Ministry for Primary Industries
Manatū Ahu Matua

Metabolisable energy and crude protein concentrations in grazed pastures in New Zealand

Final Report

MPI Technical Paper No: 2018/75

Prepared for the Ministry for Primary Industries
by Landcare Research and On-Farm Research

ISBN No: 978-1-98-857153-9 (online)
ISSN No: 2253-3923 (online)

February 2017

New Zealand Government

Disclaimer

While every effort has been made to ensure the information in this publication is accurate, the Ministry for Primary Industries does not accept any responsibility or liability for error of fact, omission, interpretation or opinion that may be present, nor for the consequences of any decisions based on this information.

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries website at http://www.mpi.govt.nz/news-and-resources/publications/

Metabolisable energy and crude protein concentrations in grazed pastures in New Zealand

Martin Upsdell, Gerald Cosgrove, Siva Ganesh, John Koolaard, David Pacheco and Jim Crush

2 February 2017

1 Contents

2 Figures

1 Report overview

The purpose of this project was to determine whether the estimates of metabolisable energy (ME) and crude protein (CP, a proxy for nitrogen content; CP = N × 6.25) used for national inventory calculations of methane and nitrous oxide are statistically robust enough to provide nationally representative values for the key livestock classes used in the national inventory calculations of methane and nitrous oxide emissions.

A dataset containing 3680 data points that was used for the previous analysis of ME and CP values in the national greenhouse gas inventory calculations reported in 2013, was complemented with 2120 additional sample data points obtained from pastures during the past four years. Advances in statistical techniques and computing power has enabled a different approach to analysis compared with that used previously.

The data are dominantly calibrated near-infrared reflectance spectroscopy predictions of ME and CP, and mainly from a single analytical laboratory. In that laboratory, the predicted ME is based on digestibility, calibrated against *in vivo* trials. In the analysis reported here, no attempt has been made to account for errors in these predictions, nor, for example, the extent to which the sample analysed represents the pasture actually consumed. Under sheep and beef grazing systems these errors can be large.

The statistical model accounted for variation due to season (day of the year), stock type (dairy, sheep, sheep/beef, deer), region (17 administrative regions; 11 in the North Island and 6 in the South Island) and site (within region), being the location that samples came from. An important feature of the dataset is that it now encompasses approximately 20 years of data from 1995 - 2015. While there is year-to-year variation in both ME and CP, there were no identifiable trends over that time and in the statistical model the term for trends over time was deleted for subsequent analyses.

There were no detectable biases in the estimates of ME and CP due to the source of the data in terms of the type of pastures sampled or location. The potential for upward bias of estimates of ME and CP due, for example, to a predominance of samples from 'better' or 'higher' fertility farms, or downward bias due, for example, to a predominance of samples sent for 'problem' identification, were not evident from the data analysis. This suggests the data set is representative of the main sources of variation.

The monthly profile of estimates of ME and CP (95% least significant intervals) for each stock type lay within bands of approximately 2.4 MJME/kg DM, and 11% CP, respectively. Dairy had higher ME than sheep/beef across the year, and except for May-October, higher CP. Except for the higher ME for sheep compared with sheep/beef during November–May, sheep, sheep/beef and deer all tended to be similar.

Across regions, the monthly profile of estimates of ME and CP lay within bands (95% least significant intervals) of 1.3 MJME/kg DM, and 6% CP, respectively. After accounting for stock type, the differences among regions in ME and CP were small. This is likely due to each administrative region encompassing a diversity of land types and variation within the region being as great as or greater than among regions.

The relative standard error of the monthly means for ME (standard error as a proportion of the means) were 1.3%, 2.4%, 1.0% and 5.8% for dairy, sheep, sheep/beef and deer, respectively, and for CP were 3.3%, 6.0%, 4.4% and 14.6%, respectively, for each stock class. These errors for ME are low and would cause errors of similar magnitude in methane inventory calculations. These errors are smaller than other factors used in the model, where errors are 15% or greater. The errors associated with CP are also highly likely to be less than for other inputs to the model used for calculating nitrous oxide emissions, although they are more difficult to quantify than for methane.

The low errors suggest there is little to gain at this time from collecting additional samples to add to the current database on ME and CP concentrations. The year-to-year variation would suggest that the incremental value of collecting samples in a further, single year would be uncertain and the monthly estimates from a single year could be confounded by regional and seasonal weather variations specific to that year.

Further refinement of the analysis of the currently available data would be a higher priority. Firstly, incorporating an as yet untapped large data set could add up to six thousand additional data points and improve the precision of estimates. Secondly, assigning latitude, longitude and altitude variables to each data point to create a continuous 'Geo-location' variable, rather than the current categorical 'Regional' classification, could also better identify if regional differences should be incorporated into inventory calculations to improve the accuracy of national total emissions.

2 Executive summary

This study was undertaken to analyse the available data on metabolisable energy (ME) and crude protein (CP) levels in pasture for key livestock classes throughout New Zealand to determine whether the existing data could provide suitable values to enter into the Pickering and Wear (2013) Green House Gas Inventory equations to enable New Zealand's Green House Gas emissions to be estimated to a suitable precision.

The estimates of the mean levels of metabolisable energy throughout the year provided in the paper have relative errors of 1.3%, 2.4%, 1.0%, and 5.8% for Dairy, Sheep, Sheep/Beef and Deer farms respectively. These relative errors produce relative errors in the methane greenhouse gas emission equations of Pickering and Wear (2013) of the same amount. These are much smaller than the relative errors due to estimation of the other constants in their equations. The estimates of the mean levels of crude protein throughout the year provided in the paper have relative errors of 3.3%, 6.0%, 4.4%, and 14.6% for Dairy, Sheep, Sheep/Beef and Deer farms respectively.

The possibility of biases in the data set was investigated and no biases were detected.

The estimates provided are unbiased. The uncertainties in greenhouse gas emissions due to the remaining uncertainties in estimates of metabolisable energy and crude protein are well below the uncertainties in greenhouse gas emissions due to other aspects of the model.

Efforts to improve the estimates of the greenhouse gas emissions would be better spent on other aspects of the greenhouse gas models than on collecting more samples.

2.1 Other findings

Samples taken in May to October had metabolisable energy values 1 MJME/kg DM higher than those taken in February. Samples in the hilly country of Sheep/Beef farms taken in May to October had crude protein values 5% DM higher than those in December to March. Samples taken from the flat land of dairy farms taken in March to May had crude protein values 5% DM higher than those in November to January.

Samples from different regions gave only small differences in metabolisable energy values after adjusting for the differences in topology in the different stock type farms and no significant differences in the values of crude protein.

Samples from flat land in the dairy farms had metabolisable energy values 1 MJME/kg DM higher than samples from the hilly Sheep and Beef farms. Samples from the flat land dairy farms had higher crude protein values from February to April than samples from the hilly sheep and beef farms, with values reaching a peak difference of 5% DM. At other times of the year there was no significant differences.

Samples collected by a scientist had Metabolisable Energy values 0.5 MJME/kg DM higher than samples collect by a farmer on the same site and Crude Protein values 4% DM below the samples collected by farmer.

3 Purpose

This study was undertaken to analyse the available data on Metabolisable Energy (ME) and Crude Protein (CP) levels in pasture for key livestock classes throughout New Zealand to determine whether the existing data could provide suitable values to enter into the Pickering and Wear (2013) Green House Gas Inventory equations to enable New Zealand's Green House Gas emissions to be estimated to a suitable precision.

The estimates of the mean levels of Metabolisable Energy throughout the year provided in this paper have relative errors of 1.3%, 2.4%, 1.0%, and 5.8% for Dairy, Sheep, Sheep/Beef and Deer farms respectively. These relative errors produce relative errors in the Methane greenhouse gas emission equations of Pickering and Wear (2013) of the same amount. These are much smaller than the relative errors due to estimation of the other constants in their equations. The estimates of the mean levels of Crude Protein throughout the year provided in the paper have relative errors of 3.3%, 6.0%, 4.4%, and 14.6% for Dairy, Sheep, Sheep/Beef and Deer farms respectively.

4 Description of data

The Bown et al. (2013) report analysed a data set consisting of 19,300 samples collected from 1996 to 2011 from dairy and sheep / beef farms over New Zealand. In 2016, a team at AgResearch added 60% more data to the data set. The data sets available for use are given in Table 1.

The data sets had a variable site associated with each sample denoting the location the sample was taken. The sites in the Lincoln University corresponded to different treatments. The Taupo data set came from one trial. There were two sets of samples collected, one set by the farmer and one set by the scientist. Site in this case denotes who collected the sample. The sites in the Forages for Reduced Nitrate Leaching FRNL data set correspond to individual farms. Sites in the P21 data set are the different replicates of the trial. The samples of the Deer data set were all from the Invermay research station and assigned to the site Invermay

The sites in Bown data set were the source data base district. Samples from each source and each Stock type within a district were assigned to a different site. Sites in the AgResearch data set corresponded to the Area column of that data set. Again samples from sites from different Stock types were assigned to different sites. Most of the sites in the survey data sets of Bown and AgResearch were associated with names of towns with one or two being post office box numbers and others RD numbers. It may well be that the sites are from the postal addresses of the farmers, which would explain the sites in Herne Bay and Mt Wellington in Auckland. Site in these data sets represent a local district. It is probable that several farms were assigned to the same site. Palmerston North, for example, has a very large number of samples.

The data sets had several observations from the same site, source, stock type and day. The mean of these observations was used in the analysis since the mean, variance and degrees of freedom are the sufficient statistics for the normal distribution. Trying to weight these estimates for different numbers of observations will be unreliable as the site to site variation is likely to be bigger than the observation to observation variation. Sites with more observations will represent more farms from a larger area and so have bigger site variances which would counter-balance the larger number of samples. The resulting reduction in numbers is given in Table 1.

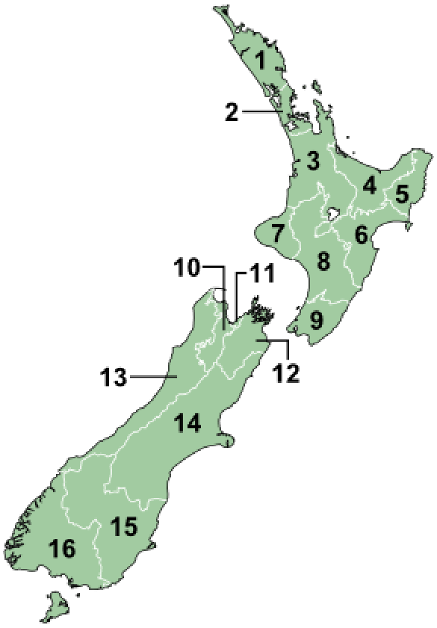
Table 1: Data sources

Source	Stock Types	Original Number	Number after averaging	Description
Bown	Dairy, Sheep/Beef	19,272	3,681	Bown et al. (2013) "Evaluation of the values for pasture ME and N content used in the National Greenhouse Gas Inventory"
AgResearch	Dairy, Sheep/Beef	3,578	1,451	P21 II Summer Autumn Feed Quality
Lincoln University	Sheep	430	262	Max Clover Project, Beef+LambNZ, AGMARDT
SLMACC	Dairy	1574	132	Cosgrove, Sustainable Land Management and Climate Change project
Taupo	Cattle	284	126	Nitrogen and Lake Taupo Catchment project
FRNL	Dairy	243	81	Forages for Reduced Nitrate Leaching collaborative programme
P21	Sheep	566	39	Stevens, Pastoral 21-II Research Consortium
Deer	Deer	110	28	Deer Industry NZ/AgResearch Core funded deer research program
Total		**26,057**	**5,800**	

As mentioned in the Bown et al. (2013) report the regions in this data set are based on the administrative regions Figure 1. These covered quite diverse agricultural districts. For instance Turangi and Whakatane are both in the Bay of Plenty. The Manawatu/Whanganui district extends from the West Coast of the North Island to the East Coast. There is a range of mountains in the middle which reduces the rainfall on its East. Two new regions were created; the Volcanic Plateau and the Wairarapa. A general check was done on the assignments of locations to regions in the Bown and AgResearch data sets and several were reassigned, particularly in the Bown data set.

The data from Taupo were from one site. However two sets of samples were collected, one by the farmer and one by the scientist. The two sets of samples were considered two different sites so that comparisons could be made between the two.

Figure 1: Administrative regions



Administrative regions in New Zealand (Regional Councils).
https://en.wikipedia.org/wiki/Regions_of_New_Zealand

	Region
1	Northland
2	Auckland
3	Waikato
4	Bay of Plenty
5	Gisborne
6	Hawke's Bay
7	Taranaki
8	Manawatu-Whanganui
9	Wellington
10	Tasman
11	Nelson
12	Marlborough
13	West Coast
14	Canterbury
15	Otago
16	Southland

Since both metabolisable energy (ME) and crude protein (CP) were expected to change with season, only samples where the sample date was recorded to at least the nearest month were included. In the 306 samples where only the month and year were recorded, the sample was assigned to the 15th day of the month recorded. For 412 samples in the AgResearch data set with a date range, the sample was assigned to the end of the range. The resulting sizes of the data sets from the different sources are given in Table 2.

The number of samples taken at the same site over different dates varied considerably.

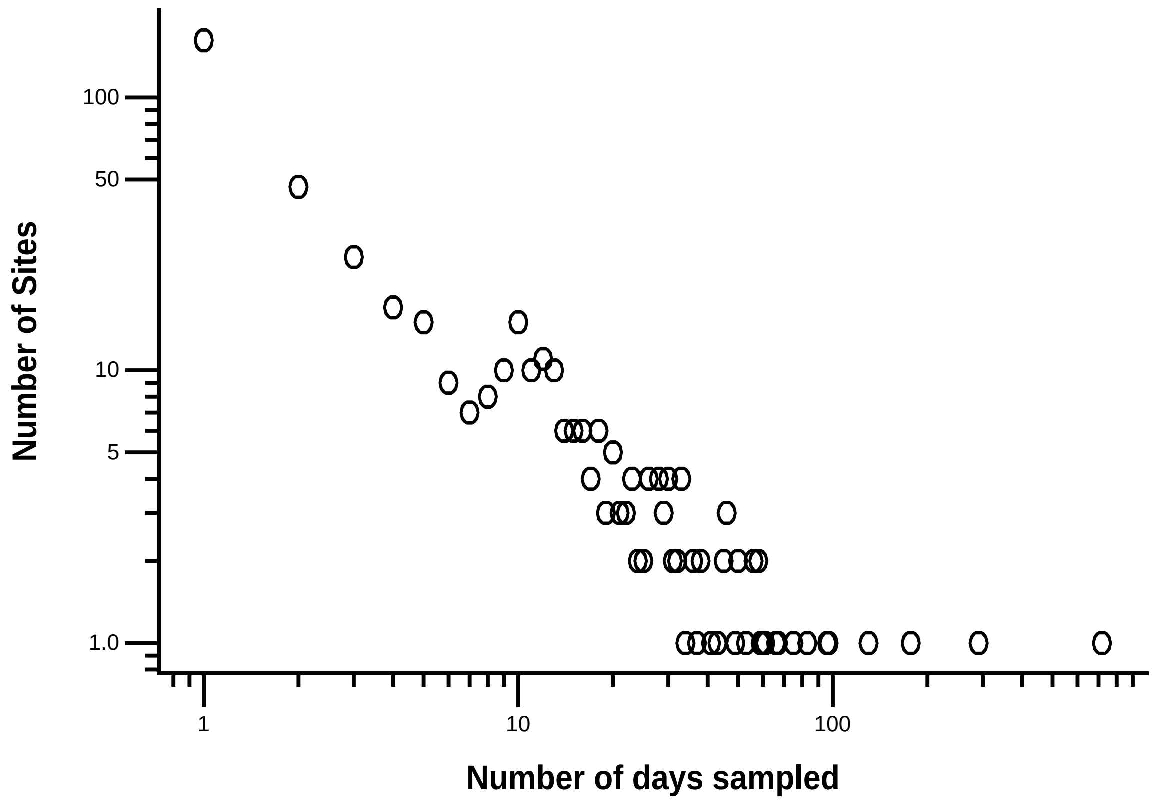
Figure 2 gives a plot of the number of sites present at each of the number of days sampled.

Figure 3 gives a plot of the distribution of sample dates which ranged from 29 June 1995 to 13 April 2016. 40% are in the years 2004 to 2006. The samples were well distributed throughout the year (Figure 4).

Table 2: Size of data sets

Source	Metabolisable energy values	Crude protein values	Regions	Sites	Stock classes
Bown	3679	3563	16	271	Dairy, Sheep/Beef
AgResearch	1451	311	14	160	Dairy, Sheep/Beef
Lincoln University	208	260	1	5	Sheep
SLMACC	132	132	4	5	Dairy
Taupo	126	126	1	2	Cattle
FRNL	81	81	1	6	Dairy
P21	39	39	1	4	Sheep
Deer	28	28	1	1	Deer
Total	**5744**	**4540**	**17**	**454**	**5**

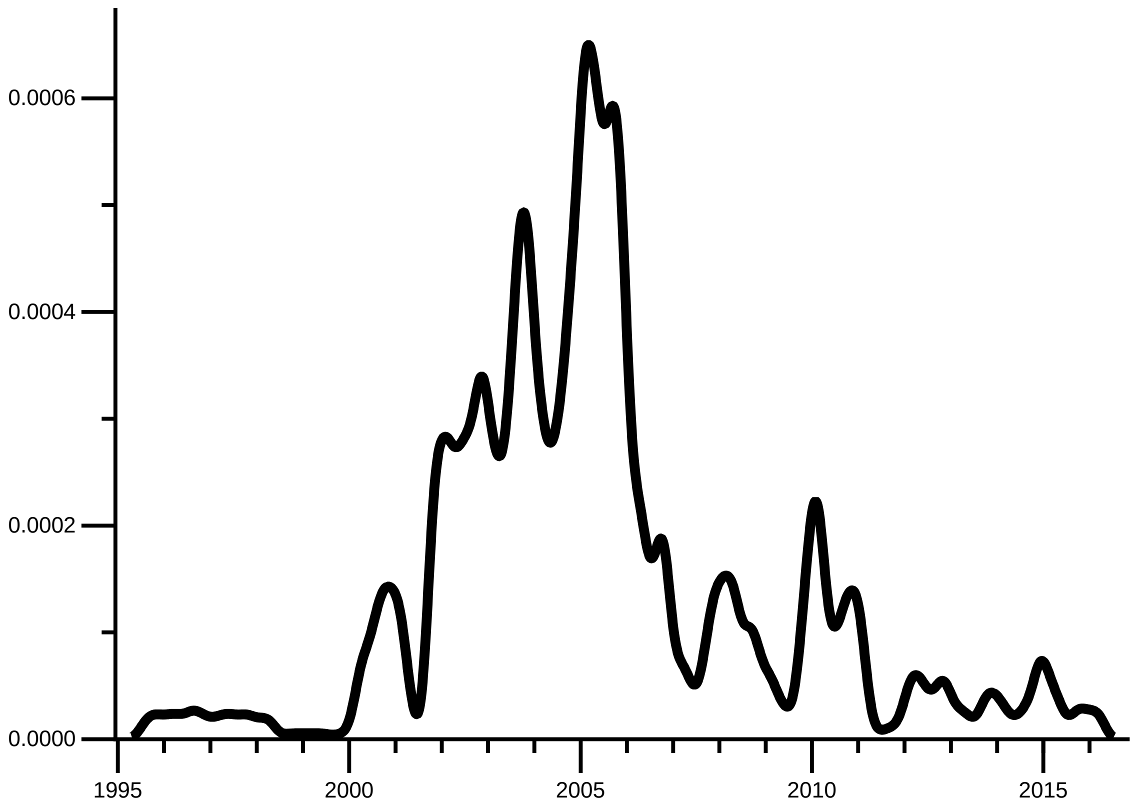
Figure 2: Distribution of number of days sampled



Plot of the number of sites which had the designated number of days sampled

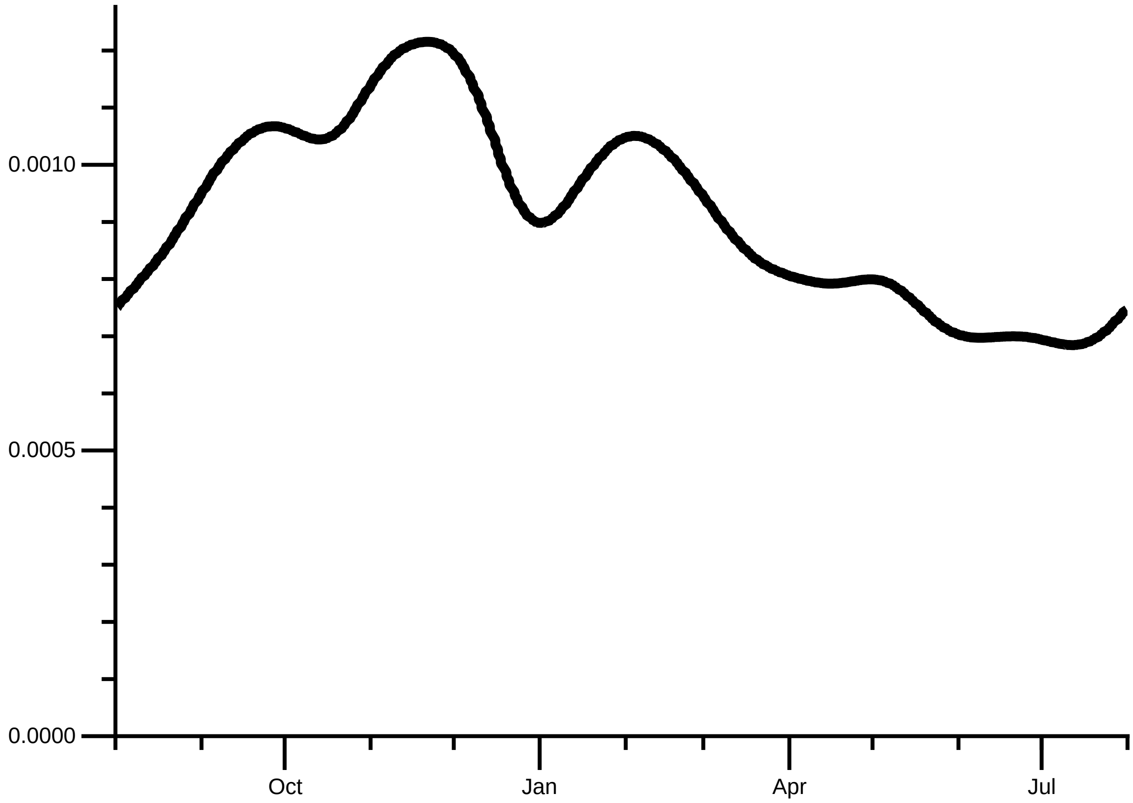
The distribution of stock classes varied widely between regions. 6% of the samples did not have the region recorded. 43% of the sites sampled were classified as Sheep/Beef and 41% of the sites did not have the stock class recorded. Table 3 gives a summary of the distribution. Table 4 gives the counts of stock class by region.

Figure 3: Distribution of sample dates



Kernel density estimate of the distribution of sample dates. (GENSTAT procedure KernelDensity)

Figure 4: Distribution of sample seasons



Kernel density estimate of the distribution of sample dates within the year (GENSTAT procedure KernelDensity)

Table 3: Summary of stock distribution

Region	Number of Sites	% Sheep / Beef	% Unknown
Northland	41	41%	41%
Auckland	4	25%	75%
Bay of Plenty	16	50%	38%
Waikato	47	17%	64%
Volcanic Plateau	29	52%	41%
Central North Island	6	100%	0%
Hawkes Bay	27	33%	48%
Taranaki	27	41%	52%
Manawatu / Wanganui	43	58%	33%
Wairarapa	21	48%	52%
Wellington	2	50%	50%
Marlborough	11	82%	18%
Tasman	7	0%	100%
West Coast	5	0%	80%
Canterbury	87	48%	22%
Otago	36	53%	31%
Southland	38	53%	21%
Unknown	28	7%	89%
Total	474	43%	41%

Table 4: Counts of stock type by region

Region	Cattle	Dairy	Sheep	Sheep / Beef	Deer	Unknown	Total
Northland	0	7	0	17	0	17	**41**
Auckland	0	0	0	1	0	3	**4**
Bay of Plenty	0	2	0	8	0	6	**16**
Waikato	0	9	0	8	0	30	**47**
Volcanic Plateau	2	0	0	15	0	12	**29**
Central North Island	0	0	0	6	0	0	**6**
Hawkes Bay	0	1	4	9	0	12	**26**
Taranaki	0	2	0	11	0	14	**27**
Manawatu/ Wanganui	0	4	0	25	0	14	**43**
Wairarapa	0	0	0	10	0	11	**21**
Wellington	0	0	0	1	0	1	**2**
Marlborough	0	0	0	9	0	2	**11**
Tasman	0	0	0	0	0	7	**7**
West Coast	0	1	0	0	0	4	**5**
Canterbury	0	21	5	42	0	19	**87**
Otago	0	5	0	19	1	11	**36**
Southland	0	10	0	20	0	8	**38**
Unknown	0	1	0	2	0	25	**28**
Total	**2**	**63**	**9**	**203**	**1**	**196**	**474**

5 Possible biases

The Bown et al. (2013) report identified a potential bias due to who was taking samples and why. “Due to the nature of the databases and the studies for which the data were collected, the data is likely to be biased towards “better” farms in terms of greater sampling frequency and sample numbers, i.e. farmers with better management practises and, therefore, higher pasture quality are more likely to collect samples for analysis or co-operate with research studies.” (p13) They also note “There is evidence of sampling bias towards higher fertility farms (easy/rolling/flat) with poor representation across hill country.”(p17) This would imply that the sample values are biased upward and that the mean metabolisable energy and crude protein obtained are too high.

