ca (%)	0.22	0.11	0.20	0.18	0.17	0.16

Species		Collection date					
		Autumn	Winter	Early spring	Late spring	Early summer	Late summer
Grasses (cont.)							
Native Woodrush	CP (%)	9.5	9.5	9.4	11.5	18.7	13.9
(*Luzula alopcuris*)	DMD (%)	53.6	42.9	55.5	52.0	63.3	62.2
	ME (MJ/kg)	7.6	5.9	7.9	7.3	9.1	8.9
	NDF (%)	54.9	58.7	67.5	57.2	54.5	54.0
	P (%)	0.05	0.09	0.10	0.11	0.25	0.15
	Ca (%)	0.21	0.25	0.20	0.26	0.31	0.26
White-grass (green leaf)	CP (%)	10.1	6.5	8.0	8.9	9.4	9.6
(*Cortaderia pilosa*)	DMD (%)	52.4	45.0	46.8	46.3	48.1	52.1
	ME (MJ/kg)	7.4	6.2	6.5	6.4	6.7	7.3
	NDF (%)	74.2	76.0	74.0	74.9	75.2	73.9
	P (%)	0.05	0.10	0.09	0.11	0.08	0.09
	Ca (%)	0.16	0.14	0.13	0.15	0.14	0.16
White-grass (whole plant)	CP (%)	7.8	3.6	5.1	4.0	4.4	9.6
(*Cortaderia pilosa*)	DMD (%)	45.5	42.1	42.8	42.6	41.1	46.7
	ME (MJ/kg)	6.3	5.7	5.8	5.8	5.6	6.4
	NDF (%)	76.4	78.3	77.1	80.5	80.7	75.6
	P (%)	0.03	0.02	0.04	0.02	0.03	0.03
	Ca (%)	0.06	0.07	0.05	0.06	0.06	0.06
Native rush	CP (%)	5.3	6.7	2.6	4.8	5.5	-
(*Juncus scheuzerioides*)	DMD (%)	45.2	40.3	38.6	43.8	46.3	-
	ME (MJ/kg)	6.2	5.4	5.2	6.0	6.4	-
	NDF (%)	77.2	74.5	80.8	77.1	80.2	-
	P (%)	0.03	0.02	0.02	0.04	0.03	-
	Ca (%)	0.05	0.05	0.06	0.02	0.04	-
Cinamon Grass	CP (%)	7.1	9.0	5.1	8.6	9.5	10.5
(*Heirocholë redolens*)	DMD (%)	59.0	59.7	51.3	54.5	60.1	58.3
	ME (MJ/kg)	8.4	8.5	7.2	7.7	8.6	8.3
	NDF (%)	71.0	71.8	79.4	71.4	69.4	68.8
	P (%)	0.11	0.13	0.10	0.11	0.15	0.17
	Ca (%)	0.08	0.09	0.10	0.10	0.10	0.09
Sand Grass	CP (%)	7.1	-	-	-	-	-
(*Ammophila arenaria*)	DMD (%)	59.8	-	-	-	-	-
	ME (MJ/kg)	8.5	-	-	-	-	-
	NDF (%)	68.3	-	-	-	-	-
	P (%)	-	-	-	-	-	-
	Ca (%)	-	-	-	-	-	-
Tussac Grass	CP (%)	12.1	12.3	-	-	-	12.2
(*Poa flabellata*)	DMD (%)	58.2	50.9	-	-	-	54.0
	ME (MJ/kg)	8.3	7.1	-	-	-	7.2
	NDF (%)	69.7	66.6	-	-	-	65.6
	P (%)	0.08	0.08	-	-	-	0.08
	Ca (%)	0.10	0.13	-	-	-	0.10
Forbs							
Chickweed	CP (%)	11.9	13.0	12.9	13.5	14.0	12.5
	DMD (%)	50.6	54.4	48.1	56.5	52.8	55.9
	ME (MJ/kg)	7.1	7.7	6.7	8.0	7.4	7.9
	NDF (%)	47.5	49.0	48.3	48.2	46.9	45.2
	P (%)	0.12	0.11	0.11	0.09	0.13	0.13
	Ca (%)	0.20	0.21	0.21	0.20	0.18	0.23