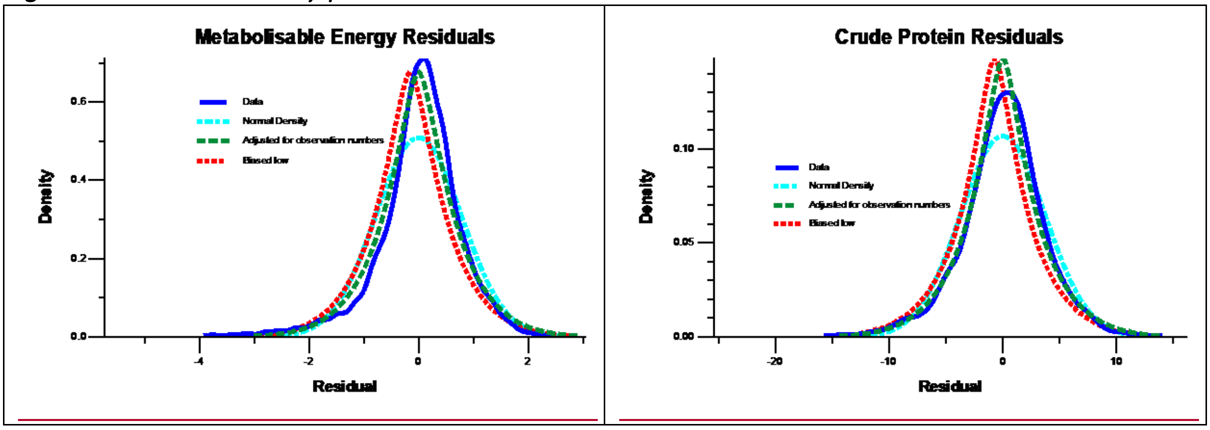
Giltrap et al. (2016) have noted in the accompanying report “Pasture Quality draft report 5 August 2016” p21, that “farms with pasture problems are more likely to seek commercial pasture testing” which would imply that the sample values are biased downward and that the mean metabolisable energy and crude protein values obtained are too low.

In either case we would expect the distribution of the residuals from the model described below, to depart from a normal distribution. If Bown et al. (2013) are correct, the distribution should be long tailed to the right, with more points at higher values. If Giltrap et al. (2016) are correct then the distribution should be long tailed to the left, having more points with lower values.

Figure 5 gives kernel density estimators for the metabolisable energy and crude protein residuals as the solid blue lines. The dashed cyan lines give the density of the best fitting normal distributions.

The sample values entered into the analysis are the means over the observations on that site, stock type and day effect. Thus the samples will have different standard errors due to the differing numbers of observations. The dashed green curve in Figure 5 is the expected distribution of the residuals adjusted for the differing observation numbers in the samples.

Figure 5: Residual density plots



The dotted red curves are the expected density distributions if samples with low values of metabolisable energy and crude protein were more likely to be included in our sample. The probability of inclusion was based on a simple logistic model. The values chosen for the bias were -0.15 for metabolisable energy and -0.72 for crude protein, which are the standard errors for dairy farms. The unit of one standard error was chosen as the value above which the bias would need to be considered as influencing the validity of the dataset.

The curves representing the dataset (blue) are clearly closer to the curves which have been adjusted to the observation numbers (green) than to the curve for which samples with low values were more likely to be included (red). The data curves would need to be as extreme as, or more extreme than the red curves for significant biases to be present in the data.

Thus there is no indication of any biases in our sample. Aggregation, which is the principle that an estimate from the whole sample is better than estimates from any part is the first statistical pillar in the book *The Seven Pillars of Statistical Wisdom* by Stephen Stigler. “In ancient and even modern times, too much familiarity with the circumstances of each observation could undermine intentions to combine them. The strong temptation is, and has always been, to select one observation thought to be the best, rather than to corrupt it by averaging with others of suspected lesser value”. (Chapter one, Aggregation. In *The Seven Pillars of Statistical Wisdom*, Stigler, 2016). Bigger data sets give better estimates of the population parameters than smaller data sets. The deficiencies in each individual sample are corrected by the other samples.

There are no detectable biases in our sample.

6 Requirements of the statistical analysis

The statistical analysis was undertaken to thoroughly evaluate available pasture Metabolisable Energy and Crude Protein values from a number of sources across a diverse range of pastures from throughout New Zealand.

The data set includes data from all the significant agricultural regions of New Zealand. Unfortunately the Region recorded in the data set are administrative regions (Figure 1) and not agricultural region. The main pastoral land uses are dairy or mixed livestock (predominately sheep and cattle).

The data set is very unbalanced with quite different proportions of stock type present in the data for the different regions (Table 3). Differences in Region may be due to the differences in stock type present in the regions. Conversely differences in Stock Type may be due to differences in the regions where the stock are present. Hence we will need to adjust for the other factor when assessing the effects of either Region or Stock Type. The effects given will be the conditional effect of changing stock type while keeping Region constant and the conditional effect of changing Region while keeping Stock Type constant.

42% of the samples do not have stock type recorded. Leaving these samples out would reduce the size of our data set. However, if Stock Type had no effect then not knowing the stock type would not be of any consequence. These samples still provide some information on the effect of region, however the information is not as good as the information coming from samples where stock type is recorded and hence these samples need to be down weighted appropriately in the assessment of the effect due to Region.

Different sites can give us quite different information about the seasonal effect. 160 sites have only 1 date on which they were sampled. 47 sites had 12 or more dates on which they were sampled. If all the sites had only 1 date sampled but these were at different times of the year we could still estimate a seasonal pattern. However the variation about each sample includes site to site variation as well as observational variation. Data from the same site does not have site-to-site variation so can give us better estimates of the seasonal variation. We need to combine estimates of the seasonal variation from both sources, down weighting the estimates from the sites which had fewer dates on which they were sampled.

The effect due to Season is unlikely to follow a simple sine wave. We would like to let the data tells us the shape of the seasonal curve, subject to the requirement that the values for December should be close to the values of both January and November.

7 The statistical model

Smoothing models can cope with all the above requirements. One model can be fitted including the effects of both Stock Type and Region. The conditional effects of Stock Type adjusted for Region and the effect of Region adjusted for Stock Type can both be obtained from the model. These effects allow us to properly and fairly compare between stock types and also separately between regions. The final shape of the curve fitted is controlled by the covariance function chosen. Choosing a cyclic covariance function with a cycle time of 365 days for the Seasonal effect ensures that it has a yearly cycle. Where a sample does not have a stock type (or region) recorded it has the Stock Type (or Region) variance added to it, but this variance is uncorrelated with any other sample. This effectively removes the sample from the estimation of Stock Type (or Region, whichever is missing) and down weights it appropriately in the estimation of the non-missing factor.

The models used were

Metabolisable energy = constant + Season * (Stock Type + Region + Site)

Crude protein = constant + Season * (Stock Type + Region + Site)

Season is some curve over time, due to improved management practices or improved cultivars for example. Season is some curve repeating every 365 days. . Stock Type and Region give different curves for different stock types and regions. Site gives a different curve for each site. The distribution for the estimates for the different curves for different stock types have zero mean, similarly for Region and Site.

Clearly the concentrations of either metabolisable energy or crude protein are not directly affected by the class of animal that will eat it. Stock type is likely to be a proxy for some other effect such as differences in pasture species composition or management practices. It is quite likely a proxy for topography. There are comparatively few sheep/beef farms on flat land as dairy farming is more profitable here. Similarly, there are even fewer dairy farms on hill country because of topography constraints. Hence the differences between sheep/beef farms and dairy farms is likely to include differences between hill country and flat land.

The estimates for Stock Type are the best estimates for a new site from that stock type if the Region was unknown or if the information about Region was ignored. Similarly for Region. It is the consistency of the curves for different sites with the same Stock type or Region which enables us to estimate the variability associated with our estimate of the Stock Type and Region effects. This variability is shown in the figures as 95% Least Significant Intervals. These may be used to determine significance between the classes in the figures. Two curves are significantly different at the 5% level where their bands do not overlap. The variability in the final estimates are shown by 95% confidence bands and standard errors of the estimates.

The standard deviations from the square root of the variance components of the terms are given in Table 5. The sampling standard deviation (S.D.) is the square root of the sum of squares of the S.D. for the *units* + Site + Season.Site terms.

Table 5: Standard deviations from variance components

	Metabolisable energy	Crude protein
Season	0.17	1.0
Stock Type	0.54	2.6
Region	0.07	0.2
Site	0.11	2.4
Season.Stock Type	0.64	2.7
Season.Region	0.26	0.9
Season.Site	0.73	2.1
Units	0.57	2.5
Site+Season.Site+Units	0.93	4.0

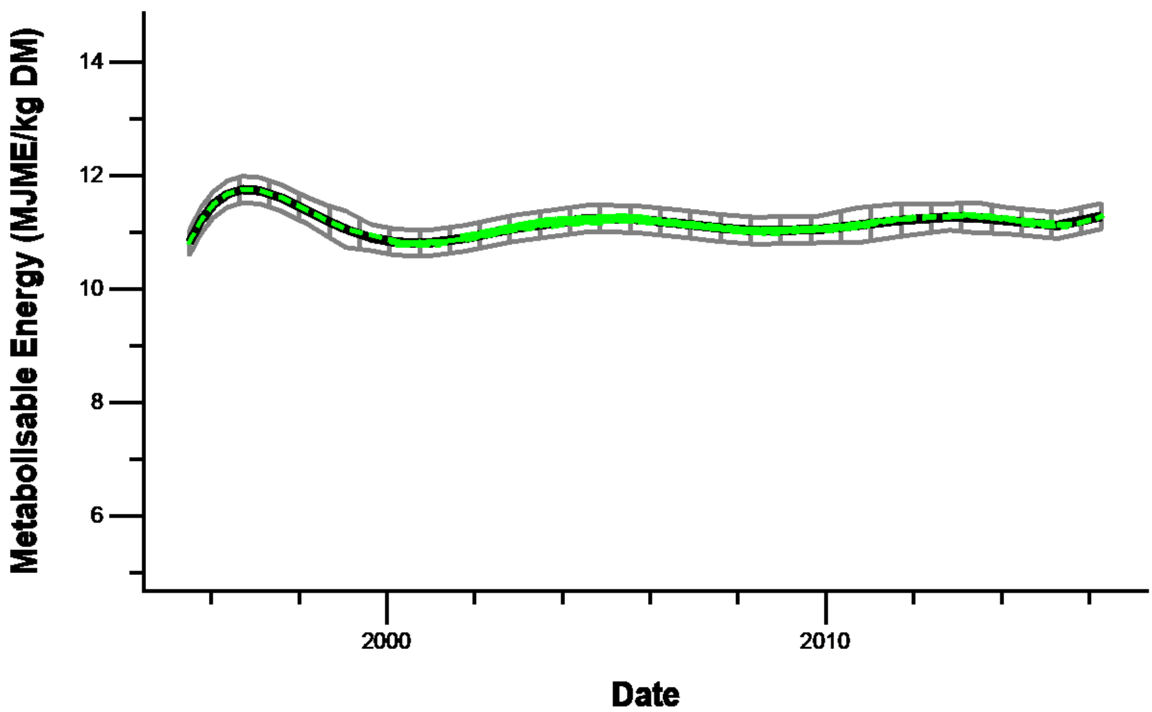
8 Changes over time

There is a possibility that changes in management practices and/or changes in pasture species and cultivars that have occurred during the 20 year span of data collection have resulted in gradual changes in the levels of metabolisable energy and crude protein over time. To check for this, the basic models were augmented with a Time effect. Figure 6 gives the plot of metabolisable energy over time. There is an indication that the samples in 1998 have higher metabolisable energies than at other times, but as this occurs over a very short time span it is likely due to sampling variation rather than long term trends. Hence there is no evidence that there are changes in the metabolisable energy levels over time

Figure 7 gives the plot of crude protein over time. The Least Significant bands easily cover any changes with time. Hence there is no evidence that there are changes in the crude protein levels over time.

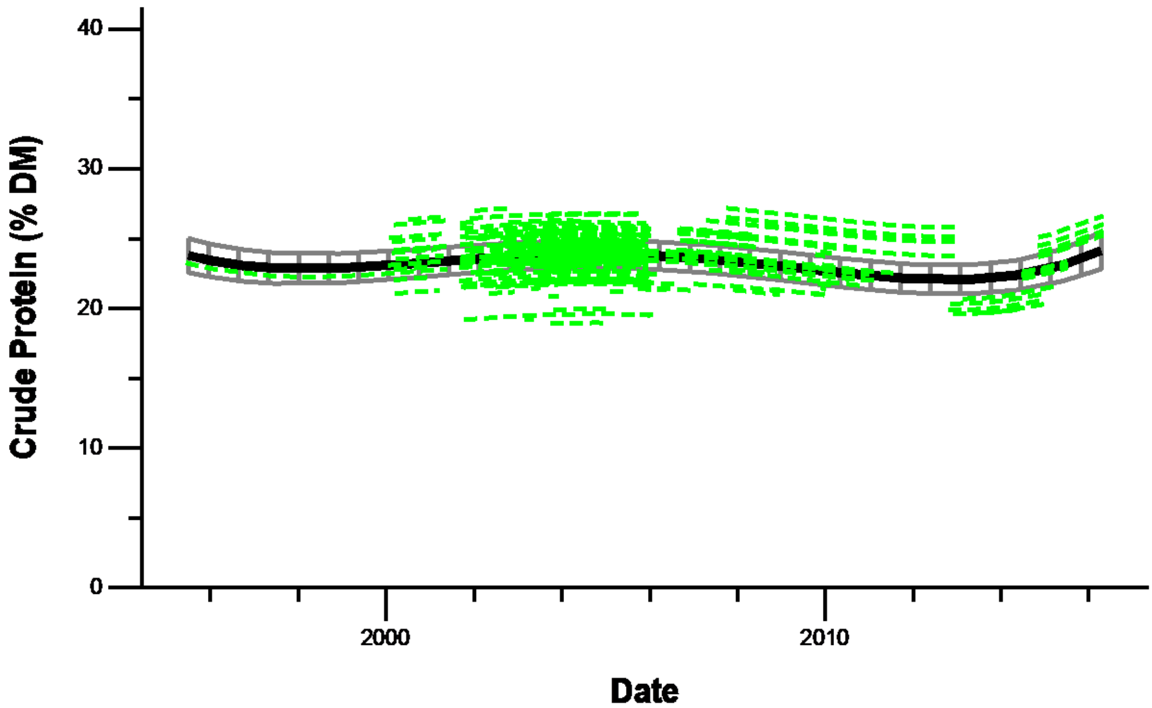
There were no changes in either metabolisable energy or crude protein over time, so this term was left out of subsequent analyses.

Figure 6: Metabolisable energy over time



Metabolisable energy over time. The bands are 95% Least Significant Intervals for differences in Time. Two points on the curve are significantly different at the 5% level where their bands do not overlap. The green dashed lines represent different sites adjusted for Stock Type and Region. The Site curves are difficult to see as they overlap the main curve.

Figure 7: Crude protein over time



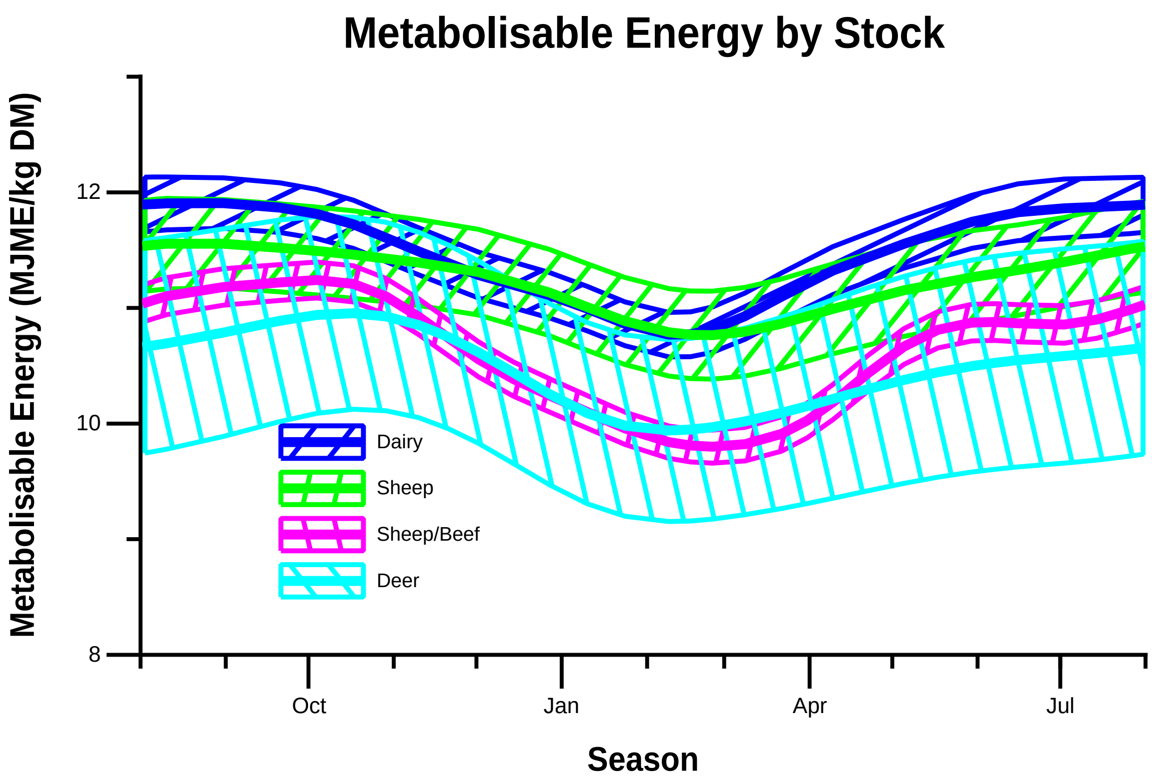
Crude protein over time. The bands are 95% Least Significant Intervals for differences in Time. Two points on the curve are significantly different at the 5% level where their bands do not overlap. The green dashed lines represent different sites adjusted for Stock Type and Region.

9 Stock type effect

Figure 8 gives a plot of the metabolisable energy for different stock types by Season after adjusting for Region. The cattle stock type has been left out and will be discussed in section 10 Research vs commercial, below. The seasonal pattern is similar for all stock types. However Dairy samples are a unit higher than the Deer and Sheep/Beef farms. Sheep farms are intermediate being 0.6 MJME/kg DM above Sheep / Beef and 0.4 MJME/kg DM below Dairy.

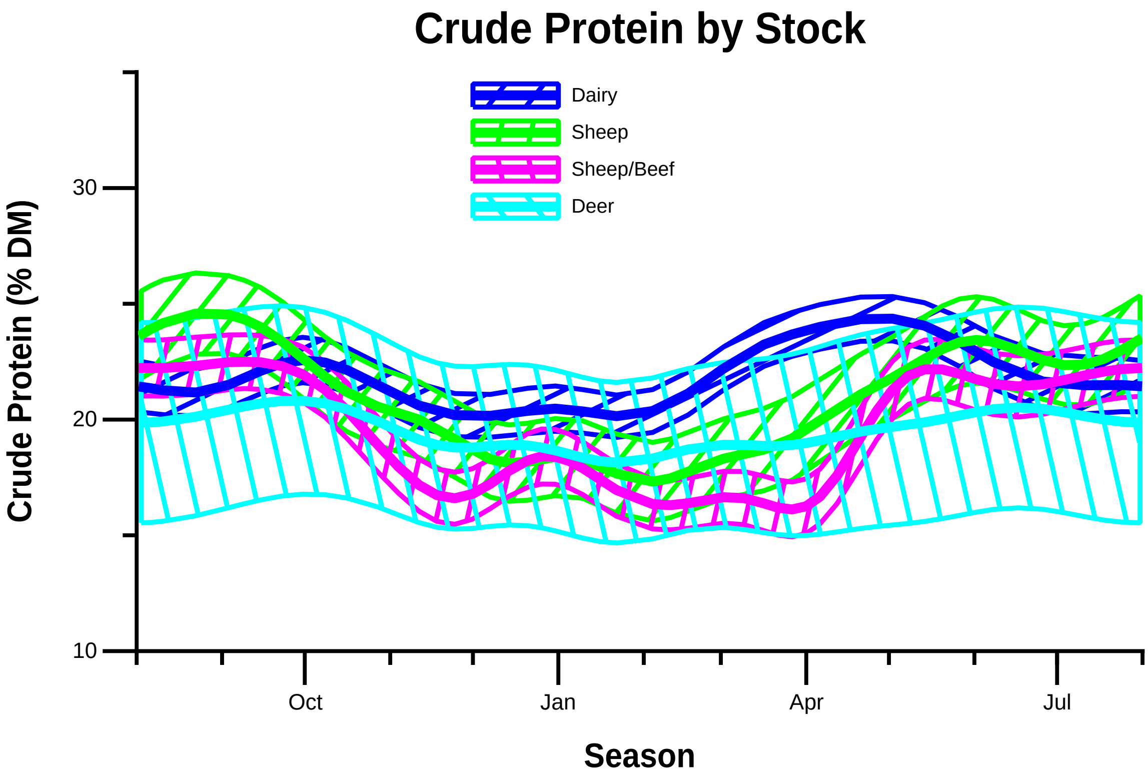
Figure 9 gives a plot of crude protein for the different stock types by Season. Again the cattle stock type has been left out to be discussed in section 10 Research vs commercial, below. Dairy farms have higher values of crude protein in the autumn than the other types rising to a peak difference of 7 % DM compared with sheep/beef. Otherwise there were no differences among the other stock types. Figure 11 gives the different stock types showing the curves for the sites within the Stock type.

Figure 8: Effect of stock type on metabolisable energy



Seasonal changes in metabolisable energy by Stock Type after adjusting for Region. The bands are 95% Least Significant Intervals for differences in stock type. Two curves are significantly different at the same time at the 5% level where their bands do not overlap.

Figure 9: Effect of Stock Type on crude protein



Seasonal changes in crude protein by stock type. The bands are 95% Least Significant Intervals for differences in stock type. Two curves are significantly different at the same time at the 5% level where their bands do not overlap

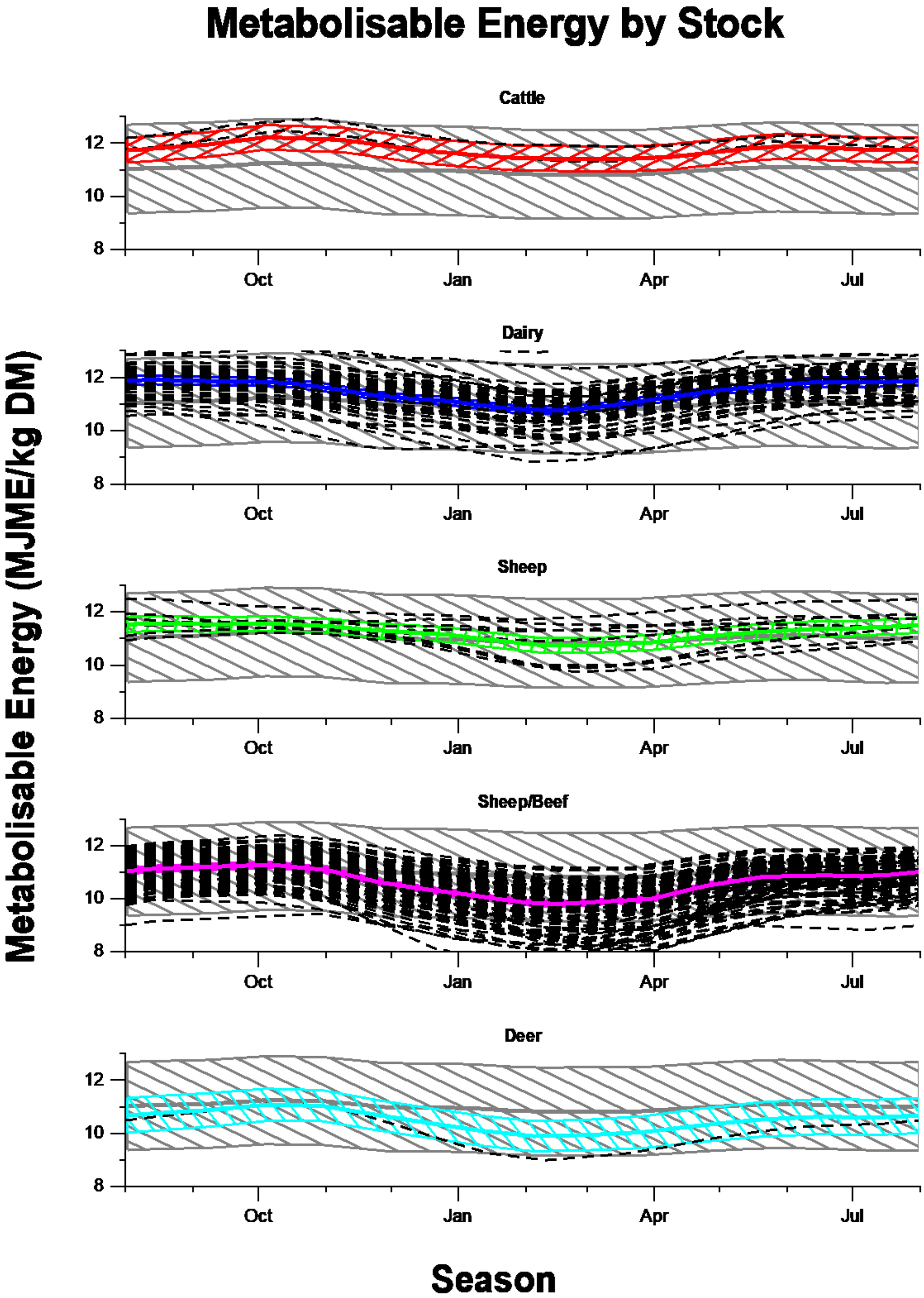
There is a discrepancy between Sheep farms and Sheep/Beef farms for metabolisable energy but not for crude protein. Sheep/Beef farms are a general category used by the larger data sets which includes both types of farms. Therefore the Least Significant Intervals of the two types would be expected to overlap.

As noted above, stock type is likely a proxy for topology.

Figure 10 and Figure 11 give the metabolisable energies and crude protein levels for different stock types. Also shown as a grey band is the curve when the stock type is unknown. This provides a test for stock type outliers. Stock types which go outside the grey bands would be unusual and not belong to the distribution of stock types. The cattle curves, although higher than the other curves, does not go outside the grey bands and therefore still belongs to the collection of typical stock curves.

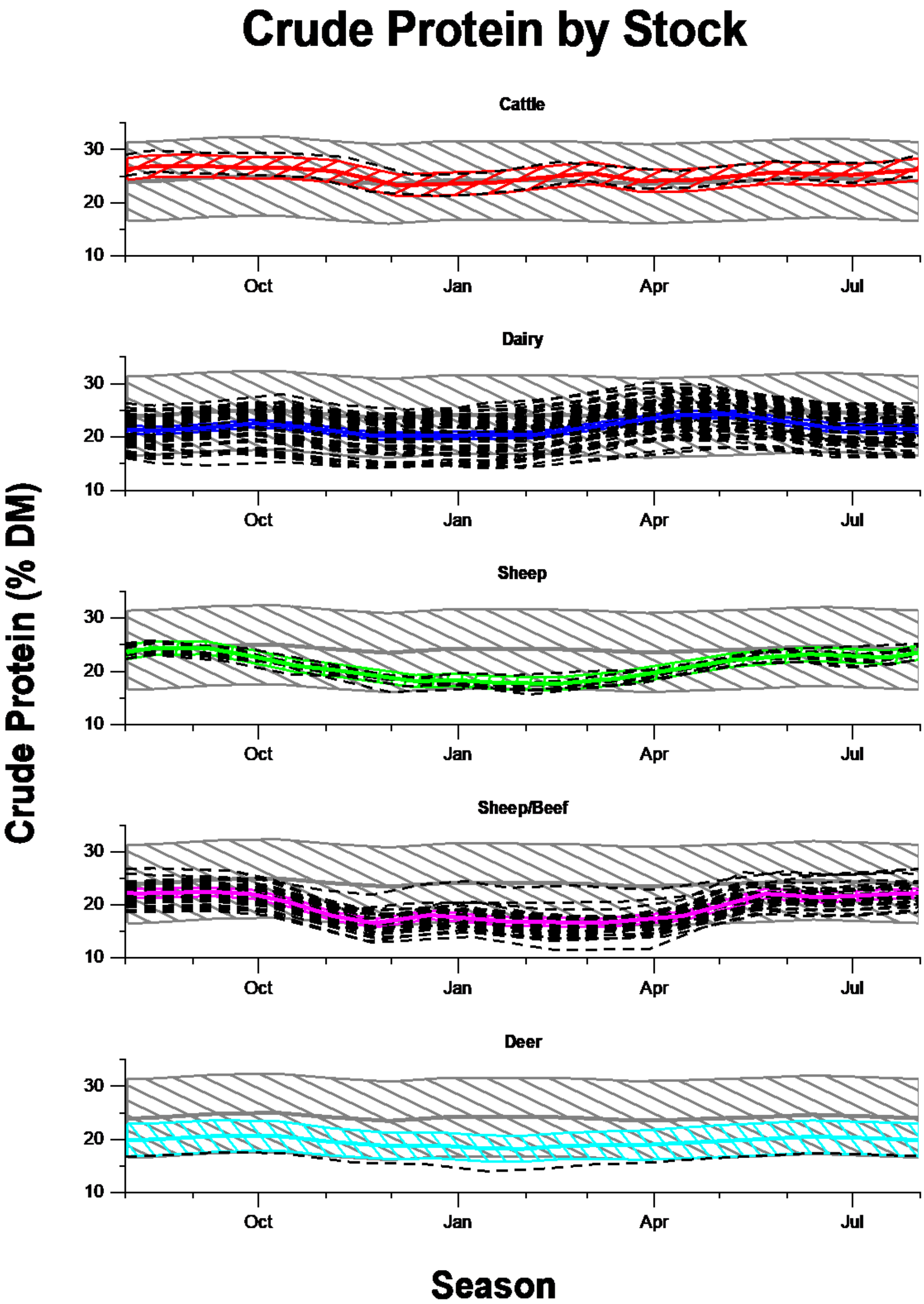
The site curves belonging to each stock type are shown as dashed lines.

Figure 10: Metabolisable energy by stock type



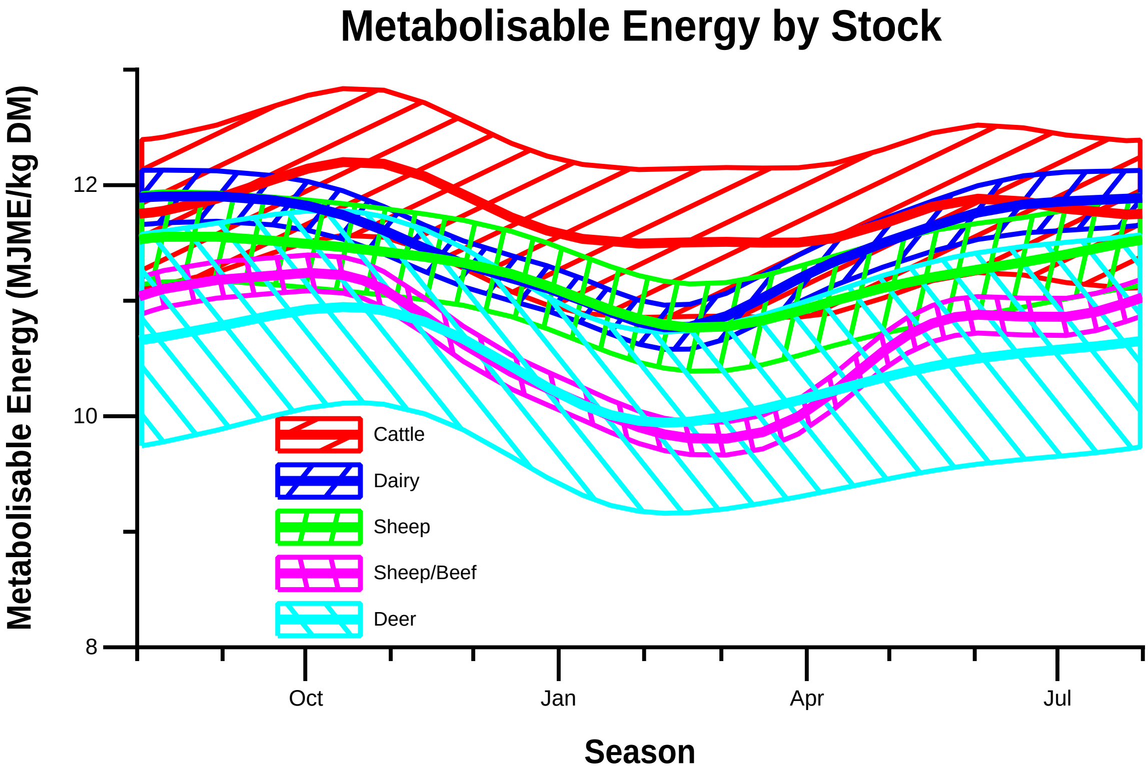
Plots by season of the different stock types. The coloured lines give the estimated values for the different stock types. The coloured bands are the 95% Least Significant Intervals for changes in season. Two values at different dates in the season are not significantly different at the 5% level if it is possible to draw a horizontal line entirely within the band between the two points. The grey curves are the estimated main effect of season. The grey bands are the 95% Least Significant Intervals for an unknown stock type. Stock type curves that lie outside the grey bands are outliers. The dashed lines are curves for the individual sites that have that stock type.

Figure 11: Crude protein by stock type



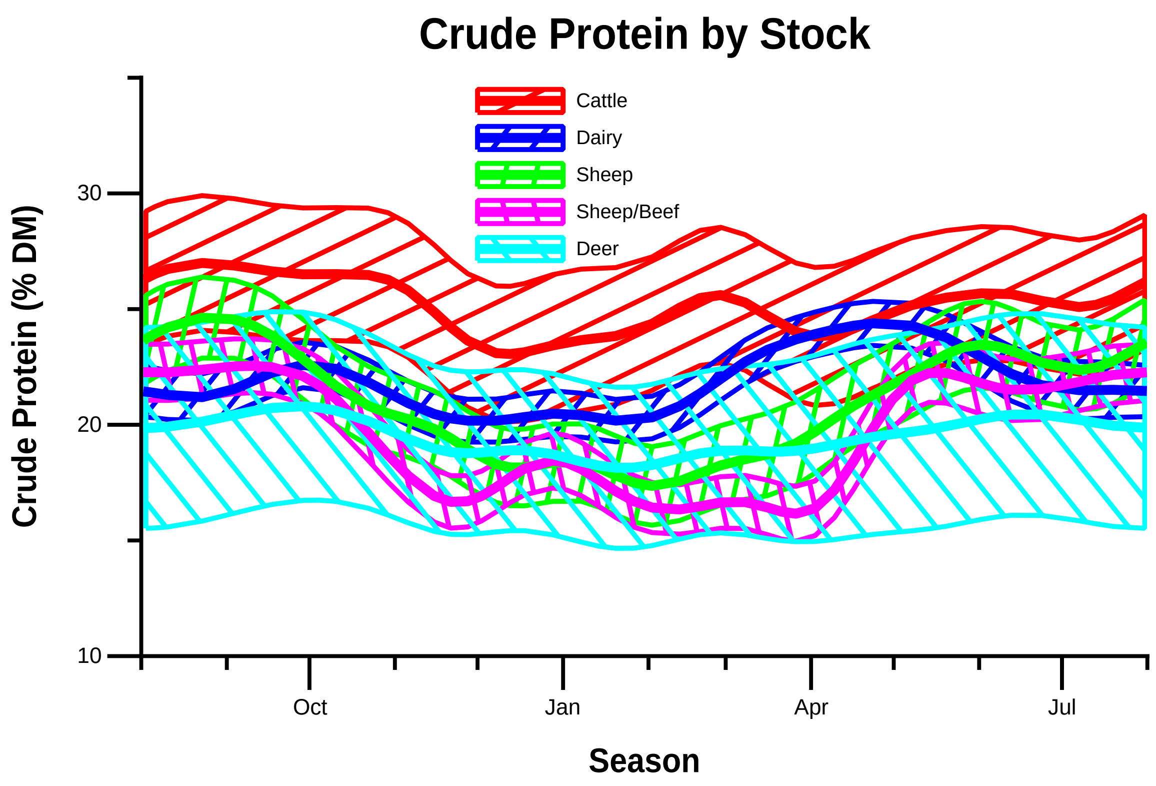
Plots by season of the different stock types. The coloured lines give the estimated values for the different stock types. The coloured bands are the 95% Least Significant Intervals for changes in season. Two values at different dates in the season are not significantly different at the 5% level if it is possible to draw a horizontal line entirely within the band between the two points. The grey curves are the estimated main effect of season. The grey bands are the 95% Least Significant Intervals for an unknown stock type. Stock type curves that lie outside the grey bands are outliers. The dashed lines are curves for the individual sites that have that stock type.

Figure 12: Effect of all stock types on metabolisable energy



Seasonal changes in metabolisable energy by stock type after adjusting for Region. The bands are 95% Least Significant Intervals for differences in stock type. Two curves are significantly different at the same time at the 5% level where their bands do not overlap.

Figure 13: Effect of all stock types on crude protein



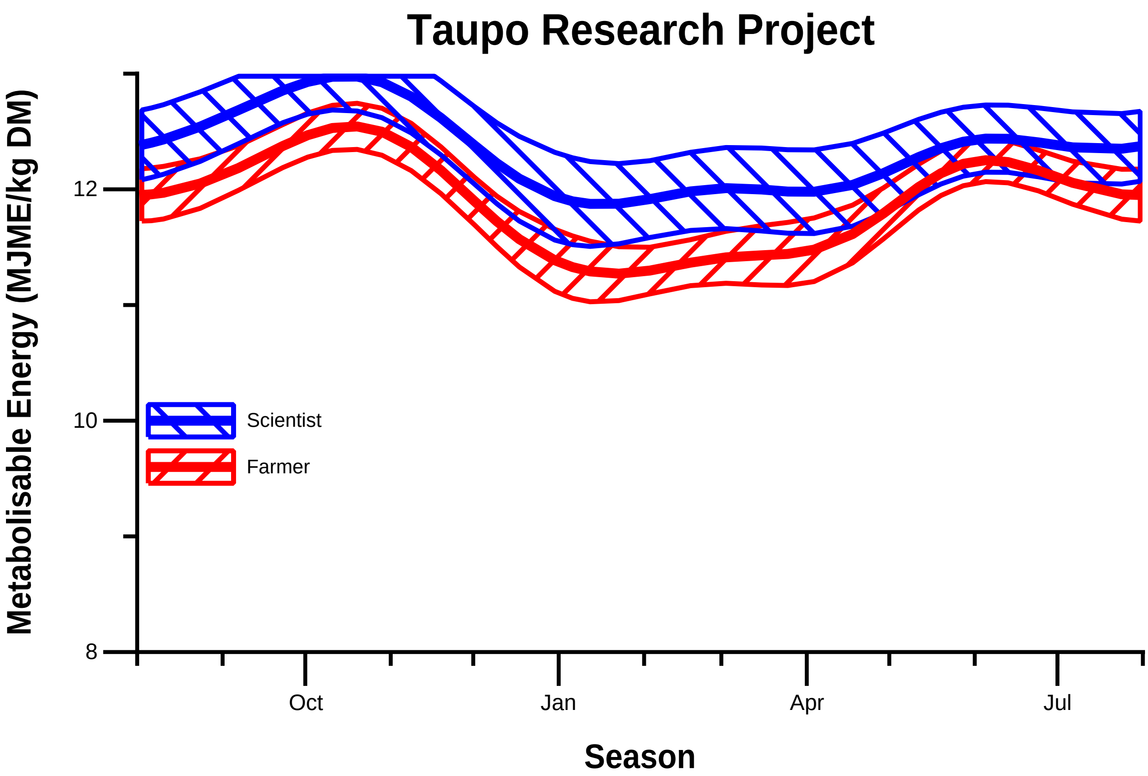
Seasonal changes in crude protein by stock type. The bands are 95% Least Significant Intervals for differences in stock type. Two curves are significantly different at the same time at the 5% level where their bands do not overlap

It seems strange that there is such a discrepancy between cattle and sheep/beef farms for both metabolisable energy and crude protein.

10 Research vs commercial sites

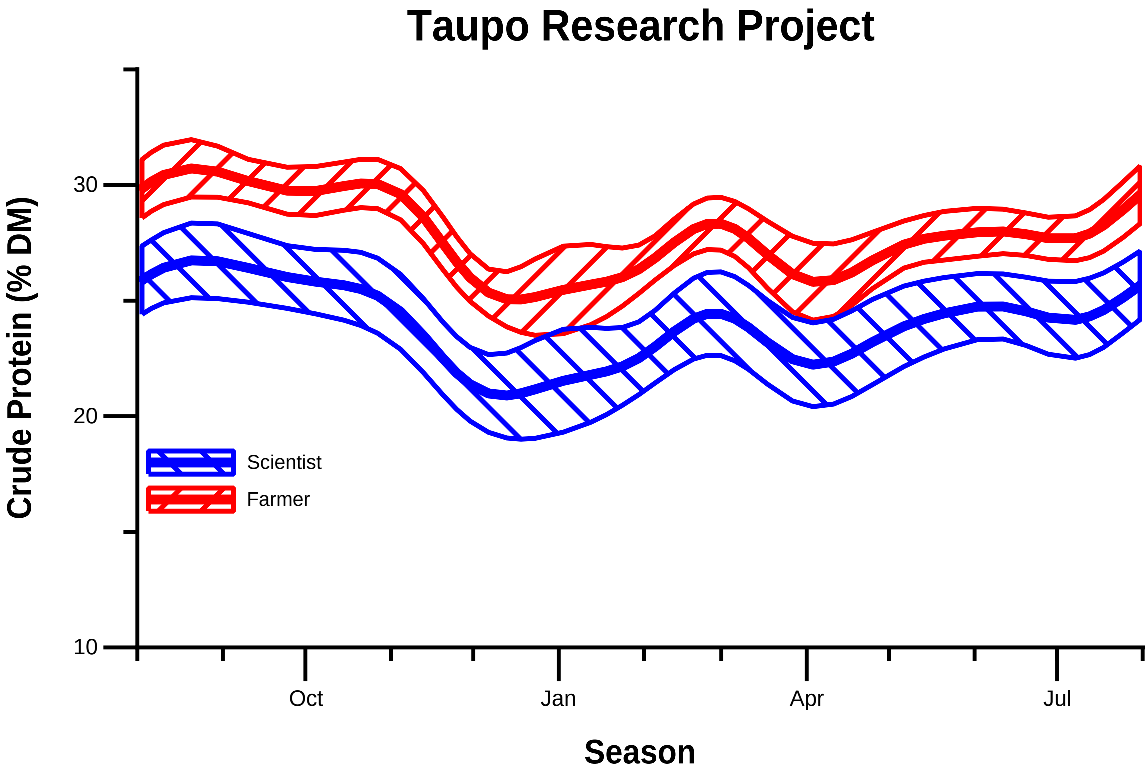
Figure 14 and Figure 15 a specific effect on metabolisable energy and crude protein due to sampling method, within a single stock type (cattle) and at a single location. There are just two cattle 'sites' from within the Taupo catchment project. One 'site' consists of the samples collected by the farmer and the other 'site' consists of samples collected by the scientist on the same farm. Figure 14 and Figure 15 give the plots of the metabolisable energy and crude protein in samples collected by the scientist and those collected by the farmer. The samples that the scientist collected are 0.5 MJME/kg DM higher in metabolisable energy and 5% lower in crude protein than those that the farmer collected.

Figure 14: Research vs. commercial differences in metabolisable energy



Metabolisable energy differences in methods of collection. Both sets of samples come from the same site. One set was collected by the scientist, the other by the farmer. The bands are 95% Least Significant Intervals for comparing the 2 curves. 2 Curves are significantly different at the 5% level where their bands do not overlap.

Figure 15: Research vs. commercial differences in crude protein



Crude protein differences in methods of collection. Both sets of samples come from the same site. One set was collected by the scientist, the other by the farmer. The bands are 95% Least Significant Intervals for comparing the 2 curves. Two curves are significantly different at the 5% level where their bands do not overlap.

Further details and discussion are presented in Appendix 4.

11 Regional effects

12 Figure 16 and Figure 17 give the effect of Region on metabolisable energy and crude protein for the 17 regions after adjusting for Stock Type. Figure 18 and Figure 19 add the Least Significant Intervals. The regions differ by less than 0.5 MJME/kg DM of metabolisable energy and less than 1% in crude protein. There are no significant differences between regions after adjusting for stock type as the Least Significant bands all overlap. Plots of the sites within regions are given in Appendix 1. Derivation of the effect of metabolisable energy on methane production

The effect of Metabolisable Energy on methane production can be approximated by Equation 1 in section 13.1, Effect of metabolisable energy on methane production

$$Methane = c\frac{\sum_i expression_i}{(0.02ME + 0.5)ME}$$

where c and $expression_i$ depend on Stock type and various activities of the stock.

This is derived from the Pickering and Wear (2013) equations via the following steps.

Equation 2

$$Methane = DMI * c$$

where DMI is the dry matter intake, c is a constant depending on the stock type. (Equations 52, 54, 55, 57 Pickering and Wear (2013)).

Equation 3

$$DMI = \frac{\sum_i \frac{expression_i}{efficiency\,factor_i}}{ME}$$

(Equations 12, 14, 20, 25, Pickering and Wear (2013))

where ME is the metabolisable energy of the pasture, $expression_i$ and $efficiency\,factor_i$ depend on the stock type and the various activities of the stock type (tables 2, 3, 4, 5, Pickering and Wear, 2013)

Most of the efficiency factors are of the form

Equation 4

$$efficiency\,factor = c_1 ME + c_2$$

where c_1 and c_2 are constants differing on stock type and function but approximately 0.02 and 0.5 respectively (Equations 3, 5, 8, 9, 10, Pickering and Wear (2013)).

The methane equation can be approximated by

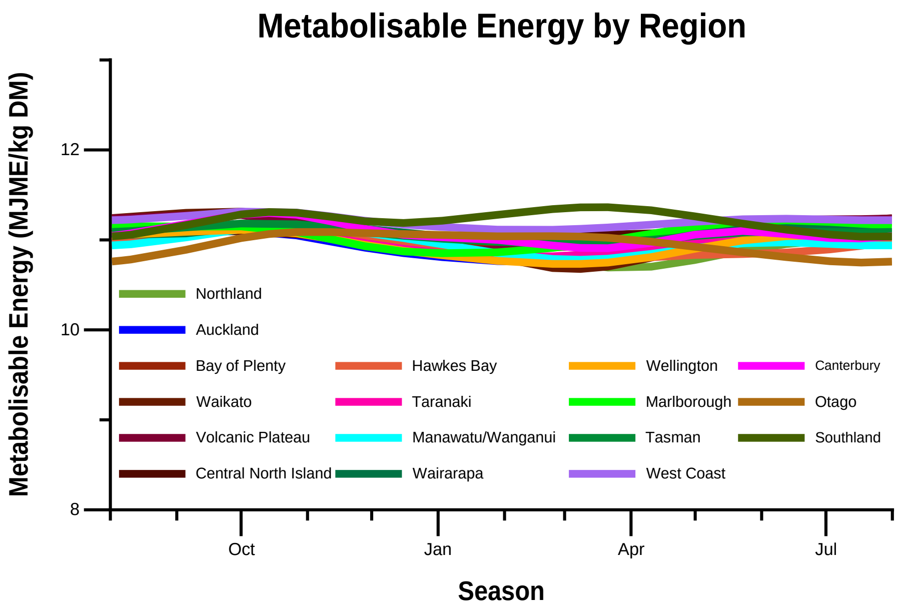
Equation 5

$$Methane = c\,\frac{\sum_i expression_i}{(0.02ME + 0.5)ME}$$

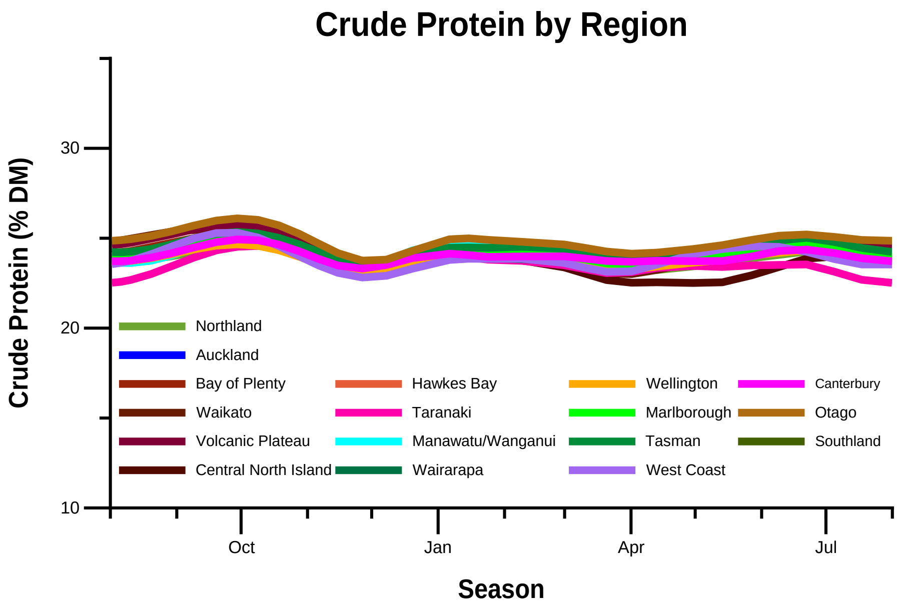
where c and $expression_i$ depend on Stock type and various activities of the stock.