Species		Collection date					
		Autumn	Winter	Early spring	Late spring	Early summer	Late summer
Forbs (cont.)							
Small fern	CP (%)†	8.0	12.4	7.6	8.7	7.5	8.1
(*Blechnum penna-marina*)	DMD (%)†	52.2	43.0	45.5	46.3	44.6	55.3
	ME (MJ/kg)	7.3	5.9	6.3	6.4	6.1	7.8
	NDF (%)†	32.0	40.3	42.6	38.7	38.6	28.3
	P (%)	0.12	0.08	0.09	0.11	0.08	0.10
	Ca (%)	0.60	0.60	0.59	0.63	0.52	0.54
Carrot weed	CP (%)	12.6	12.1	10.5	14.3	13.0	13.3
(*Cotula scariosa*)	DMD (%)	68.4	65.0	66.2	70.1	70.8	73.8
	ME (MJ/kg)	9.9	9.4	9.6	10.2	10.3	10.8
	NDF (%)	38.4	41.6	42.1	35.6	35.8	35.4
	P (%)	0.10	0.09	0.09	0.11	0.10	0.09
	Ca (%)	0.13	0.14	0.11	0.20	0.15	0.18
Daisy	CP (%)	12.9	15.8	14.6	18.0	13.5	12.9
(*Bellis perennis*)	DMD (%)	68.7	69.1	67.3	70.9	71.2	74.3
	ME (MJ/kg)	10.0	10.0	9.7	10.3	10.4	10.9
	NDF (%)	36.1	35.2	30.5	31.9	32.4	31.6
	P (%)	0.15	0.12	0.13	0.11	0.12	0.13
	Ca (%)	0.25	0.30	0.27	0.21	0.22	0.23
Pale maiden	CP (%)	-	-	-	-	6.8	8.4
(*Sisyrinchium filifolium*)	DMD (%)	-	-	-	-	55.7	63.2
	ME (MJ/kg)	-	-	-	-	7.9	9.1
	NDF (%)	-	-	-	-	60.6	52.7
	P (%)	-	-	-	-	0.14	0.18
	Ca (%)	-	-	-	-	0.20	0.26
Pig vine	CP (%)†	21.4	17.0	17.0	18.9	18.5	16.5
(*Gunnera magellanica*)	DMD (%)†	58.3	66.2	53.8	54.3	52.6	58.3
	ME (MJ/kg)	8.3	9.6	7.6	7.7	7.4	8.3
	NDF (%)†	23.0	23.2	31.7	37.5	28.1	28.5
	P (%)	0.10	0.20	0.15	0.18	0.17	0.12
	Ca (%)	0.53	0.40	0.56	0.63	0.54	0.62
Sorrel	CP (%)	19.3	17.8	17.5	16.4	16.0	12.5
(*Rumex acetosella*)	DMD (%)	58.2	56.1	55.8	53.4	54.2	53.7
	ME (MJ/kg)	8.3	7.9	7.9	7.5	7.7	7.6
	NDF (%)	36.6	37.9	38.1	38.5	36.5	35.9
	P (%)	0.11	0.12	0.11	0.13	0.10	0.12
	Ca (%)	0.20	0.21	0.23	0.21	0.26	0.23
Scurvy Grass	CP (%)	18.5	-	-	17.8‡	13.5‡	11.4‡
(*Oxalis enneaphylla*)	DMD (%)	71.6	-	-	67.3‡	67.6‡	63.1‡
	ME (MJ/kg)	10.4	-	-	9.7‡	9.8‡	9.1‡
	NDF (%)	15.8	-	-	-	-	-
	P (%)	0.05	-	-	0.27‡	0.23‡	0.15‡
	Ca (%)	0.13	-	-	0.30‡	0.41‡	0.40‡
Woody plants							
Mountain Berry	CP (%)†	6.8	7.0	6.0	5.6‡	7.7‡	6.2‡
(*Pernettya pumila*)	DMD (%)†	42.5	47.1	36.6	36.6‡	41.2‡	47.1‡
	ME (MJ/kg)	5.8	6.5	4.8	4.8‡	5.6‡	6.5‡
	NDF (%)†	45.2	43.1	54.7	-	-	-
	P (%)	0.09	0.08‡	0.08‡	0.09‡	0.10‡	0.09‡
	Ca (%)	0.90	0.70‡	0.70‡	0.78‡	0.60‡	0.65‡