Appendix

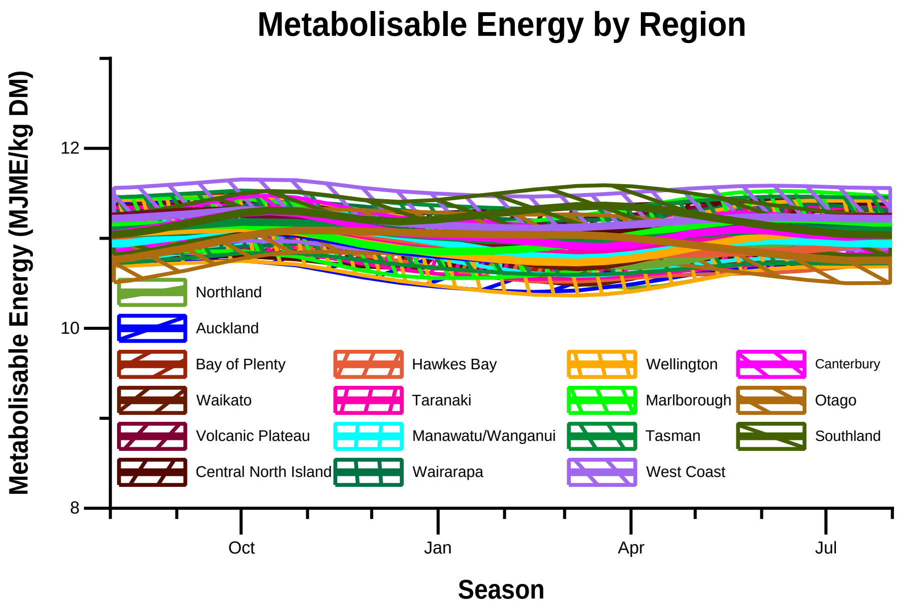
Figure



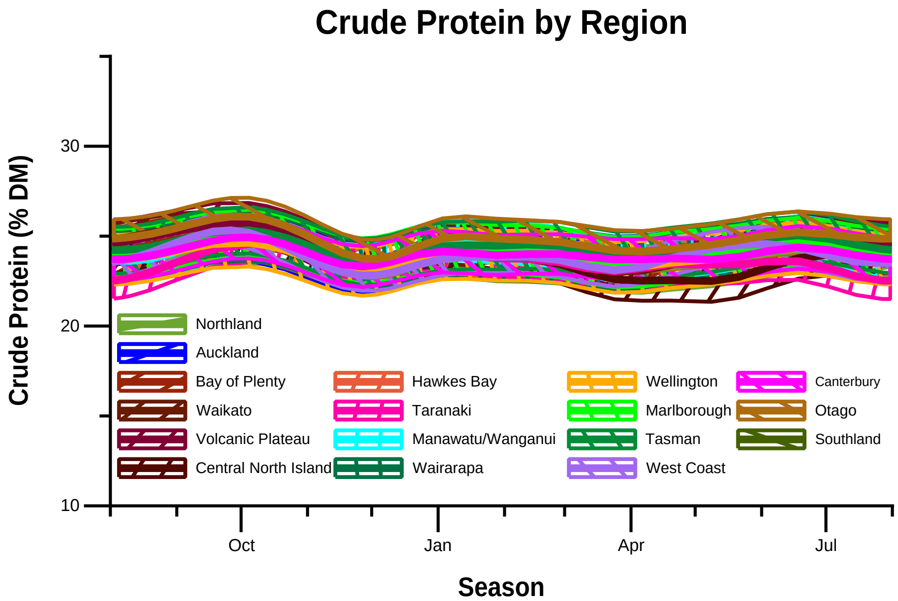
Figure



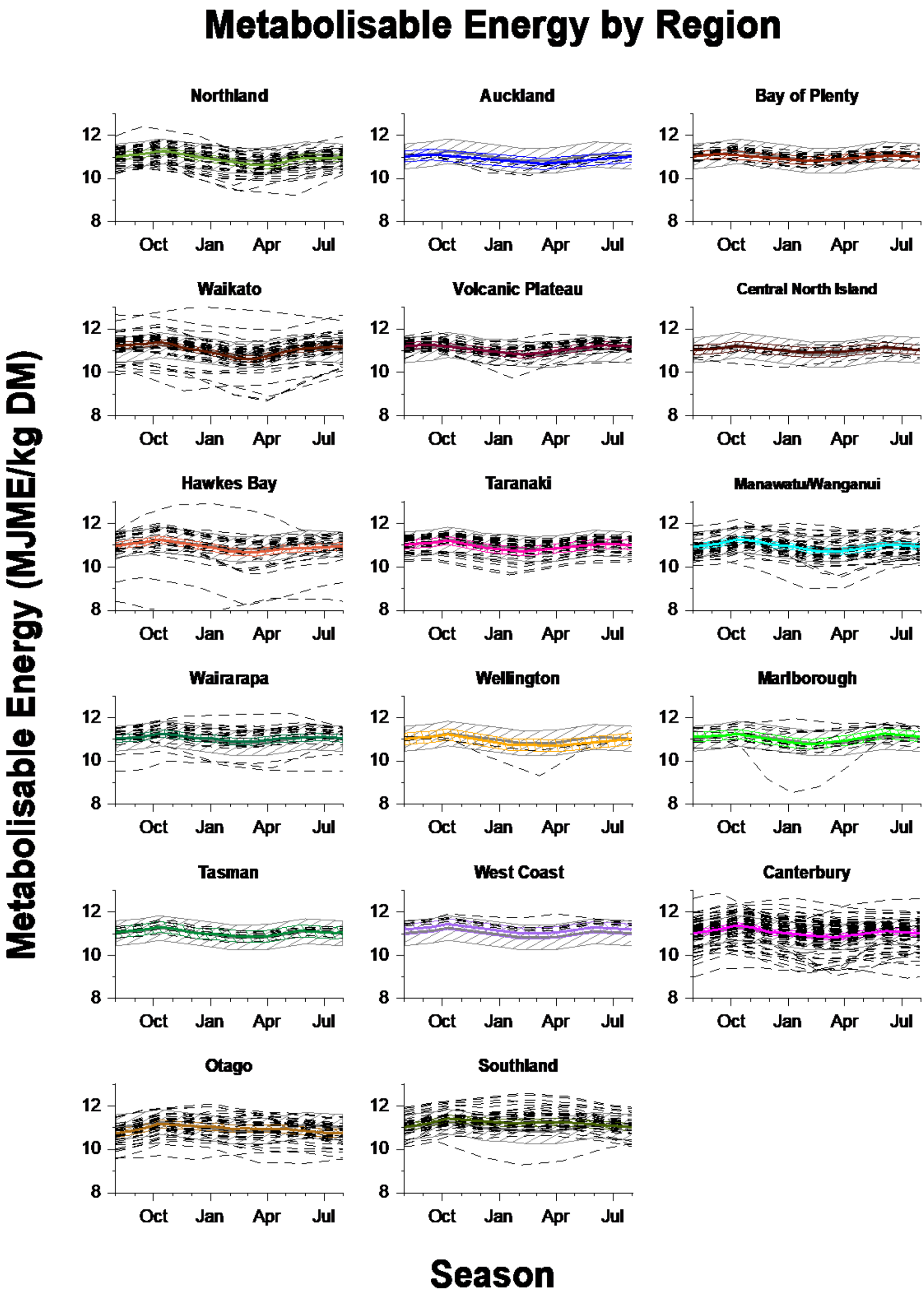
Figure



Figure

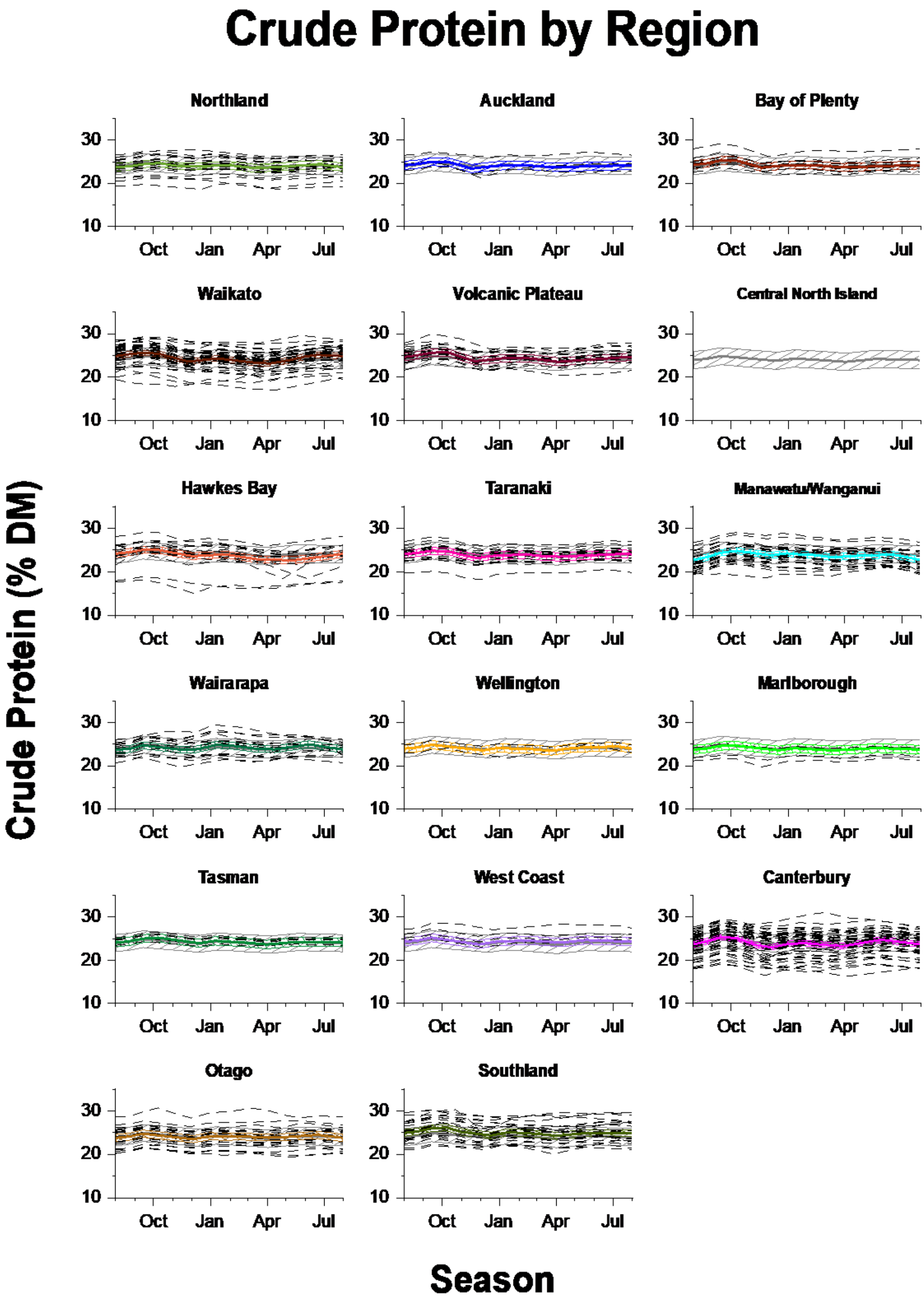


Figure



Metabolisable Energy by Region
Northland
Auckland
Bay of Plenty
Waikato
Volcanic Plateau
Central North Island
Hawkes Bay
Taranaki
Manawatu/Wanganui
Wairarapa
Wellington
Marlborough
Tasman
West Coast
Canterbury
Otago
Southland
8
10
12
Oct
Jan
Apr
Jul
Metabolisable Energy (MJME/kg DM)
Season

Figure


Crude Protein by Region
Northland
Auckland
Bay of Plenty
Waikato
Volcanic Plateau
Central North Island
Hawkes Bay
Taranaki
Manawatu/Wanganui
Wairarapa
Wellington
Marlborough
Tasman
West Coast
Canterbury
Otago
Southland
30
20
10
Oct
Jan
Apr
Jul
Crude Protein (% DM)
Season

13 Estimates

Estimates

The

$Methane$=▯$iexpressioni$0.02ME+0.5ME

where

This is derived from the Pickering and Wear (2013) equations via the following steps.

Equation 2

$$Methane = DMI * c$$

where DMI is the dry matter intake, c is a constant depending on the stock type. (Equations 52, 54, 55, 57 Pickering and Wear (2013)).

Equation 3

DMI= i▯▯$expressioniefficiency\ factoriME$

(Equations 12, 14, 20, 25, Pickering and Wear (2013))

where ME is the metabolisable energy of the pasture, $expression_i$ and $efficiency\ factor_i$ depend on the stock type and the various activities of the stock type (tables 2, 3, 4, 5, Pickering and Wear, 2013)

Most

Equation

$efficiency$

where c_1 and c_2 are constants differing on stock type and function but approximately 0.02 and 0.5 respectively (Equations 3, 5, 8, 9, 10, Pickering and Wear (2013)).

The methane equation can be approximated by

Equation 5

$Methane$ =$ciexpressioni$0.02ME+0.5ME

where

Appendix 2. Metabolisable energy by site

Table 6: Seasonal and stock type estimates of metabolisable energy (MJME/kg DM)

Season	Cattle	Dairy	Sheep	Sheep / Beef	Deer
January	11.52	10.95	10.97	10.05	10.05
February	11.50	10.76	10.77	9.80	9.94
March	11.50	11.00	10.82	9.84	10.05
April	11.57	11.37	11.02	10.29	10.24
May	11.80	11.63	11.19	10.78	10.42
June	11.87	11.82	11.32	10.86	10.54
July	11.76	11.86	11.45	10.90	10.61
August	11.80	11.90	**11.55**	11.11	10.71
September	12.01	11.87	11.52	11.20	10.85
October	12.20	11.73	11.46	11.21	10.94
November	12.06	11.43	11.37	10.84	10.80
December	11.72	11.19	11.23	10.38	10.42
Standard error of estimate	**0.46**	**0.15**	**0.28**	**0.11**	**0.61**
Relative standard error	**3.9%**	**1.3%**	**2.4%**	**1.0%**	**5.8%**

Table 7: Seasonal and stock type estimates of crude protein (% of DM)

Season	Cattle	Dairy	Sheep	Sheep / Beef	Deer
January	23.75	20.28	18.13	17.60	18.23
February	25.19	20.94	17.65	16.37	18.61
March	24.78	23.20	18.69	16.47	18.85
April	24.10	24.26	20.73	18.20	19.29
May	25.40	24.02	22.74	22.27	19.83
June	25.60	22.06	23.09	21.49	20.46
July	25.25	21.50	22.54	22.07	20.05
August	26.89	21.22	24.42	22.29	19.98
September	26.67	22.13	24.03	22.53	20.68
October	26.52	22.24	21.31	20.62	20.47
November	24.91	20.48	19.84	16.95	18.97
December	23.08	20.28	18.14	17.89	18.90
Standard error of estimate	**2.10**	**0.72**	**1.26**	**0.86**	**2.84**
Relative standard error	**8.4%**	**3.3%**	**6.0%**	**4.4%**	**14.6%**

14 Implications for the New Zealand Agricultural GHG Inventory model

One of the main uses for this study is as input to the New Zealand Green House Gas Inventory model as given by Pickering and Wear (2013).

14.1 Effect of metabolisable energy on methane production

The effect of metabolisable energy on methane production can be approximated by

Equation 1

$$Methane = c\,\frac{\sum_i expression_i}{(0.02ME + 0.5)ME}$$

where c and $expression_i$ depend on Stock type and various activities of the stock.

The derivation is given Appendix 1. Derivation of the effect of metabolisable energy on methane production below.

Since metabolisable energy values are approximately 11 the relative error in $(0.02ME + 0.5)$ is approximately zero. This means that the relative error in methane due to the uncertainty in the metabolisable energy levels is just the relative error in metabolisable energy. This is 1.3% and 1.0% for Dairy and Sheep / Beef, respectively

Some idea of the other errors in the methane model can be obtained by looking at the number of significant digits of the coefficients in the model. The constant c in Equation 1 is given as 0.5, just one significant digit in equations (3, 10) of Pickering and Wear (2013). The accuracy of this constant = 0.05/0.5 = 10%. Since metabolisable values are around 11 MJME/kg DM, the error in the efficiency factor is at least 10%. The constants K and S in Equation (3) of Pickering and Wear (2013) are given as 1.4 and either 1.0 for females or 1.15 for entire males. Thus the errors in these constants, K and S, are at least 4% and 1%, respectively. Thus the total error in one of the factors in the numerator of this equation is at least 15%.

Crude protein can be used to calculate % nitrogen (N) which appears in the equations for nitrous oxide. (% nitrogen= crude protein/6.25). Nitrogen % appears in a more complex manner and it is not so easy to directly compute how errors in % N will affect the errors in nitrous oxide levels. However the constants in the equations are similarly given with very limited precision so that the errors in these constants will have a much bigger bearing on the uncertainty in nitrous oxide emissions than the uncertainty still present in crude protein levels.

14.2 Data categories

The data for the other terms in the $expression_i$ come from either milk factories in the case of dairy cows and slaughter houses for other stock types. The equations are computed on a dairy factory or slaughter house basis.

Since milk is shipped to the nearest dairy factory and there are many of them, the terms in the equations can differ by region. Currently the regions used are the administrative regions as used by Bown (Table 1, Pickering and Wear (2013)). If the locations in the data set were assigned a latitude and longitude as suggested in the section on future work, and the area used by each dairy factory obtained, the analysis could be redone using dairy factory catchment instead of administrative region.

Stock for slaughter may be transported quite large distances around New Zealand before being slaughtered. Each slaughter house receives stock from many regions. For this reason there is little relationship between source of stock and location of processing, making infeasible the analysis by region that would be possible for dairy. Hence the equations being used are done on a New Zealand wide basis.

15 Conclusions

The relative errors in the seasonal values of the mean metabolisable energy are 1.3% and 1.0% for Dairy and Sheep / Beef, respectively. Since the metabolisable energy occurs as a multiplier in the methane equations of Pickering and Wear (2013), the uncertainty in the methane produced due to the uncertainty of the estimates of mean metabolisable energy is also 1.3% and 1.0% for Dairy and Sheep / Beef, respectively. This is much smaller than the uncertainty in the other factors in the model which are at least 15%.

The equations for nitrous oxide are more complicated and therefore it is difficult to quantify the uncertainty in nitrous oxide emissions due to the uncertainty in the mean crude protein levels. However this uncertainty is certain to be much smaller than the uncertainty due to other factors in the model.

Some of the data was collected as surveys, other as the results of science trials and others due to consultants sending in samples for analysis. The variety of methods used is likely to provide a good coverage of pasture values in New Zealand. The possibility of possible biases still being present was investigated by considering the distribution of the residual sample estimates. The biases are extremely small if present and much smaller than other uncertainties.

There seems to be little to gain in collecting further samples.

16 Future Work

16.1 Further data sets

FeedTECH has a large data set of several thousand ME values that could be made available to us. This data set has broad geographical spread and most importantly, a span over several years. Including this data set would be very worthwhile. Statistical techniques now available could be used to investigate this data, and as a next-step this option would be cost-effective and informative to conduct before embarking on further sample collection. The time available in this current project has not allowed incorporation of this data.

16.2 Regional effects

In this analysis the assignment of locations to Regions is very coarse. In the two major sets, Bown and AgResearch, the assignment was done on administrative regions which are very different from agriculturally important regions and are very large. An attempt to mitigate this was to create the Wairarapa and Volcanic Plateau, which though key agricultural regions are not administrative regions.

There is no notion of the geographical location of the regions in the current analysis. The statistical model does not know that Northland is at the opposite end of the country to Southland and treats differences between these two locations the same as differences between Wairarapa and Hawkes Bay which are neighbours and similar in climate. Giving the analysis better location detail would improve the estimates of the regional effects.

Most of the sites are allocated to a town or city which presumably is close to the farm that was sampled. It may be the postal address of the farm which would explain the presence of a site in Herne Bay in Auckland and the number of farms in Palmerston North. There are two web sites http://www.maps.ie/coordinates.html and http://www.mapcoordinates.net/en which use Google maps to give the latitude, longitude and altitude of any town or RD number in New Zealand. It would not take a lot of effort to assign an approximate latitude, longitude and altitude to each site. Replacing a nominal regional variable with continuous latitude and longitude variables would improve the regional aspect quite a bit.

Complete contour maps of Metabolisable Energy and Crude Protein for New Zealand could then be prepared and compared with contour maps produced from Landsat images (Ausseil 2012).

Latitude and longitude values could be matched with weather maps to give approximate values of the annual rainfall and mean temperature. It would be interesting to see whether rainfall, temperature and altitude could explain regional differences.

16.3 Research vs commercial sites

The fact that the samples collected by the scientist in the Taupo study are 0.5 MJME/KG DM higher than those collected by the farmer needs investigating as its size is bigger than the standard errors of the estimates on Dairy and Sheep / beef farms. Although the effect could not be substantiated by other data from this data set, the information as to which samples came from research farms and which came from commercial farms is poor. Sites with Cattle and Sheep stock types come from research stations whereas the site with Sheep / Beef stock type come predominantly from commercial farms. Are the values in the Sheep and Cattle stock types higher than the ones in the Sheep / Beef stock type due to the extra care taken in obtaining and handling the samples in a research station?

17 Acknowledgements

Data used in this analysis was obtained from several recent research programmes to augment the data used in an earlier report by Bown et al. 2013. These programmes were Pastoral 21, a collaborative venture between DairyNZ, Fonterra, the Dairy Companies Association of New Zealand, Beef + Lamb NZ, and the Ministry of Business, Innovation and Employment; Forages for Reduced Nitrate Leaching, a collaborative research programme including DairyNZ, AgResearch, Plant and Food Research, Lincoln University, the Foundation for Arable Research, Landcare Research and the Ministry of Business, Innovation and Employment; and the Sustainable Land Management and Climate Change fund, administered by the Ministry for Primary Industries.

18 References

Ausseil, Anne-Gaelle; Sutherland, Anne; Muir, Paul; Thomson, Beverley (2012) “Recommendations for using pasture quality information in the national agriculture greenhouse gas inventory”. Report prepared for the Ministry for Primary Industries, Contract 15424

Bown, MD; Thomson, BC and Muir, PD (2013) *“Evaluation of the values for pasture ME and N content in the National Greenhouse Gas Inventory”* MPU Technical Paper No 2015/29 ISBN 978-1-77665-044-6 (online) https://www.mpi.govt.nz/document-vault/9599

Genstat *for Windows* 18th Edition (2015). VSN International, Hemel Hempstead, UK. Web page: Genstat.co.uk

Giltrap, Donna; McNeill, Stephen; Saggar, Surinder; Sutherland, Anne Muir, Paul (2016) *“Statistical analysis to determine a nationally representative pasture quality sampling programme”*

Pickering, Andrea; Wear, Simon (2013) *“Detailed methodologies for agricultural greenhouse gas emission calculation”* Report prepared for the Ministry for Primary Industries, Wellington. https://mpi.govt.nz/document-vault/3059

Stigler, Stephen M; (2016) *“The seven pillars of statistical wisdom”, http://lccn.loc.gov/*2015033367, LCC QA276.15 S754 2016

19 Appendix 1. Derivation of the effect of metabolisable energy on methane production

The effect of Metabolisable Energy on methane production can be approximated by Equation 1 in section 13.1, Effect of metabolisable energy on methane production

$$Methane = c\frac{\sum_i expression_i}{(0.02ME + 0.5)ME}$$

where c and $expression_i$ depend on Stock type and various activities of the stock.

This is derived from the Pickering and Wear (2013) equations via the following steps.

Equation 2

$$Methane = DMI * c$$

where DMI is the dry matter intake, c is a constant depending on the stock type. (Equations 52, 54, 55, 57 Pickering and Wear (2013)).

Equation 3

$$DMI = \frac{\sum_i \frac{expression_i}{efficiency\ factor_i}}{ME}$$

(Equations 12, 14, 20, 25, Pickering and Wear (2013))

where ME is the metabolisable energy of the pasture, $expression_i$ and $efficiency\ factor_i$ depend on the stock type and the various activities of the stock type (tables 2, 3, 4, 5, Pickering and Wear, 2013)

Most of the efficiency factors are of the form

Equation 4

$$efficiency\ factor = c_1 ME + c_2$$

where c_1 and c_2 are constants differing on stock type and function but approximately 0.02 and 0.5 respectively (Equations 3, 5, 8, 9, 10, Pickering and Wear (2013)).

The methane equation can be approximated by

Equation 5

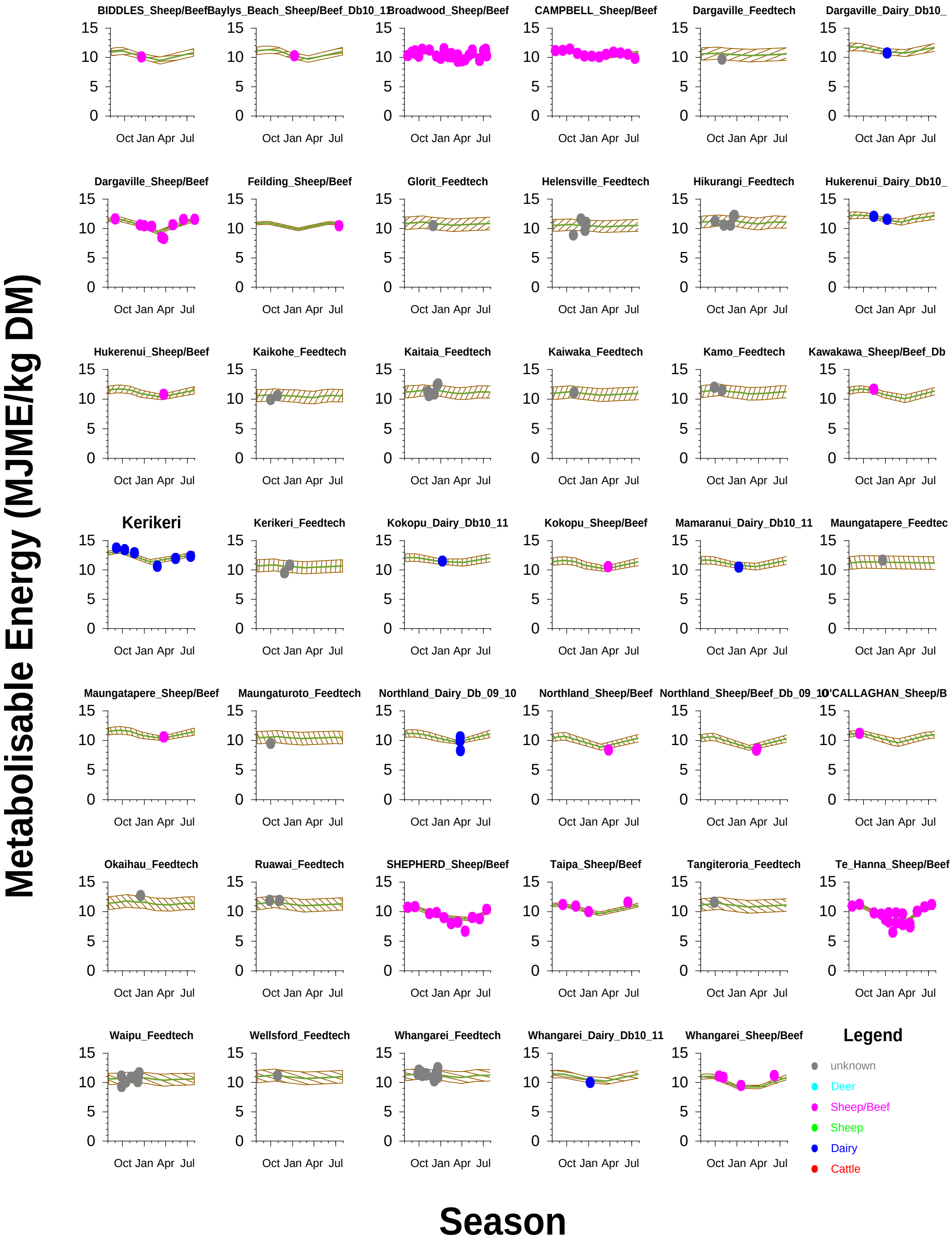
$$Methane = c\frac{\sum_i expression_i}{(0.02ME + 0.5)ME}$$

where c and $expression_i$ depend on Stock type and various activities of the stock.

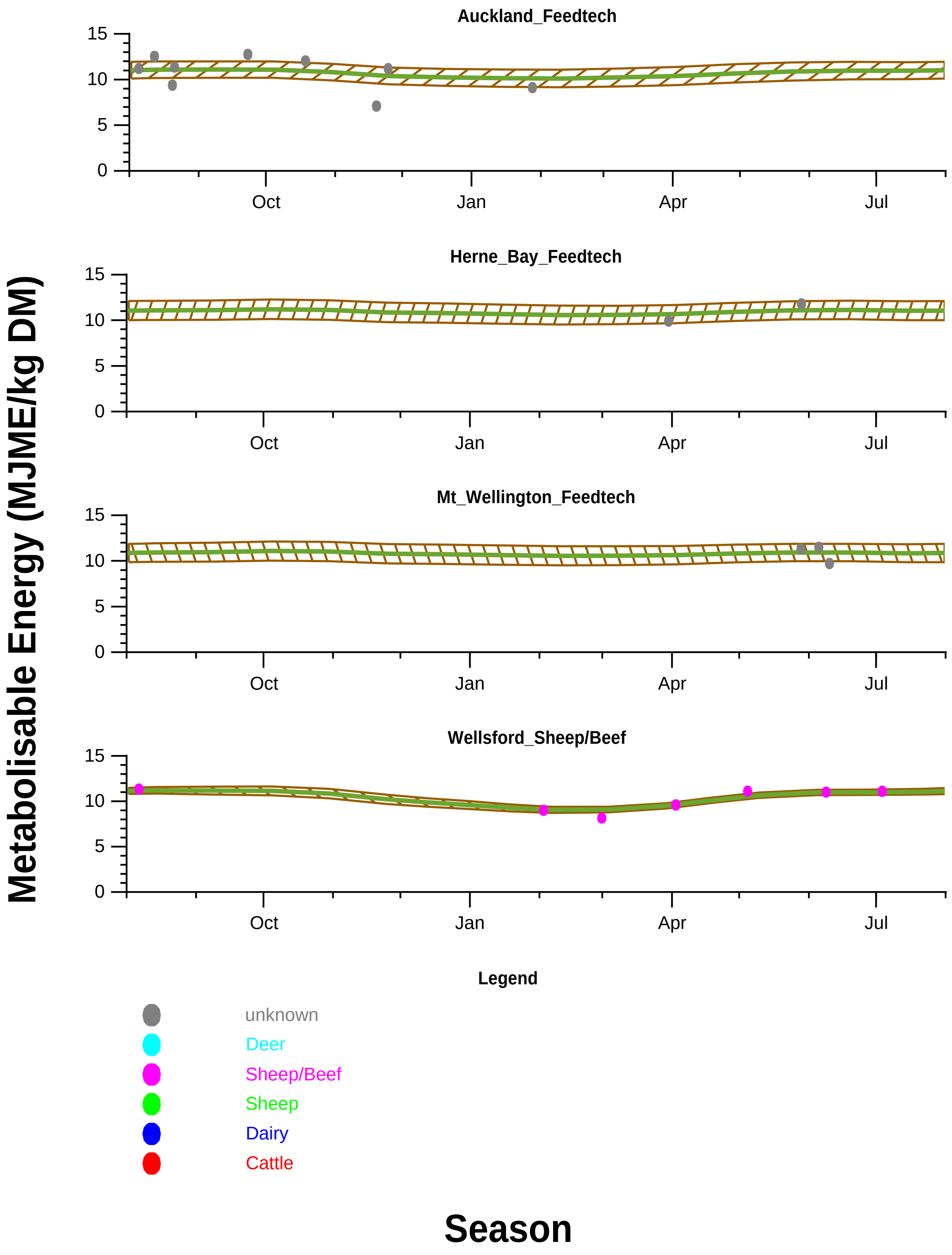
20 Appendix 2. Metabolisable energy by site

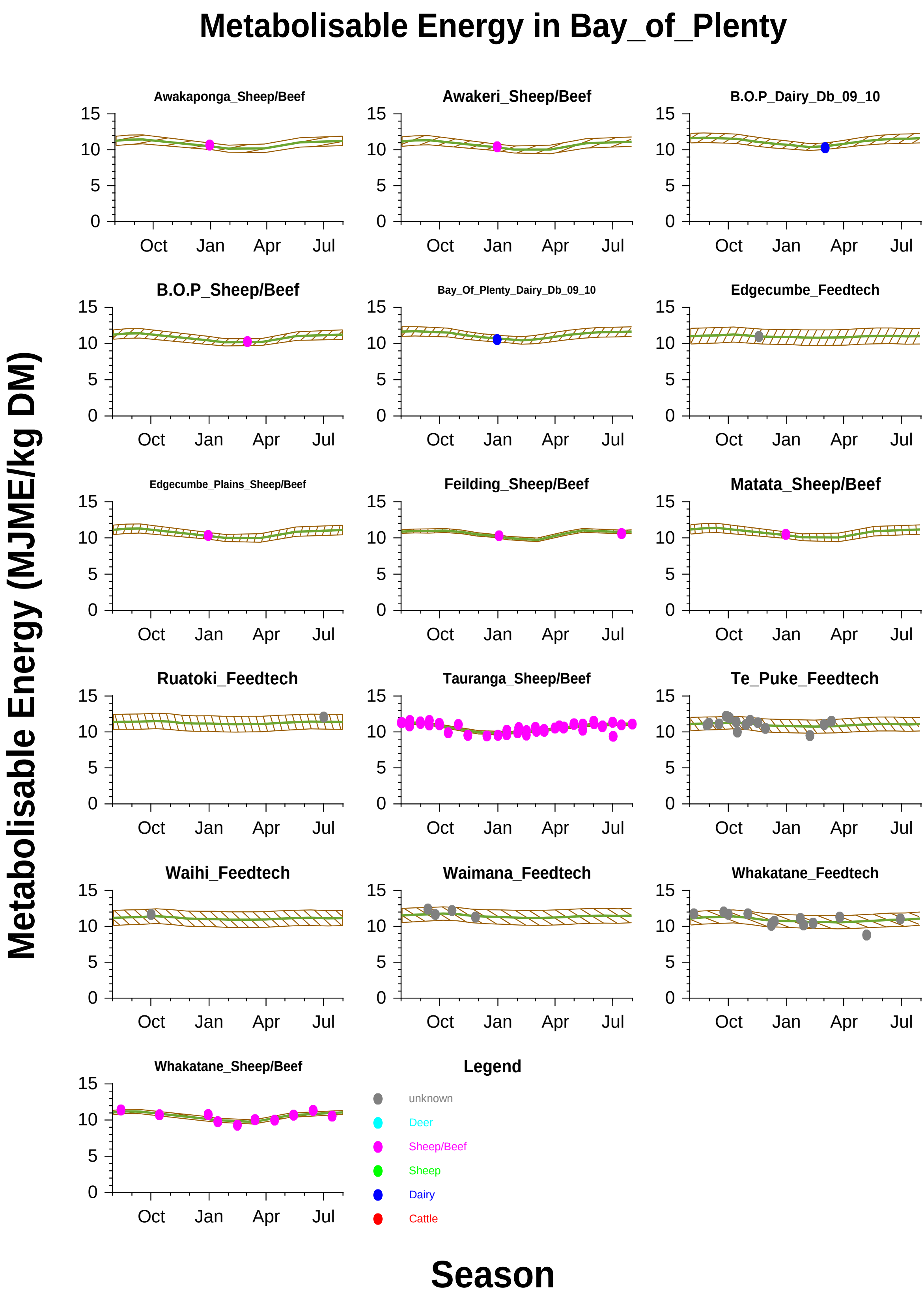
Detailed plots of sites within each region given below. The points denote means of the observations on the same site, stock type, data source and same day. The coloured lines give the estimated values of metabolisable energy (MJME/kg DM) for the different sites. The coloured bands are the 95% Least Significant Intervals for changes in season. Two values at different dates in the season are not significantly different at the 5% level if it is possible to draw a horizontal line entirely within the band between the two points.

Metabolisable Energy in Northland



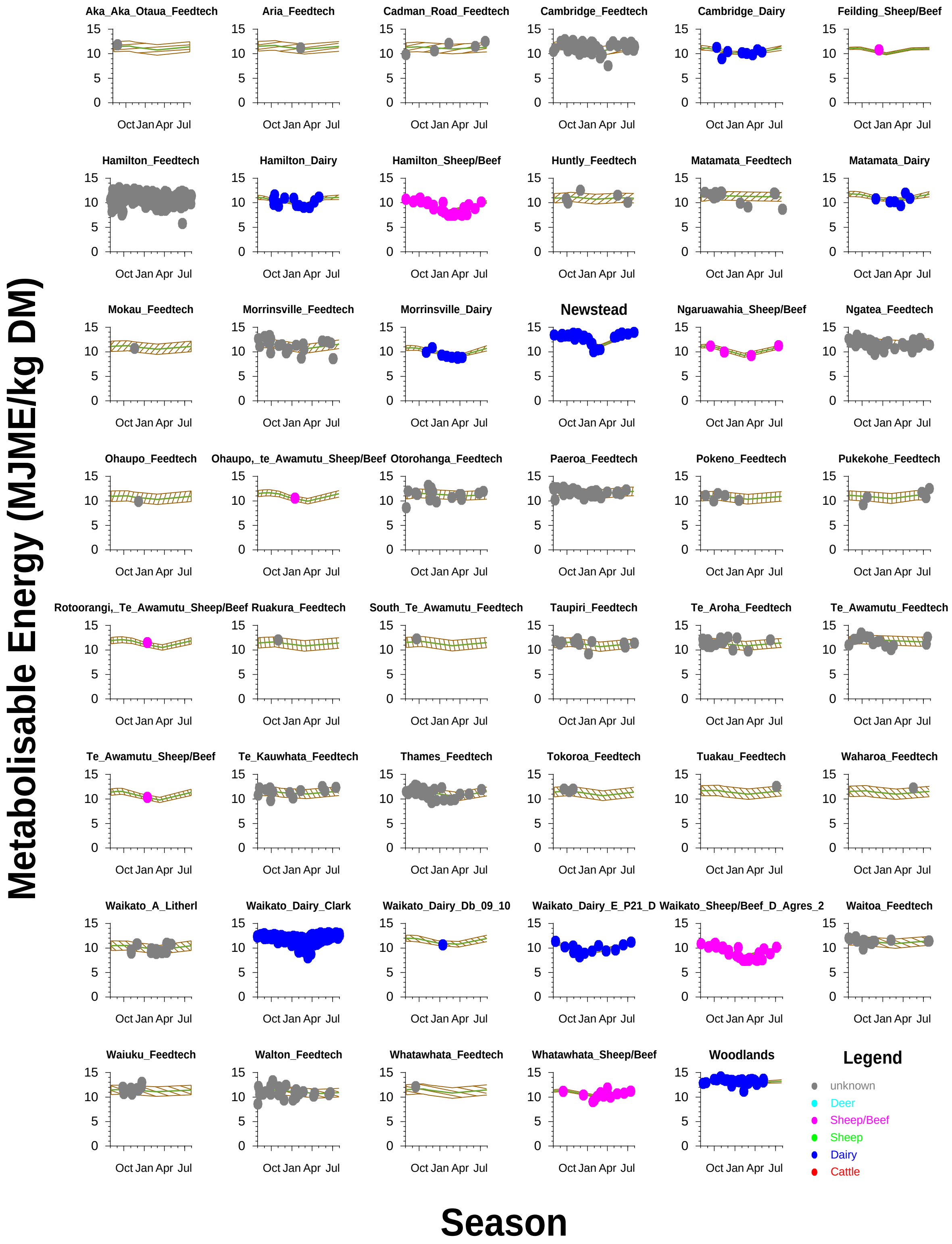
Metabolisable Energy in Auckland



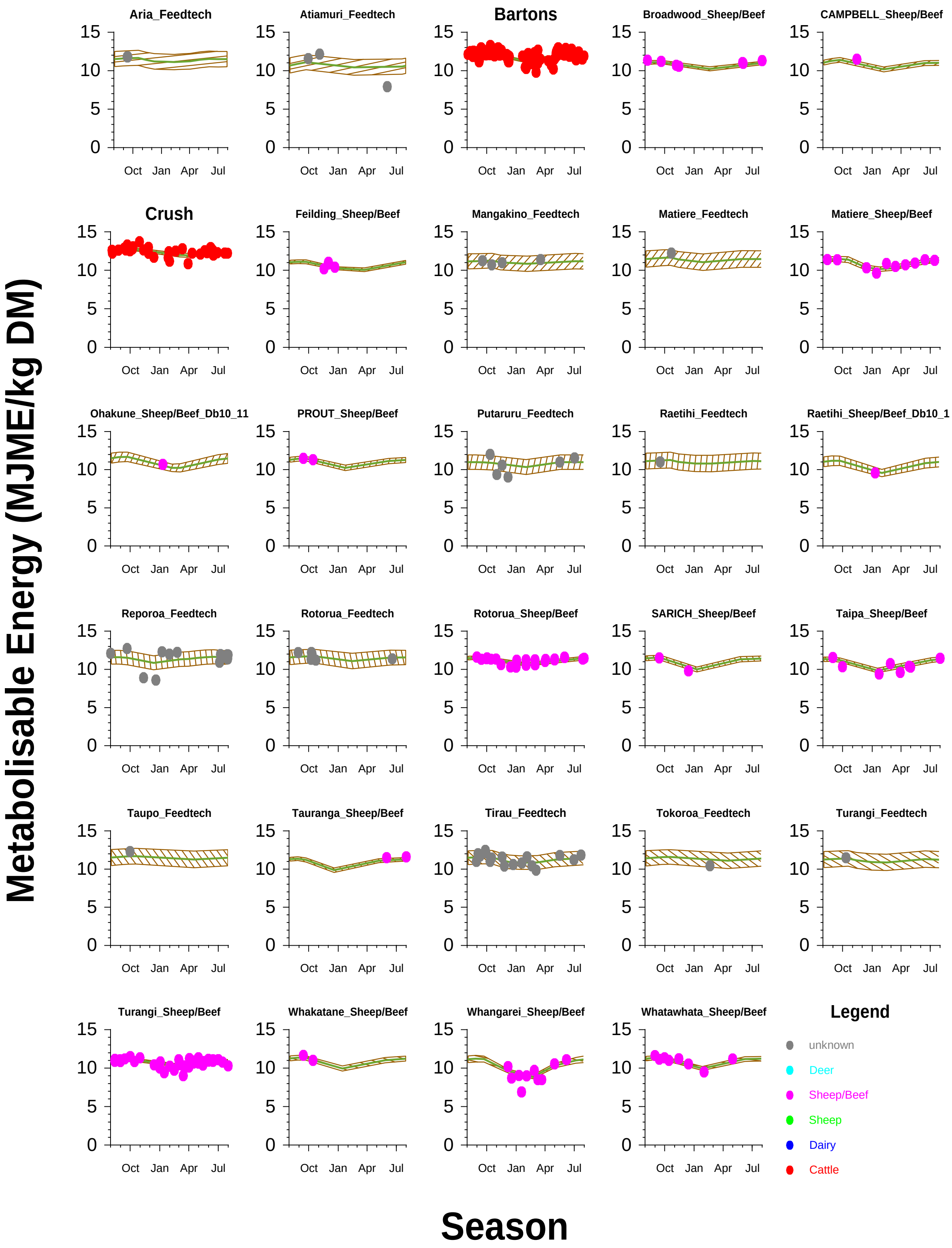


Metabolisable Energy in Bay_of_Plenty
Awakaponga_Sheep/Beef
Awakeri_Sheep/Beef
B.O.P_Dairy_Db_09_10
B.O.P_Sheep/Beef
Bay_Of_Plenty_Dairy_Db_09_10
Edgecumbe_Feedtech
Edgecumbe_Plains_Sheep/Beef
Feilding_Sheep/Beef
Matata_Sheep/Beef
Ruatoki_Feedtech
Tauranga_Sheep/Beef
Te_Puke_Feedtech
Waihi_Feedtech
Waimana_Feedtech
Whakatane_Feedtech
Whakatane_Sheep/Beef
15
10
5
0
Oct
Jan
Apr
Jul
Legend
unknown
Deer
Sheep/Beef
Sheep
Dairy
Cattle
Metabolisable Energy (MJME/kg DM)
Season

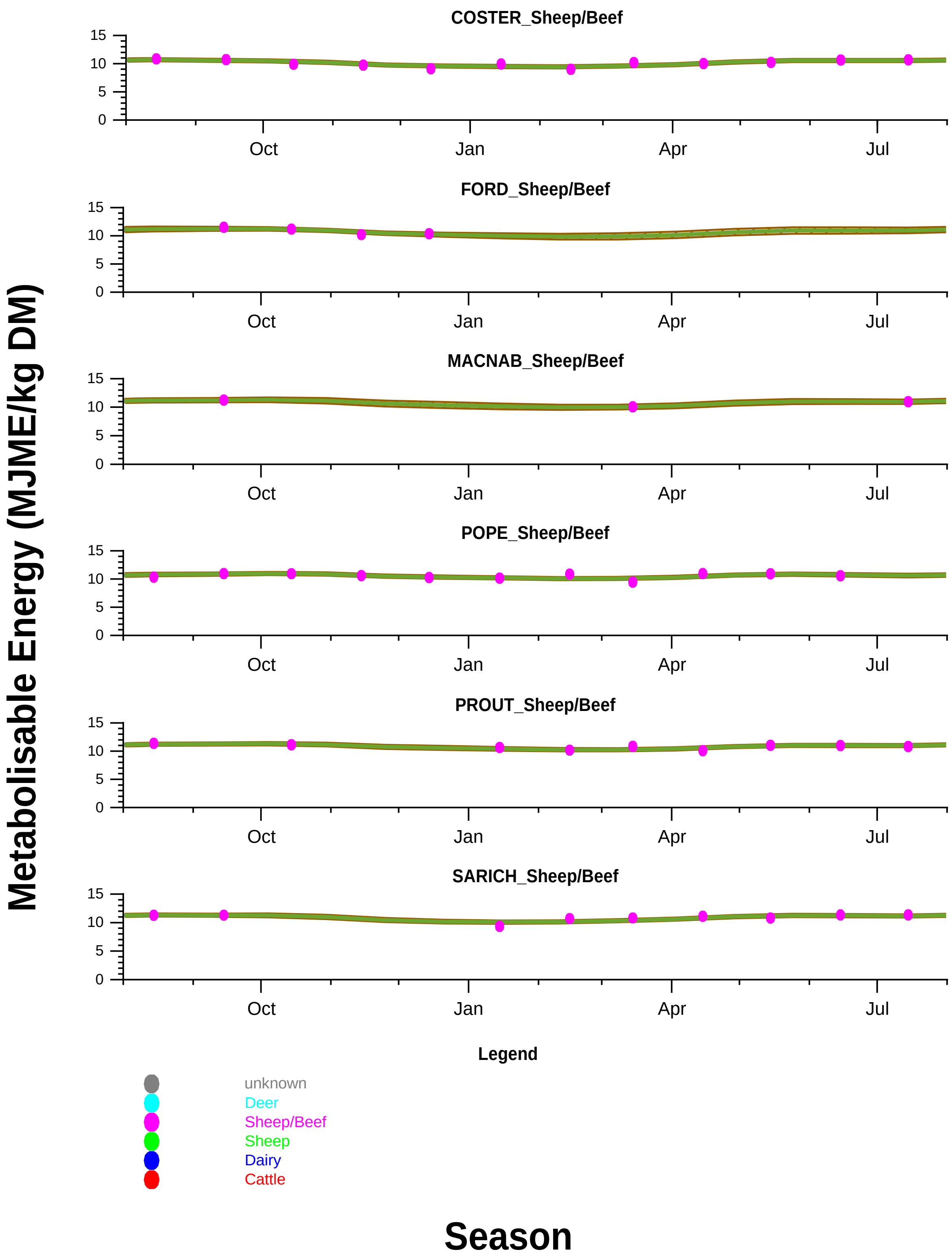
Metabolisable Energy in Waikato



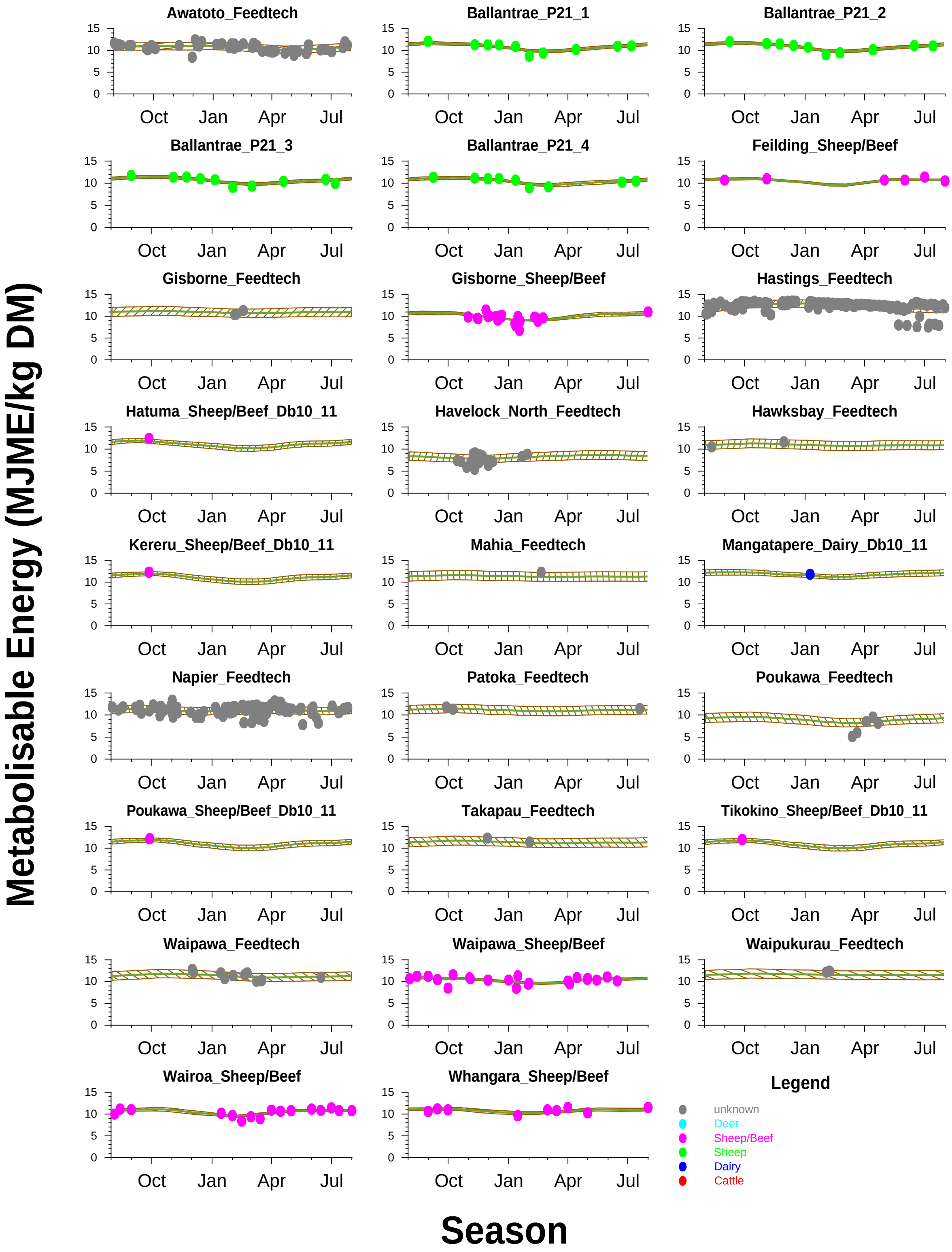
Metabolisable Energy in Volcanic_Plateau