Species		Collection date					
		Autumn	Winter	Early spring	Late spring	Early summer	Late summer
Woody plants (cont.)							
Christmas Bush	CP (%)†	5.2	5.5	6.0	6.2	7.0	5.6
(*Baccharis magellanica*)	DMD (%)†	59.7	60.1	57.3	58.3	58.4	62.3
	ME (MJ/kg)	8.5	8.6	8.1	8.3	8.3	8.9
	NDF (%)†	31.0	26.5	28.3	27.8	26.0	29.5
	P (%)‡	0.08	0.10	0.10	0.08	0.08	0.09
	Ca (%)‡	0.40	0.41	0.37	0.38	0.38	0.36
Diddle-dee	CP (%)†	4.8	6.3	4.2	4.8	5.0	6.8
(*Empetrum rubrum*)	DMD (%)†	54.7	50.8	43.0	51.1	45.2	56.0
	ME (MJ/kg)	7.7	7.1	5.9	7.2	6.2	7.9
	NDF (%)†	41.1	33.2	36.5	36.0	41.6	34.0
	P (%)	0.06	0.06	0.05	0.09	0.05	0.05
	Ca (%)	0.39	0.56	0.72	0.45	0.56	0.61
Miscellaneous samples							
Daisy flower	CP (%)	-	-	-	-	12.4	10.9
(*Bellis perennis*)	DMD (%)	-	-	-	-	69.9	70.3
	ME (MJ/kg)	-	-	-	-	10.2	10.2
	NDF (%)	-	-	-	-	33.7	31.9
	P (%)	-	-	-	-	-	-
	Ca (%)	-	-	-	-	-	-
Diddle-dee berries	CP (%)†	4.0	4.8	-	-	-	-
(*Empetrum rubrum*)	DMD (%)†	55.5	54.7	-	-	-	-
	ME (MJ/kg)	7.9	7.7	-	-	-	-
	NDF (%)†	37.9	41.1	-	-	-	-
	P (%)	0.08	0.09	-	-	-	-
	Ca (%)	0.10	0.09	-	-	-	-
Goose faeces	CP (%)	10.8	8.0	-	-	-	10.8
	DMD (%)	55.3	44.4	-	-	-	58.5
	ME (MJ/kg)	7.8	6.1	-	-	-	8.3
	NDF (%)	61.9	73.3	-	-	-	56.1
Brown Tree Kelp	CP (%)†	-	-	-	-	-	5.9
	DMD (%)†	-	-	-	-	-	81.1
	ME (MJ/kg)	-	-	-	-	-	11.9
	NDF (%)†	-	-	-	-	-	13.4
Green Sea Lettuce	CP (%)†	-	-	-	-	-	10.5
	DMD (%)†	-	-	-	-	-	74.4
	ME (MJ/kg)	-	-	-	-	-	10.9
	NDF (%)†	-	-	-	-	-	24.6

Notes:

a) all data expressed on a dry matter basis

b) Except where noted, CP, NDF and DMD analyses were performed by NIR (see **Appendix 2**)

c) † CP, NDF and DMD analyses were performed by wet chemistry methods (see **Appendix 2**)

c) — not measured on this date as the plant was either absent from the pasture sward or apparently not consumed by sheep

d) ‡ data from Davies (1988)