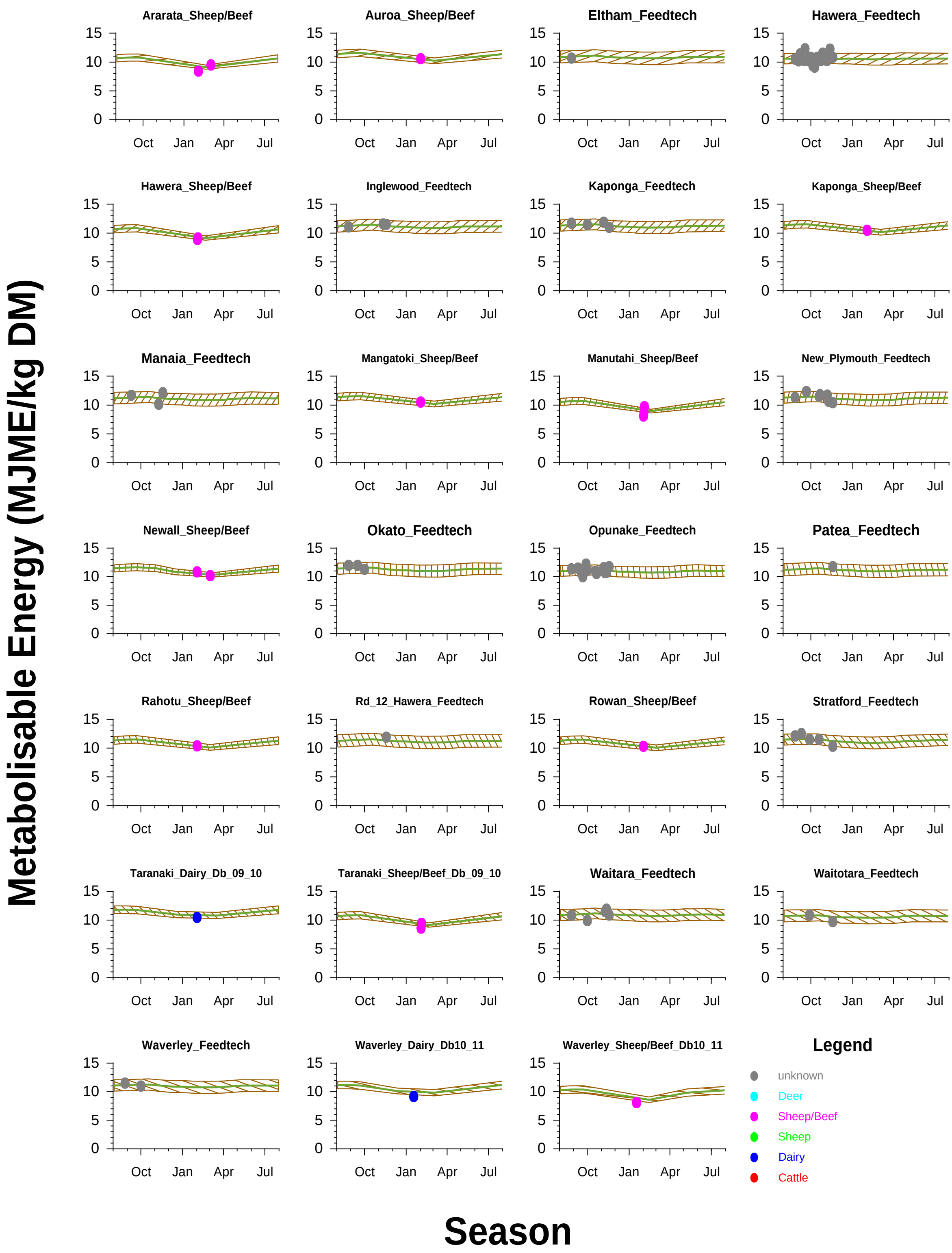
Metabolisable Energy in Central_North_Island



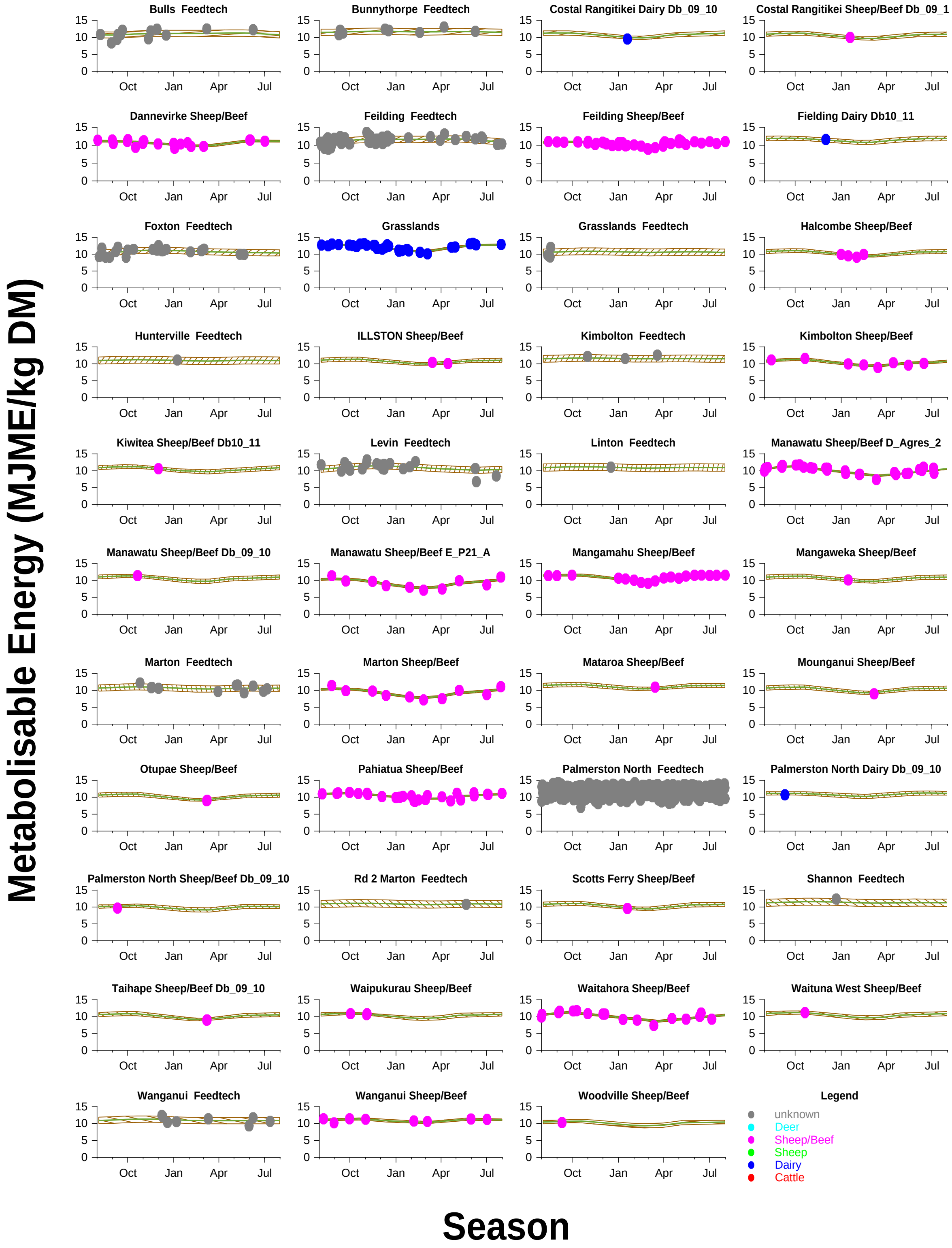
Metabolisable Energy in Hawkes_Bay



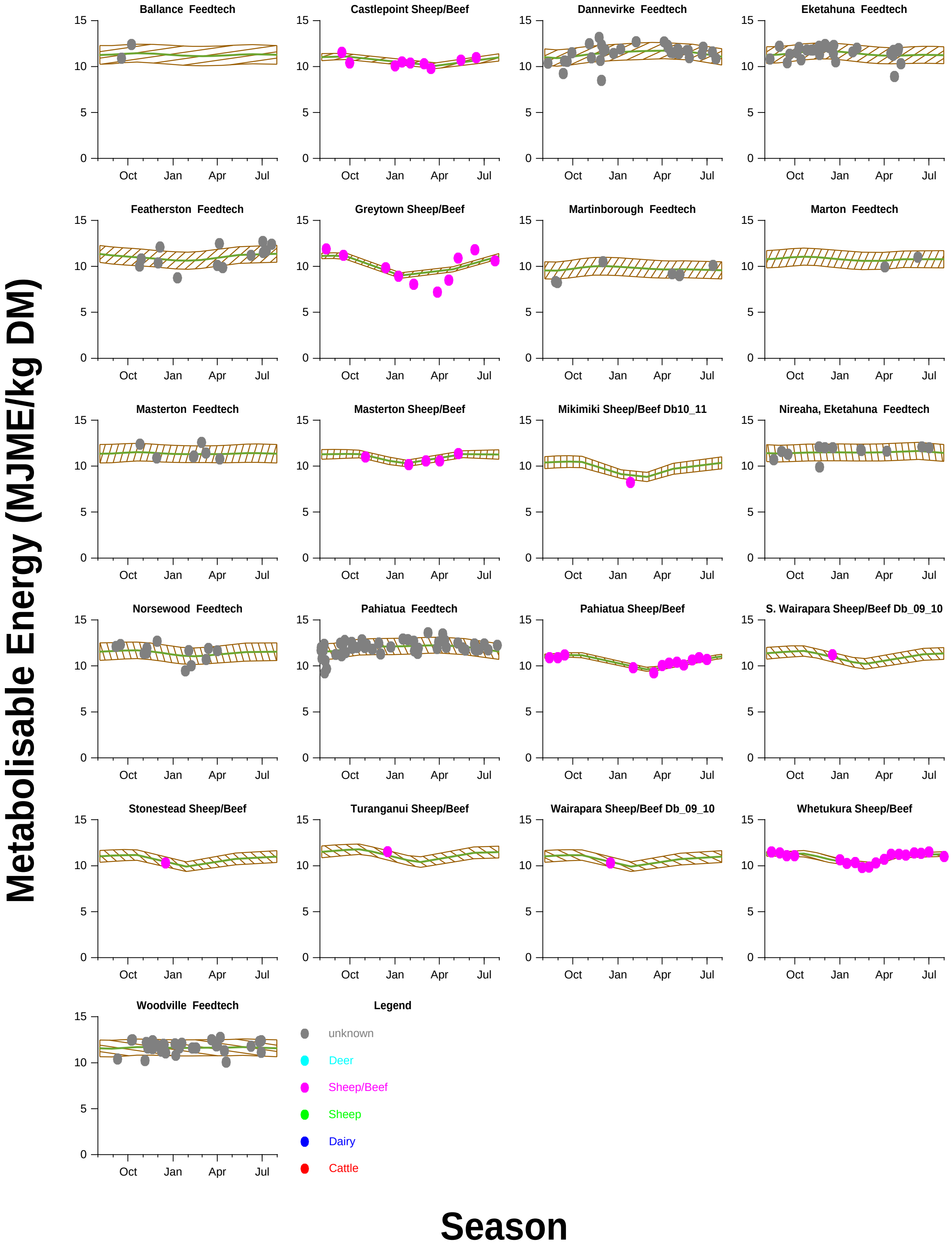
Metabolisable Energy in Taranaki



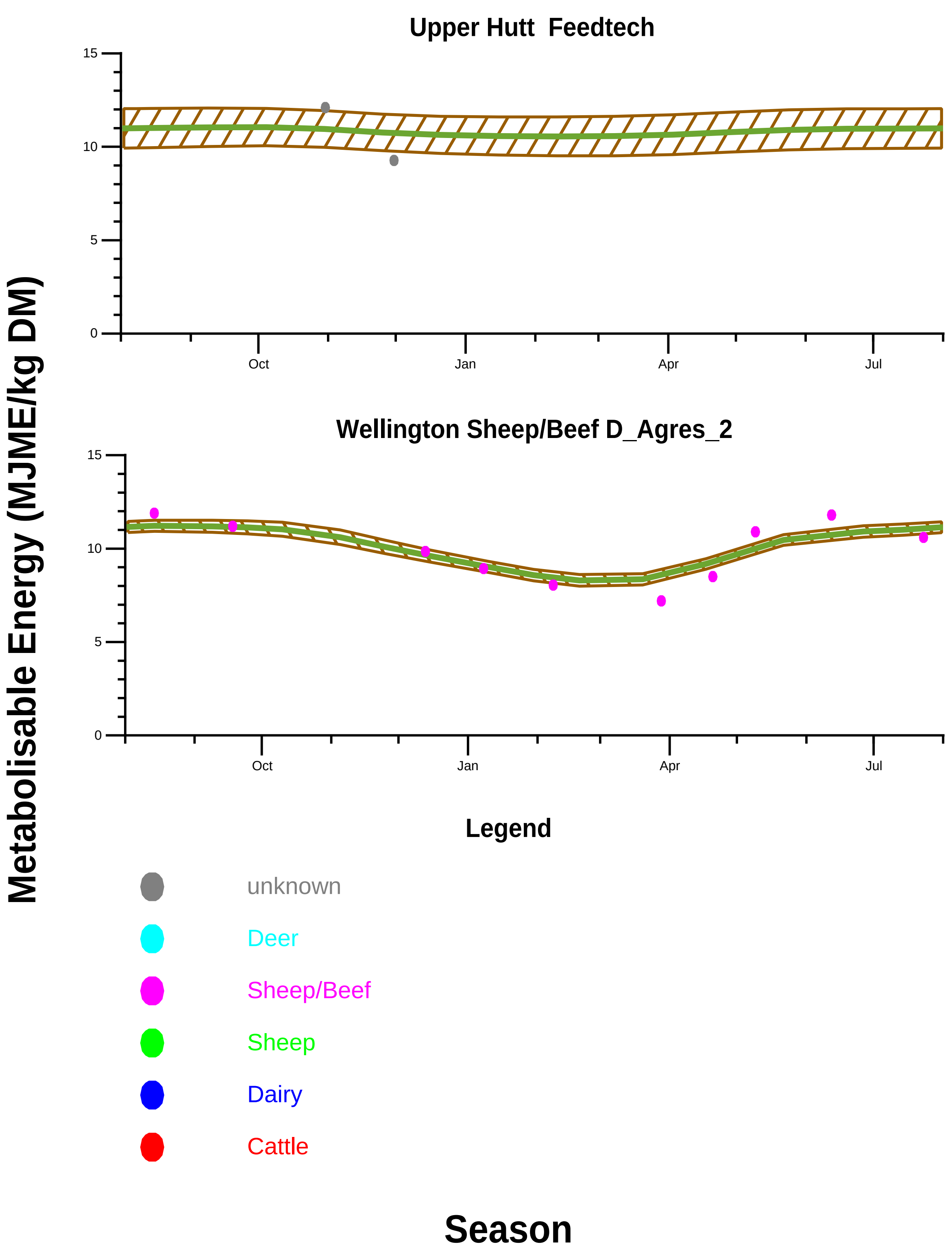
Metabolisable Energy in Manawatu/Wanganui



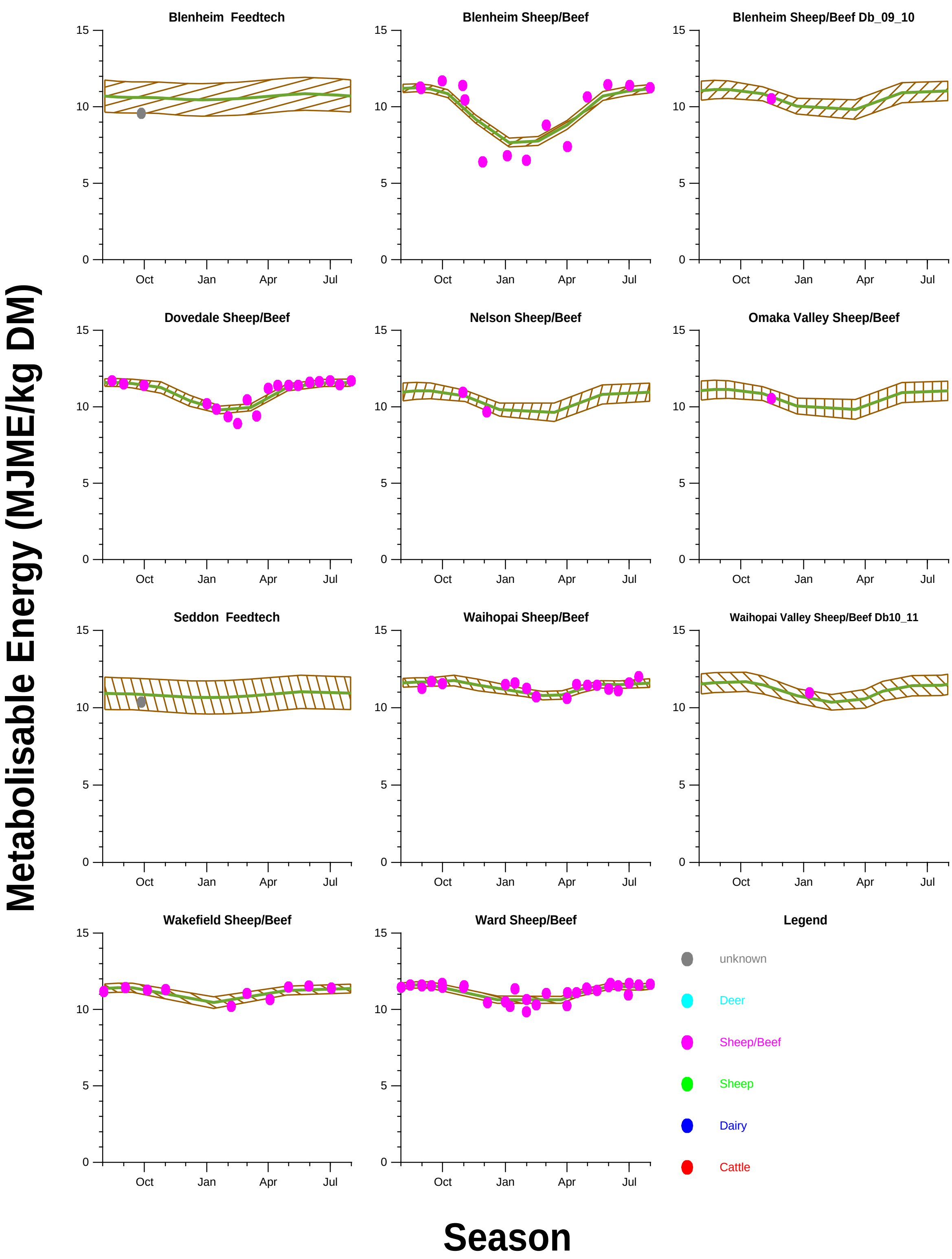
Metabolisable Energy in Wairarapa



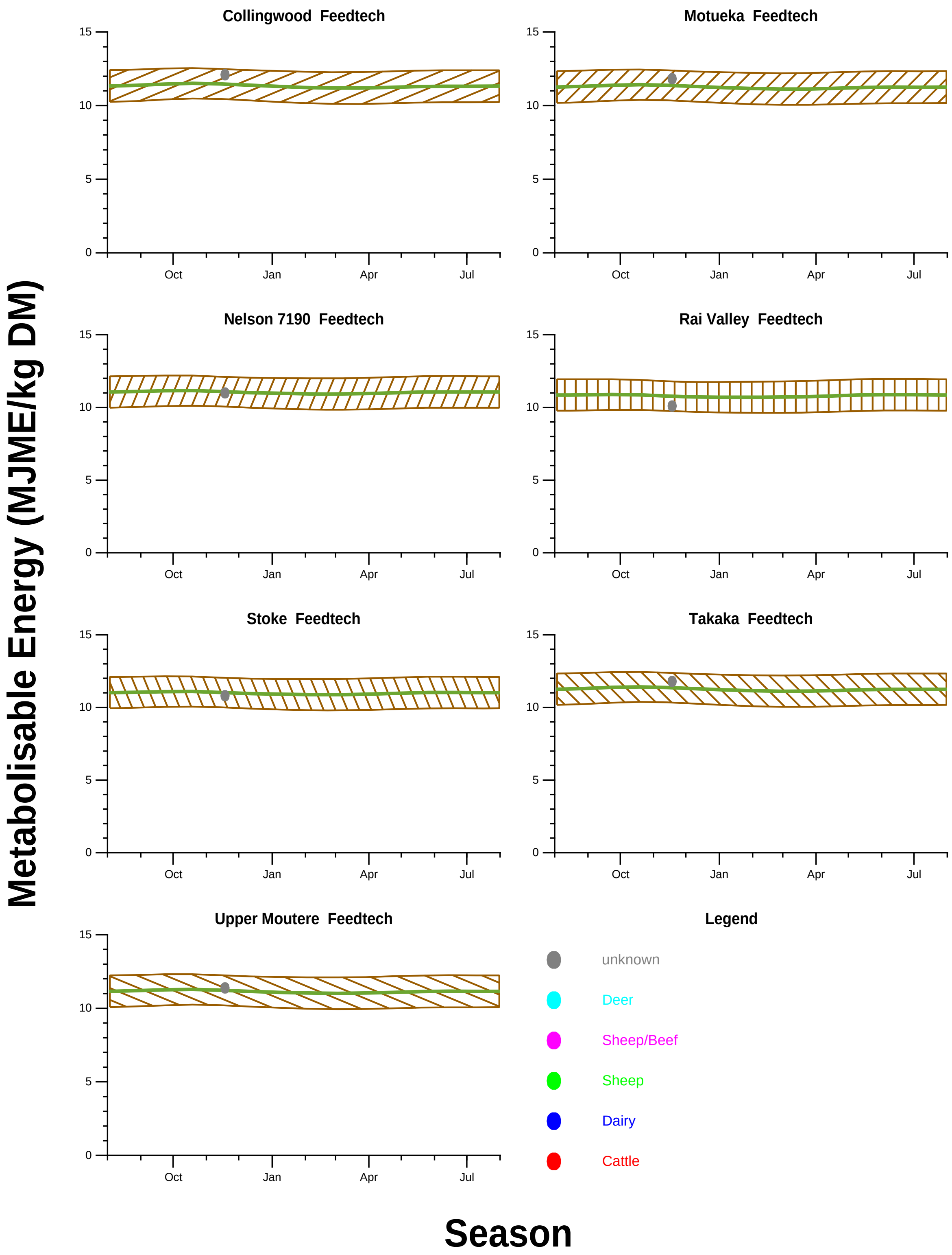
Metabolisable Energy in Wellington



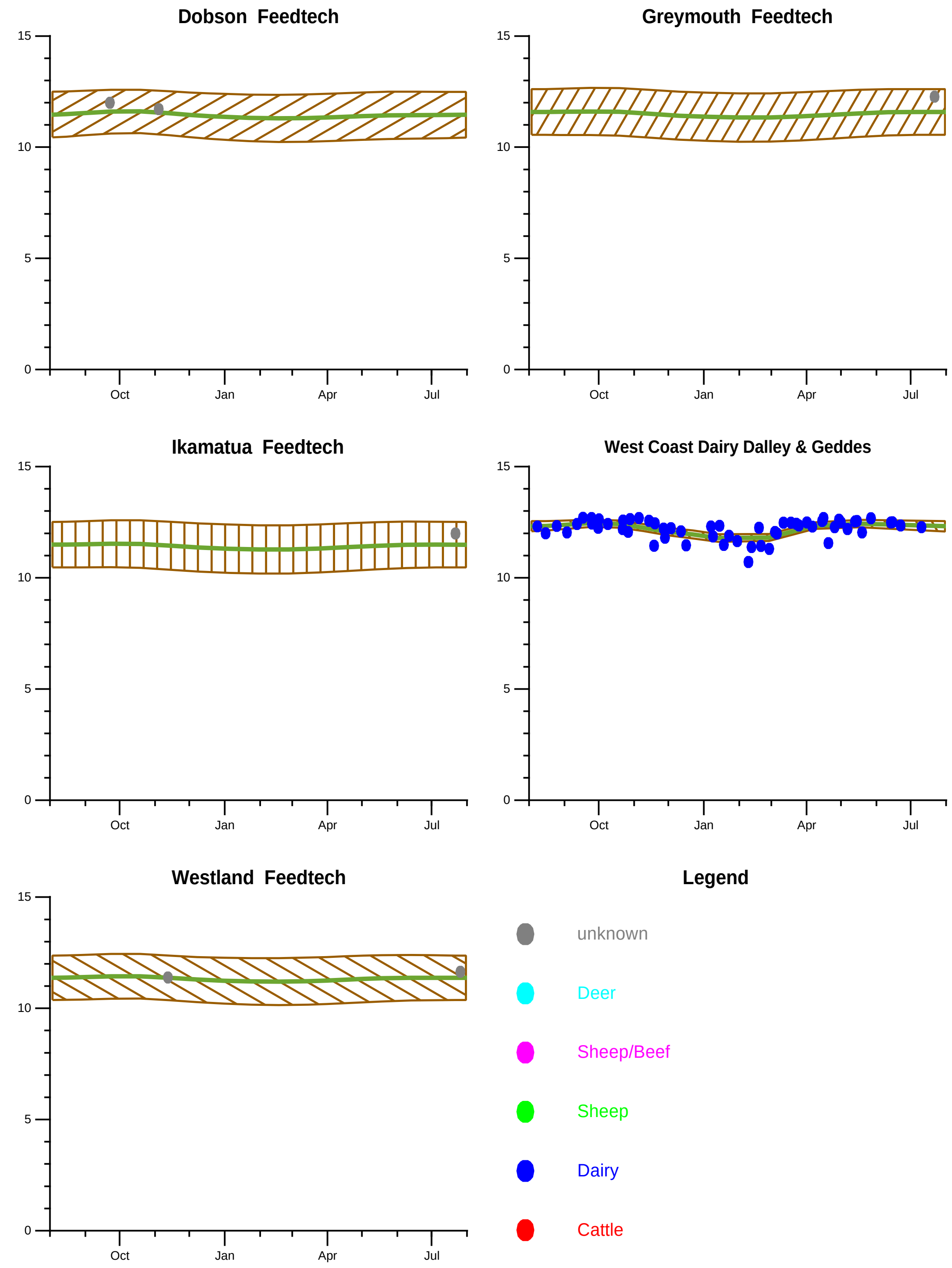
Metabolisable Energy in Marlborough



Metabolisable Energy in Tasman



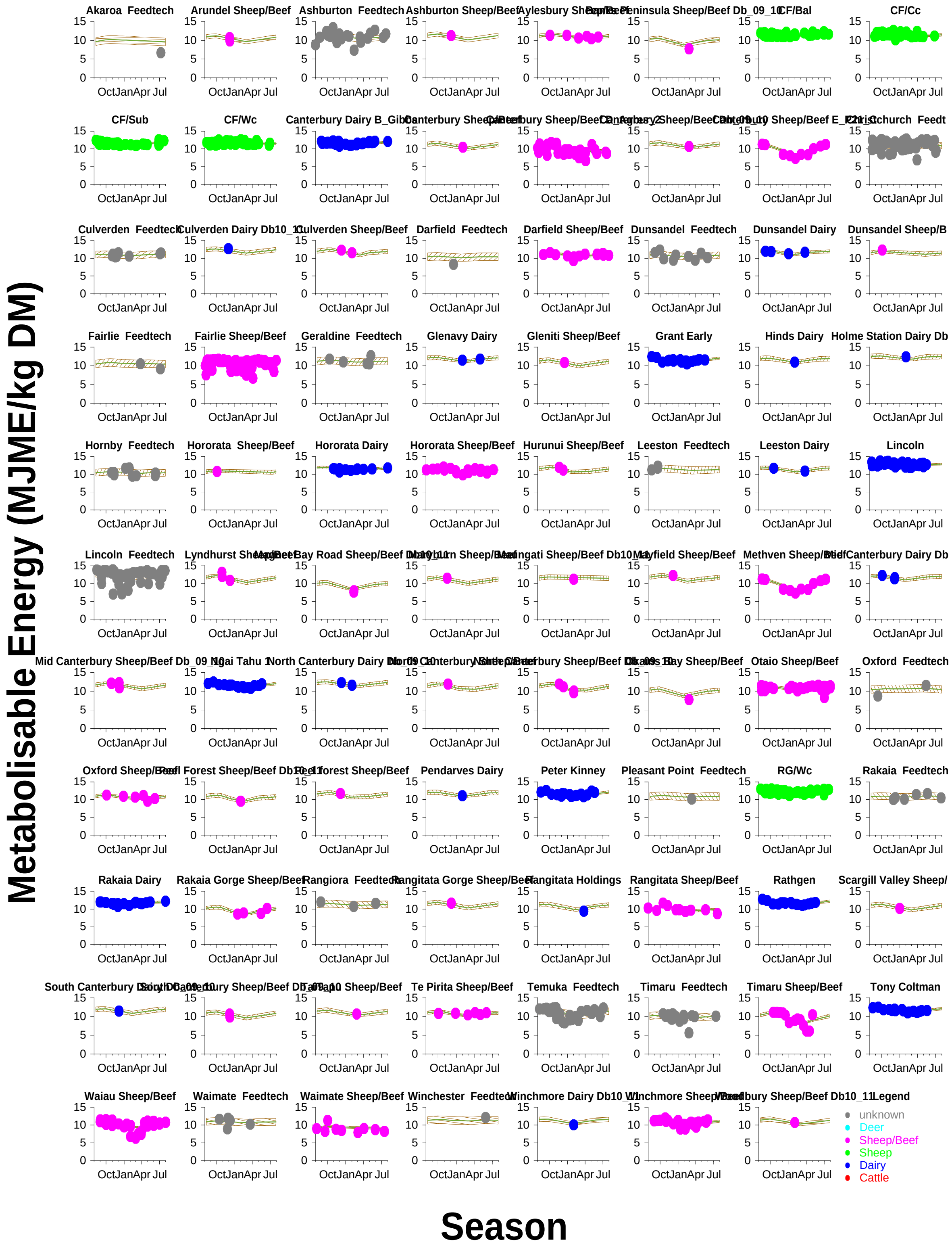
Metabolisable Energy in West Coast



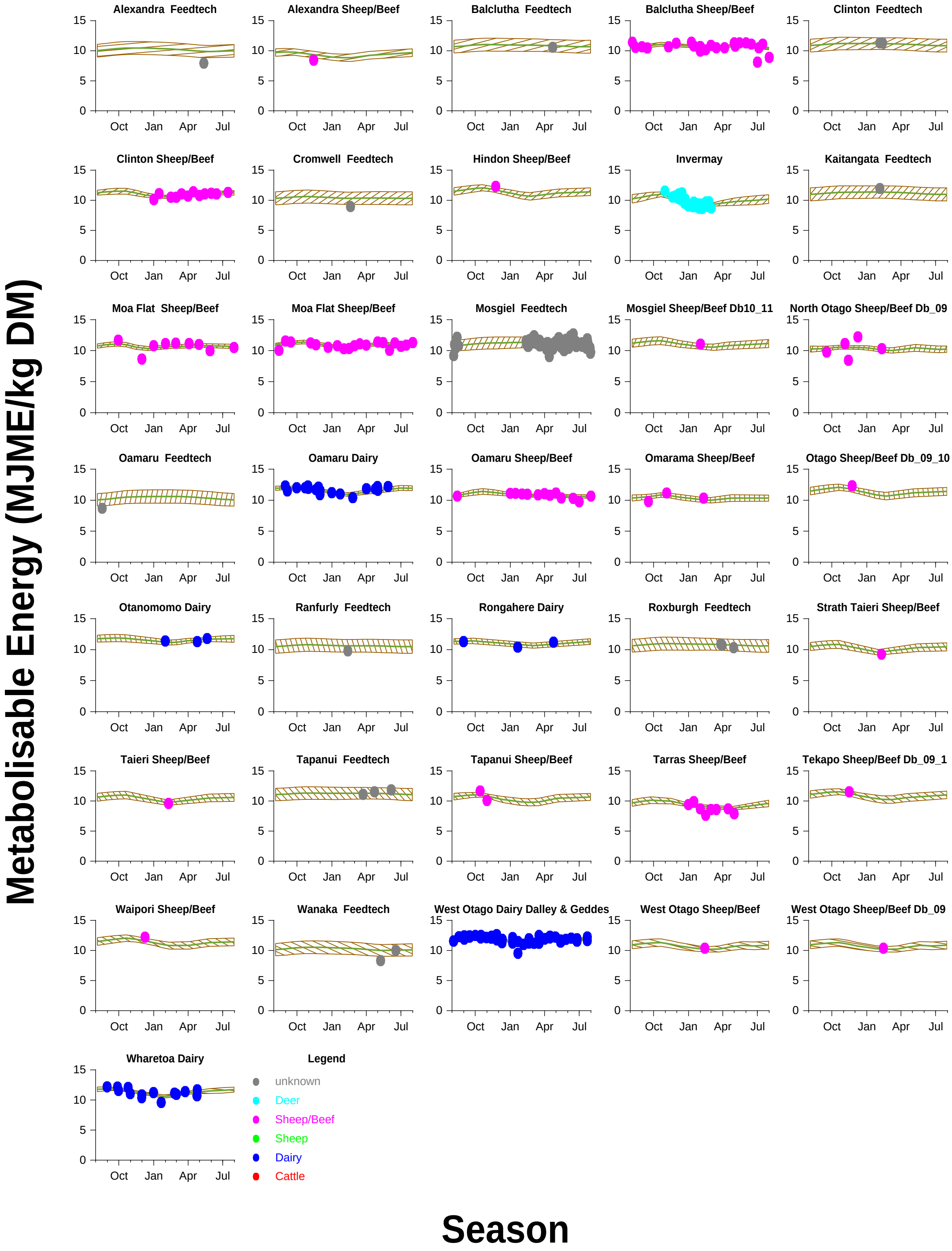
Metabolisable Energy (MJME/kg DM)

Season

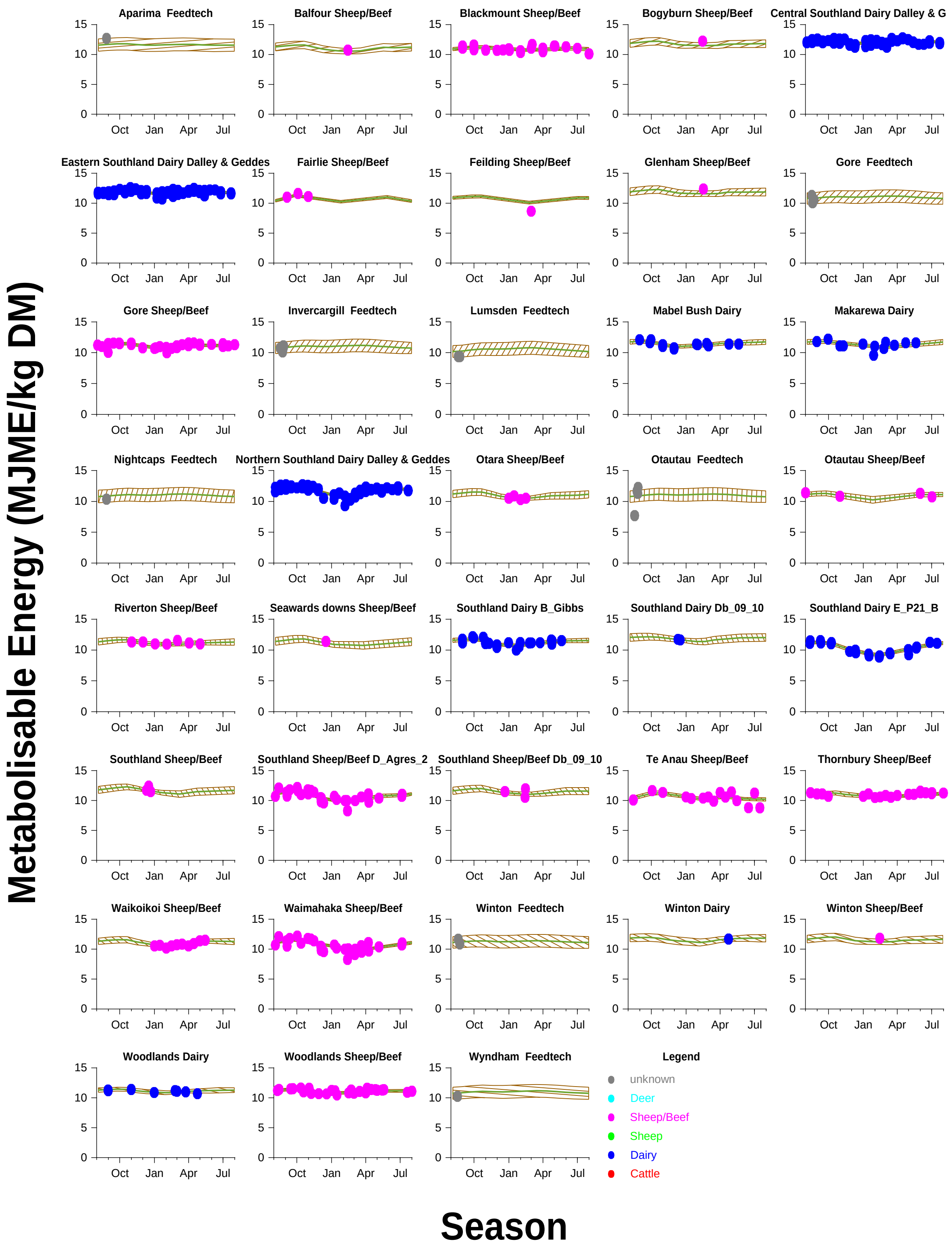
Metabolisable Energy in Canterbury



Metabolisable Energy in Otago



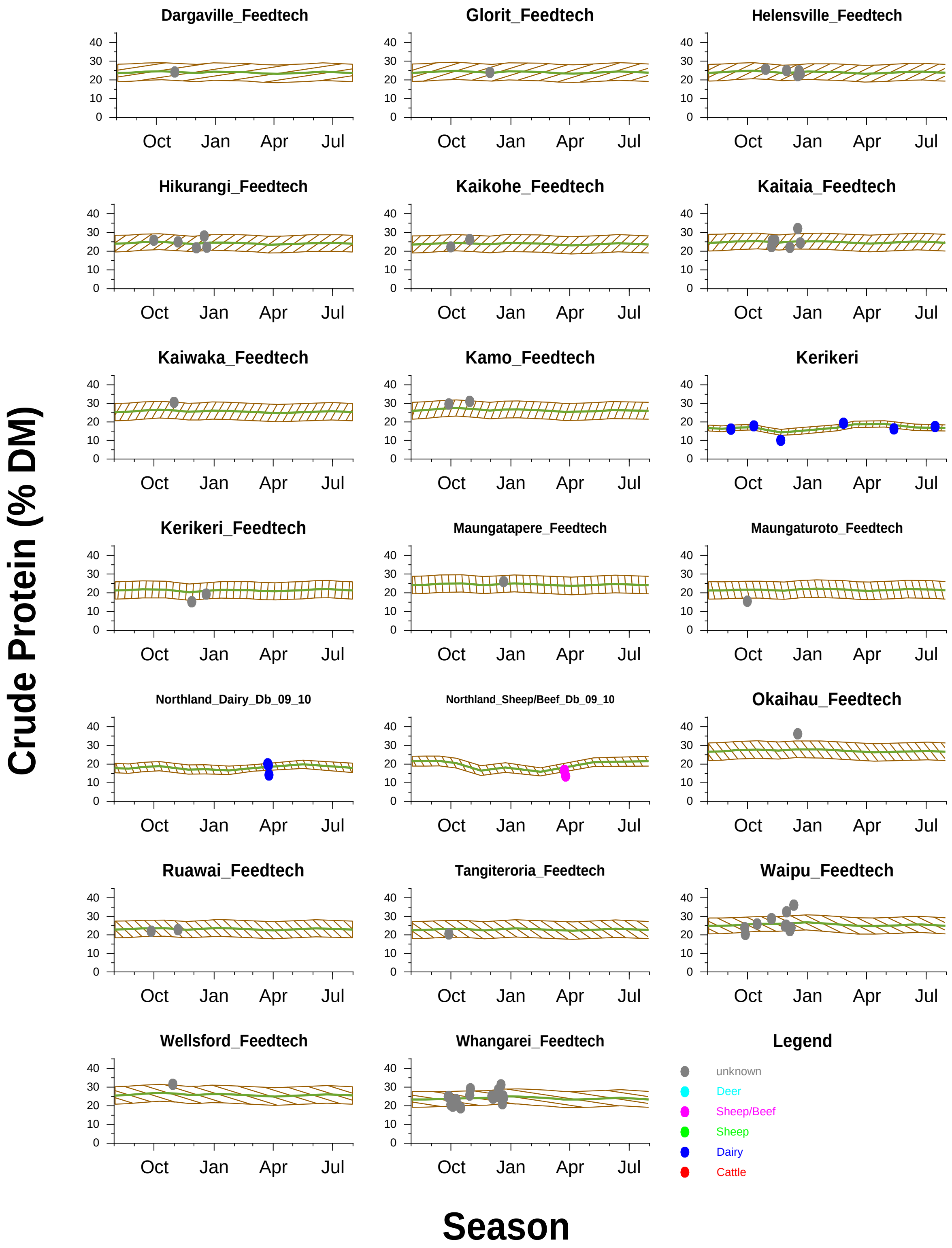
Metabolisable Energy in Southland



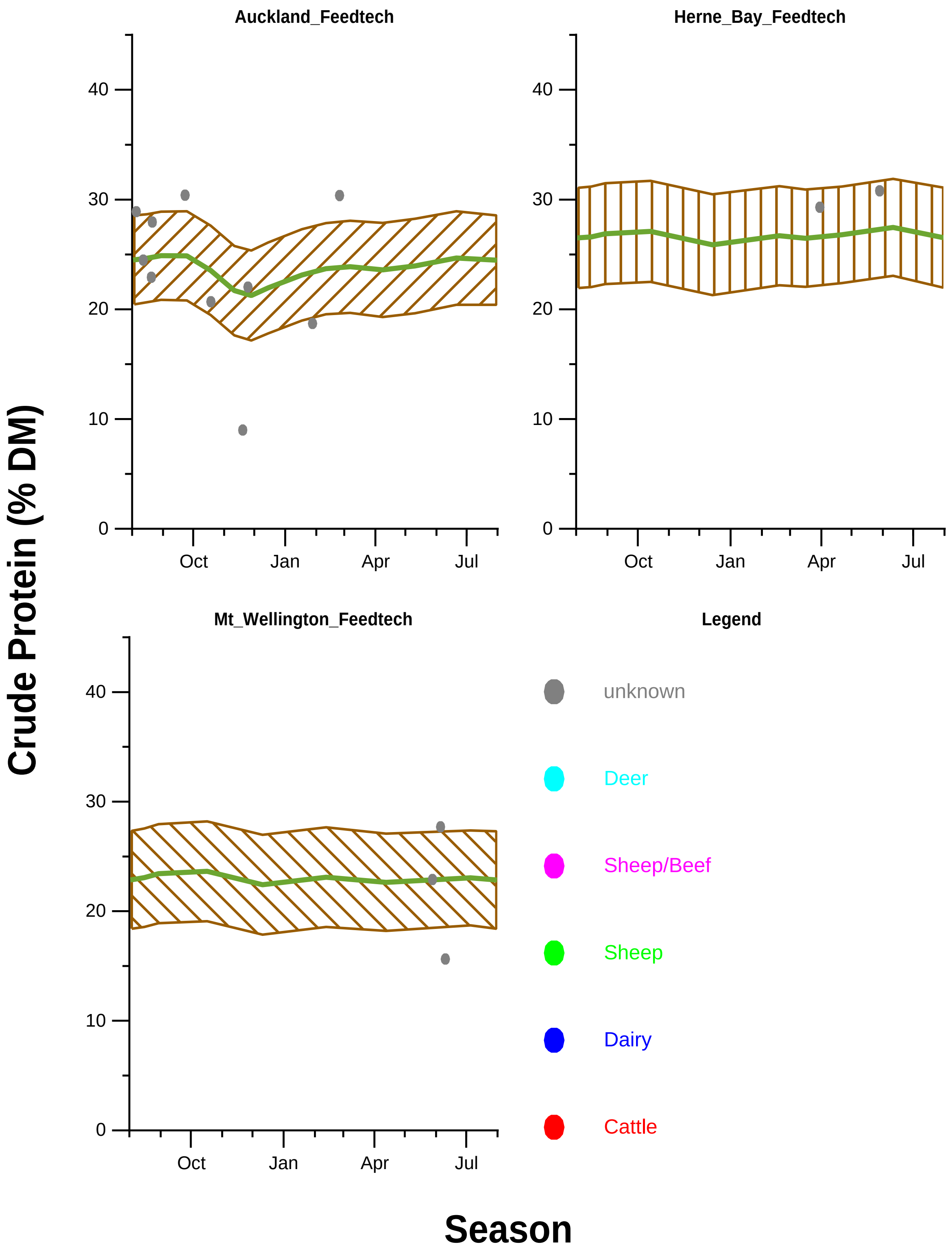
21 Appendix 3. Crude protein by site

Detailed plots of sites within each region given below. The points denote means of the observations on the same site, stock type, data source and same day. The coloured lines give the estimated values of Crude Protein (%DM) for the different sites. The coloured bands are the 95% Least Significant Intervals for changes in season. Two values at different dates in the season are not significantly different at the 5% level if it is possible to draw a horizontal line entirely within the band between the two points.

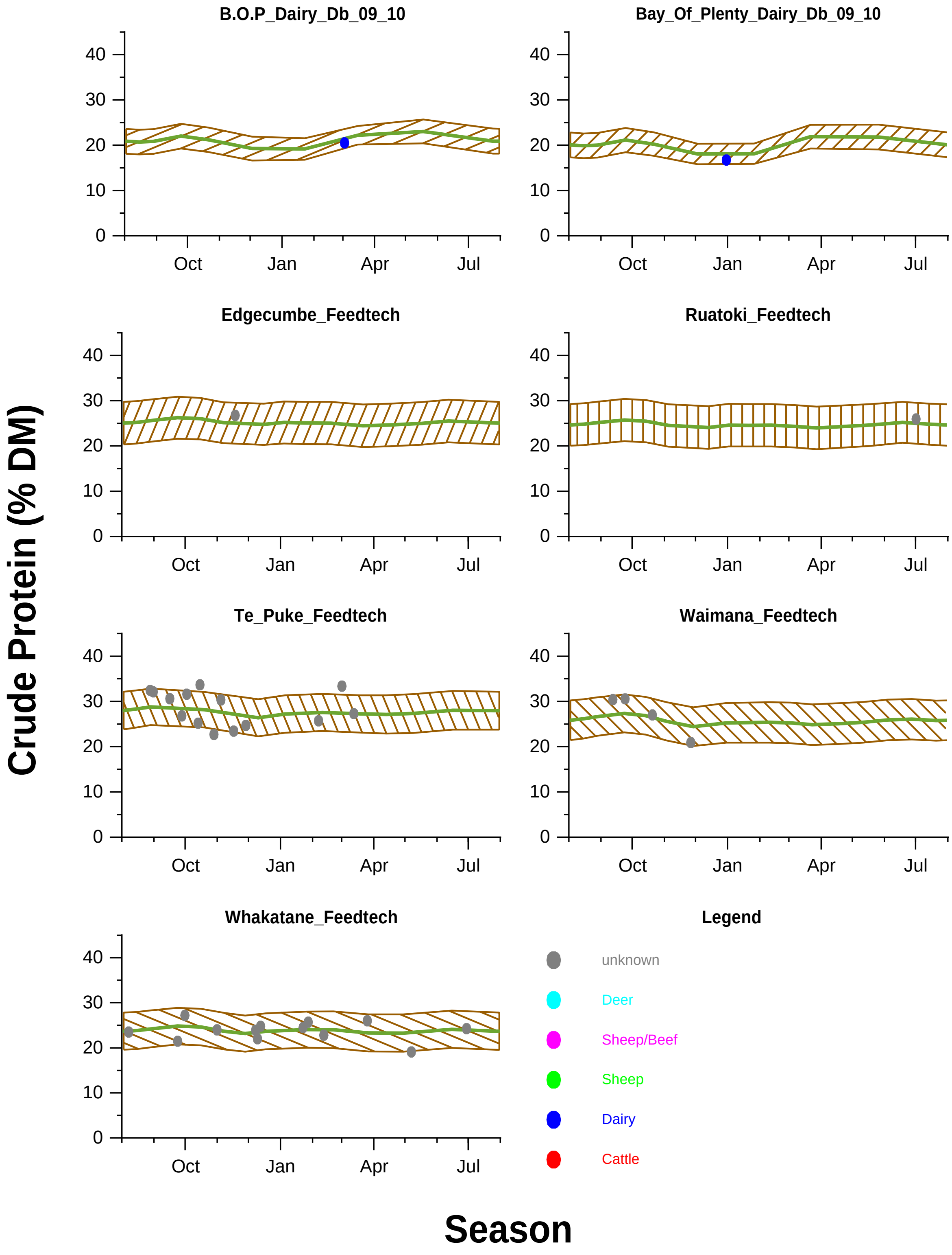
Crude Protein in Northland



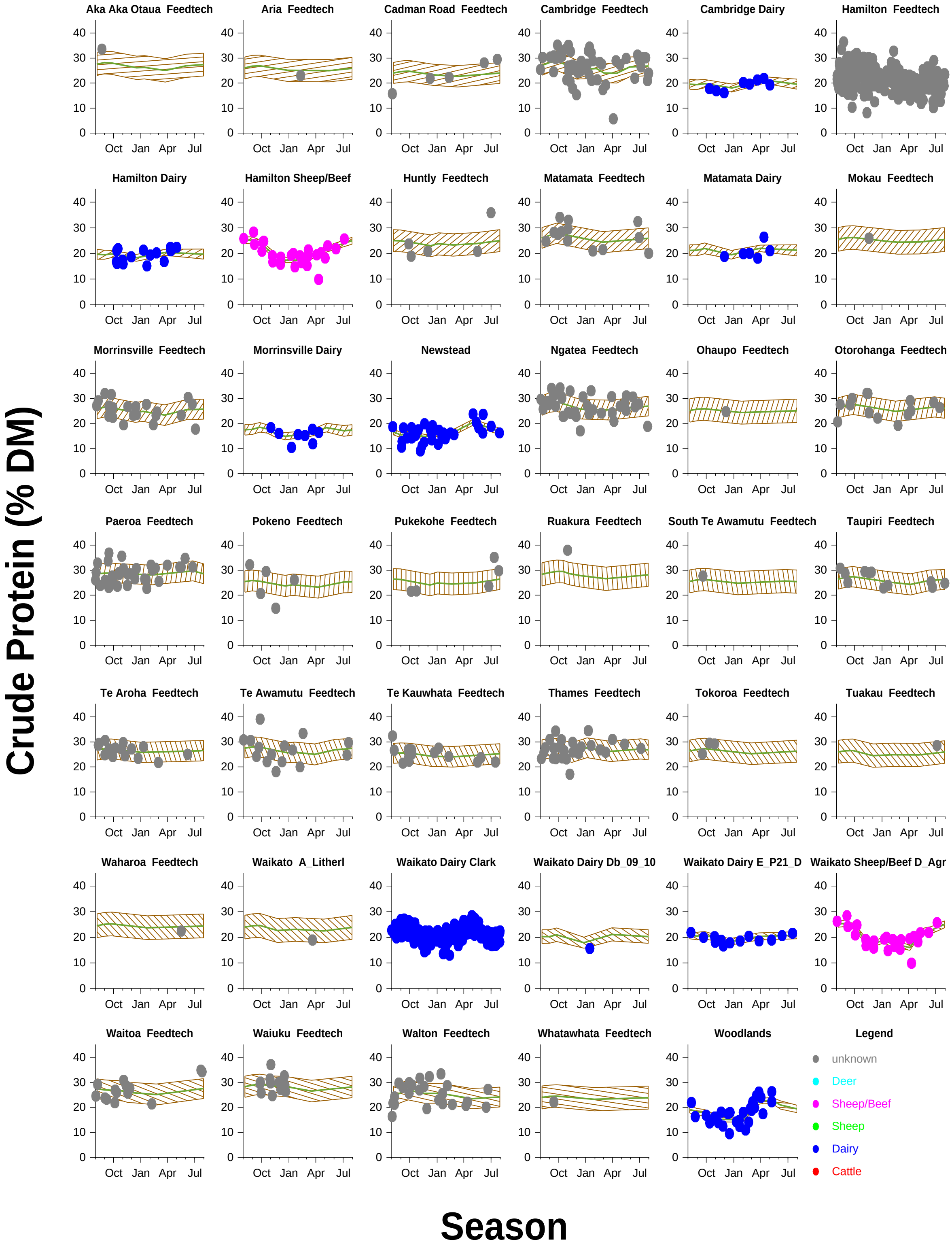
Crude Protein in Auckland



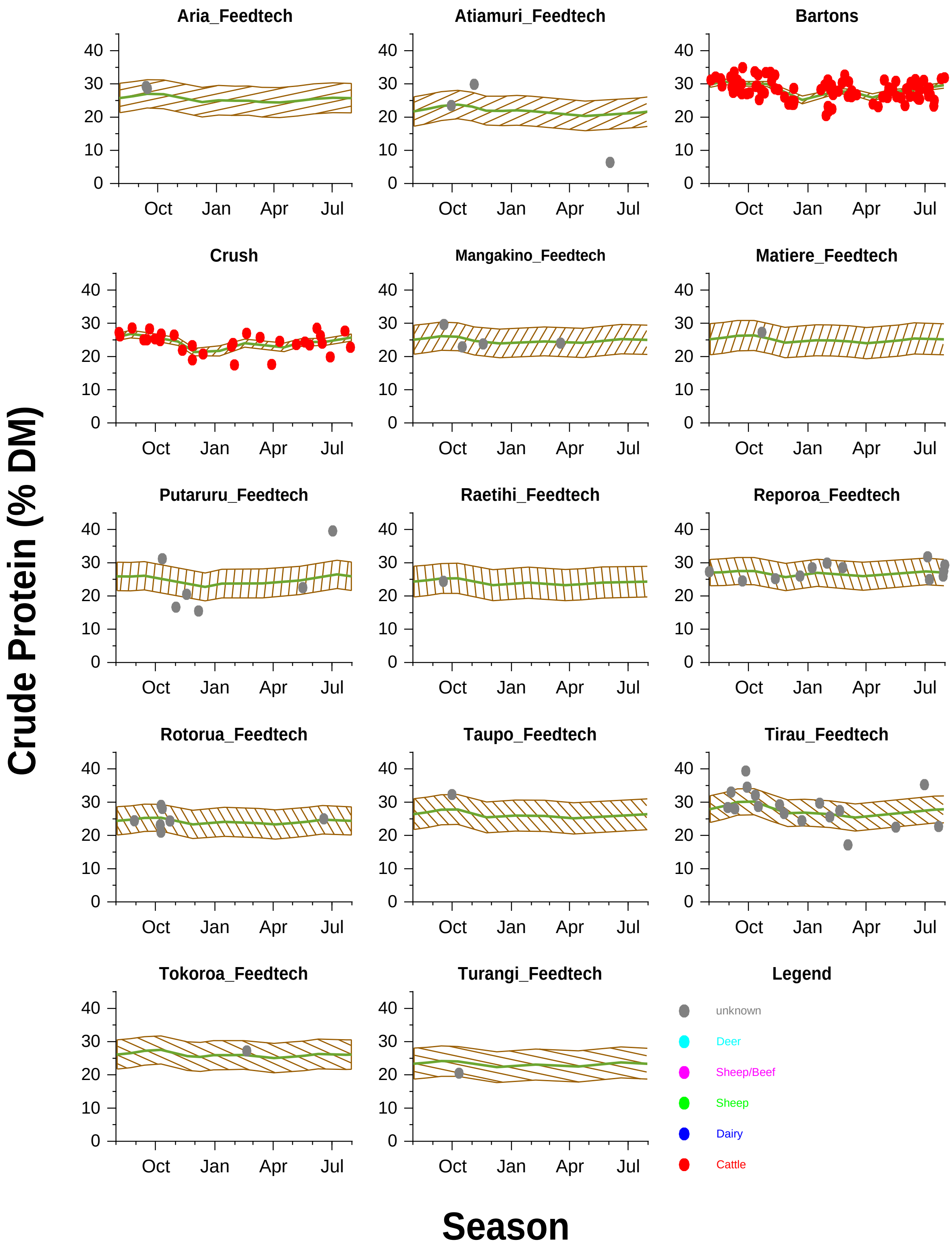
Crude Protein in Bay_of_Plenty



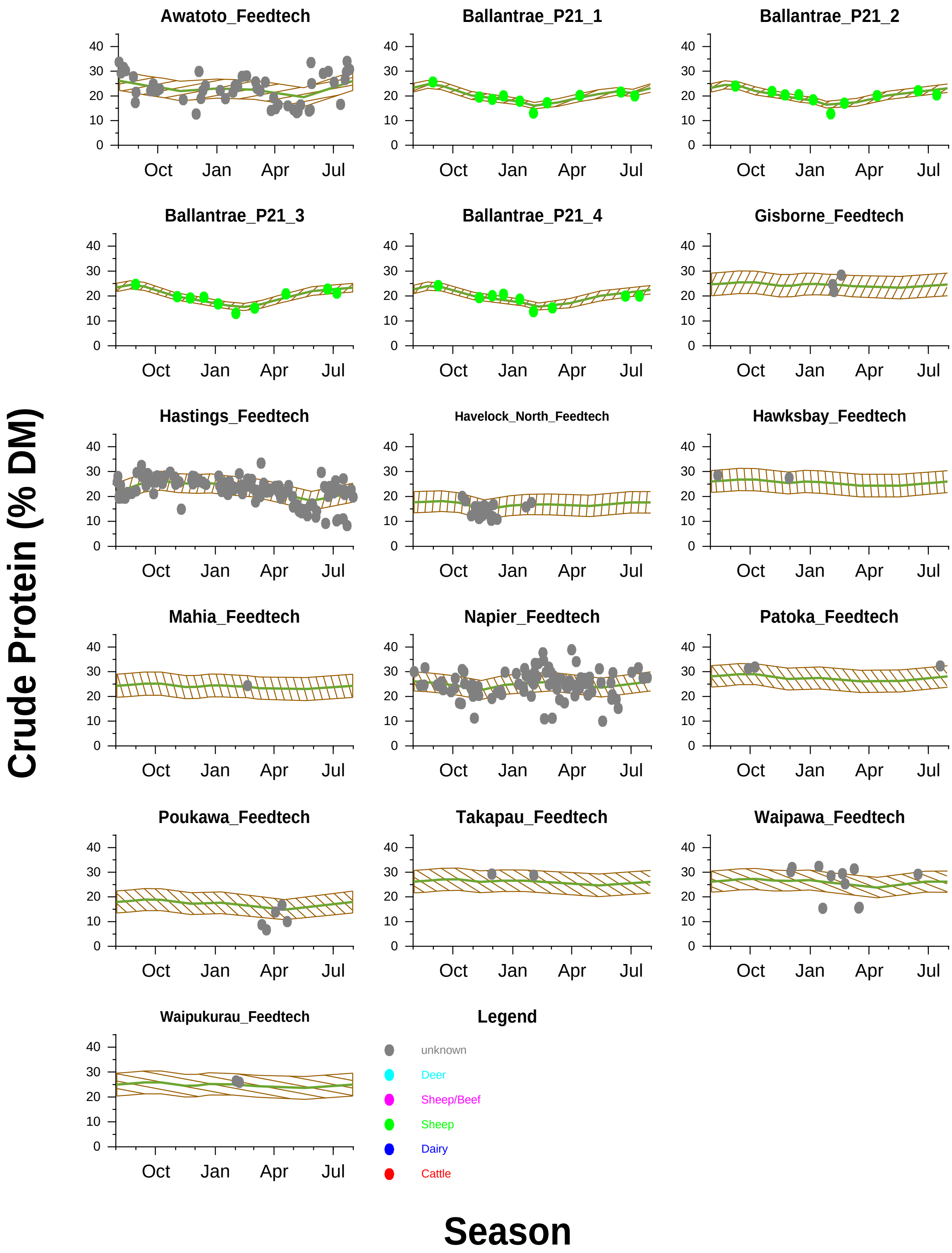
Crude Protein in Waikato



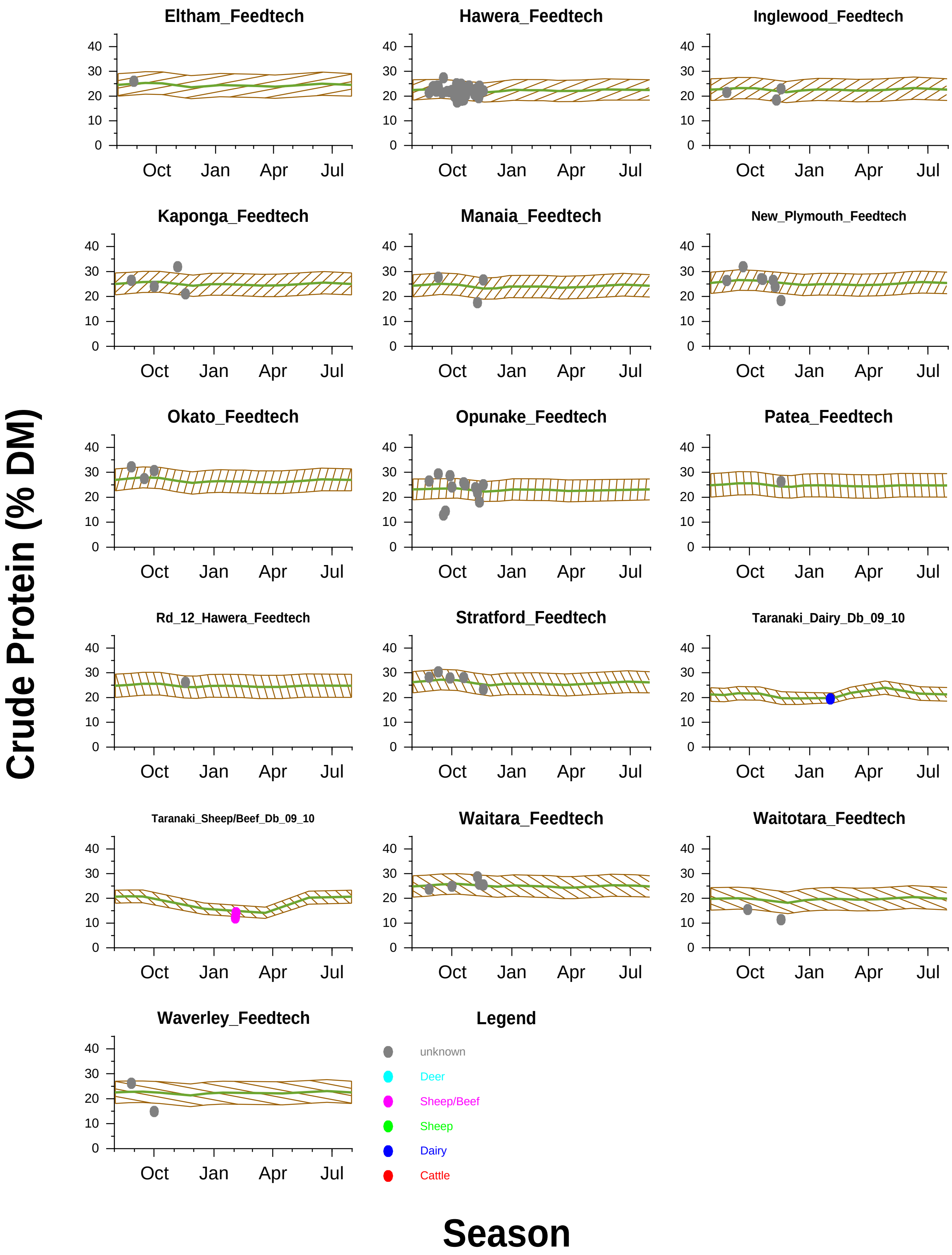
Crude Protein in Volcanic_Plateau



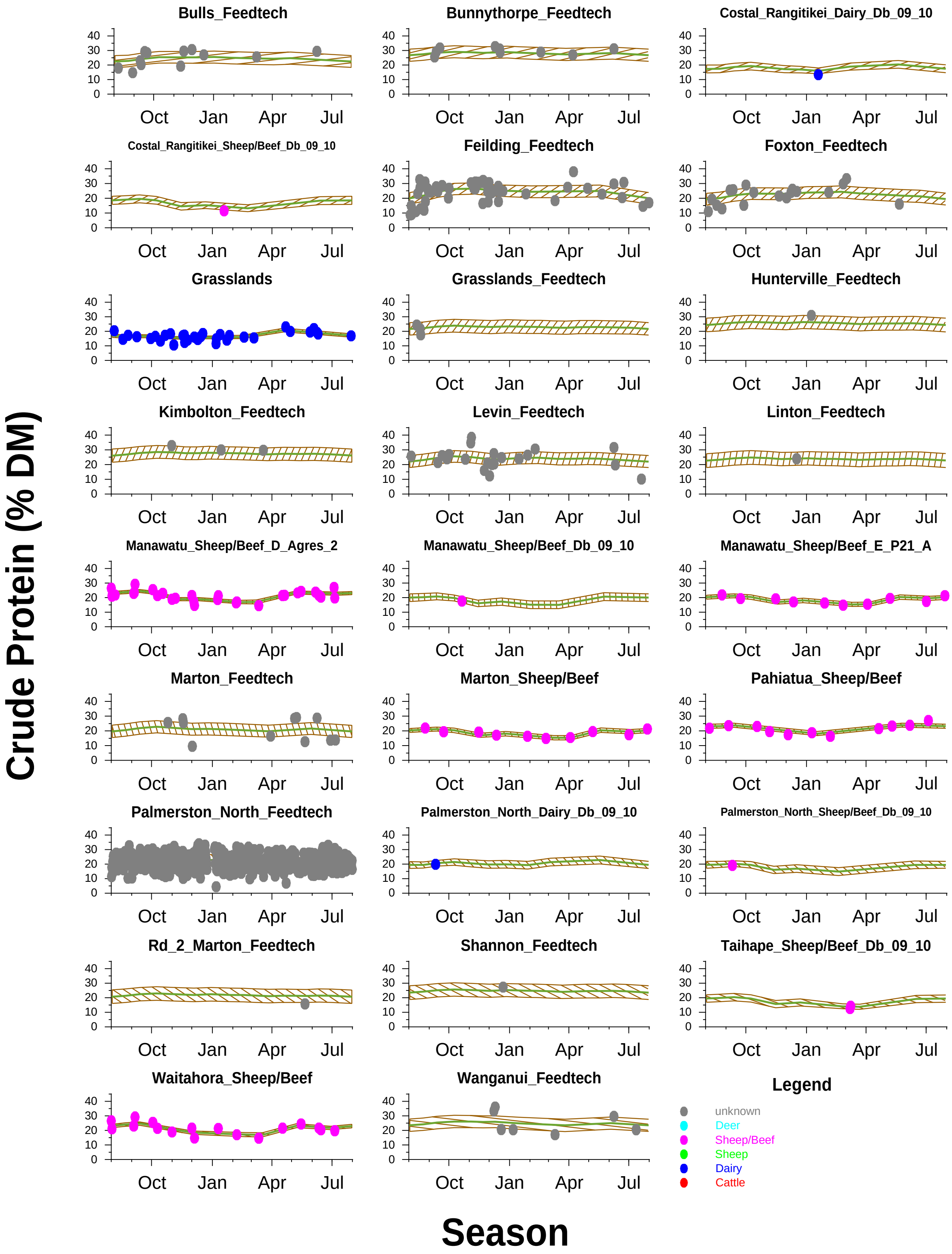
Crude Protein in Hawkes_Bay



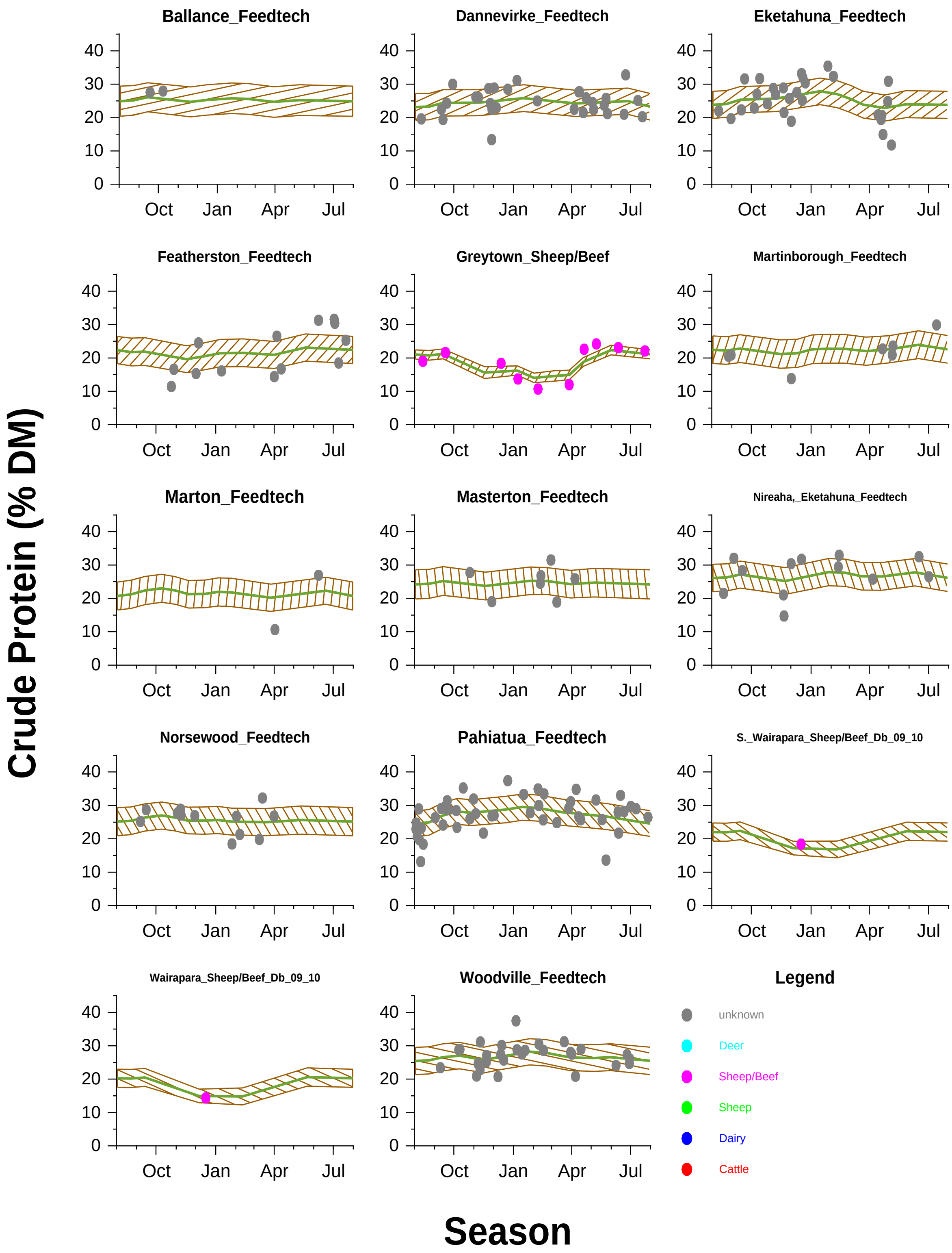
Crude Protein in Taranaki



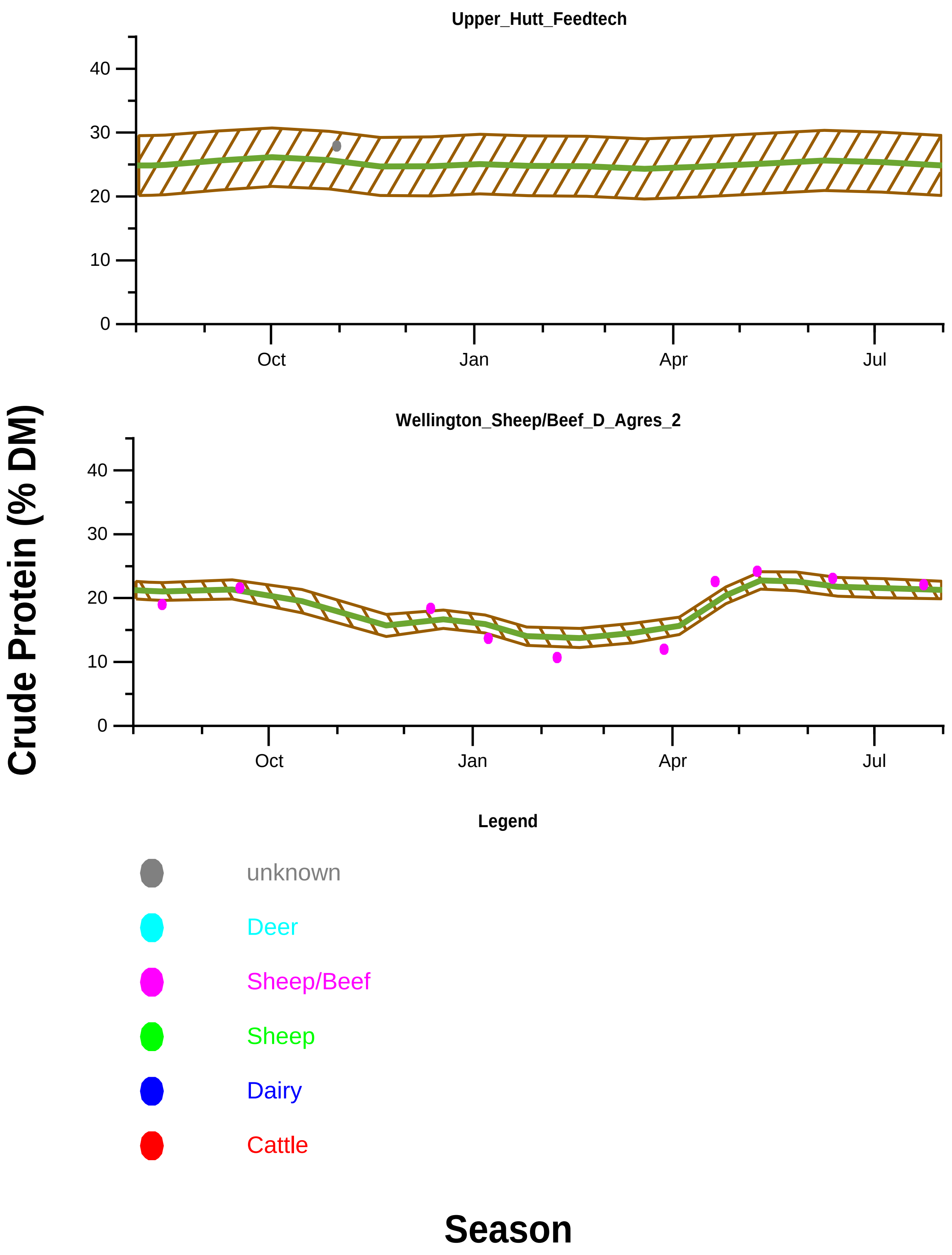
Crude Protein in Manawatu/Wanganui



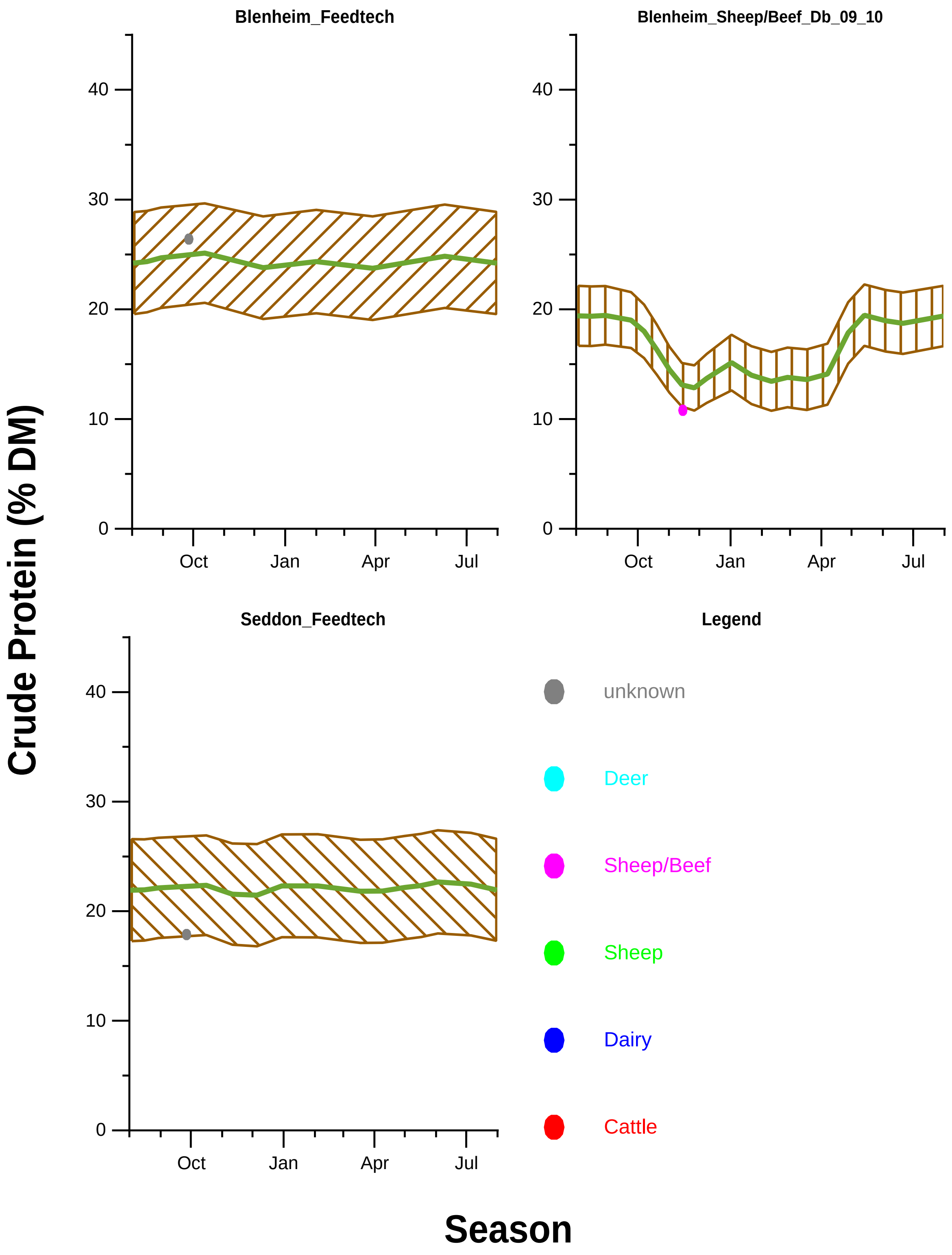
Crude Protein in Wairarapa



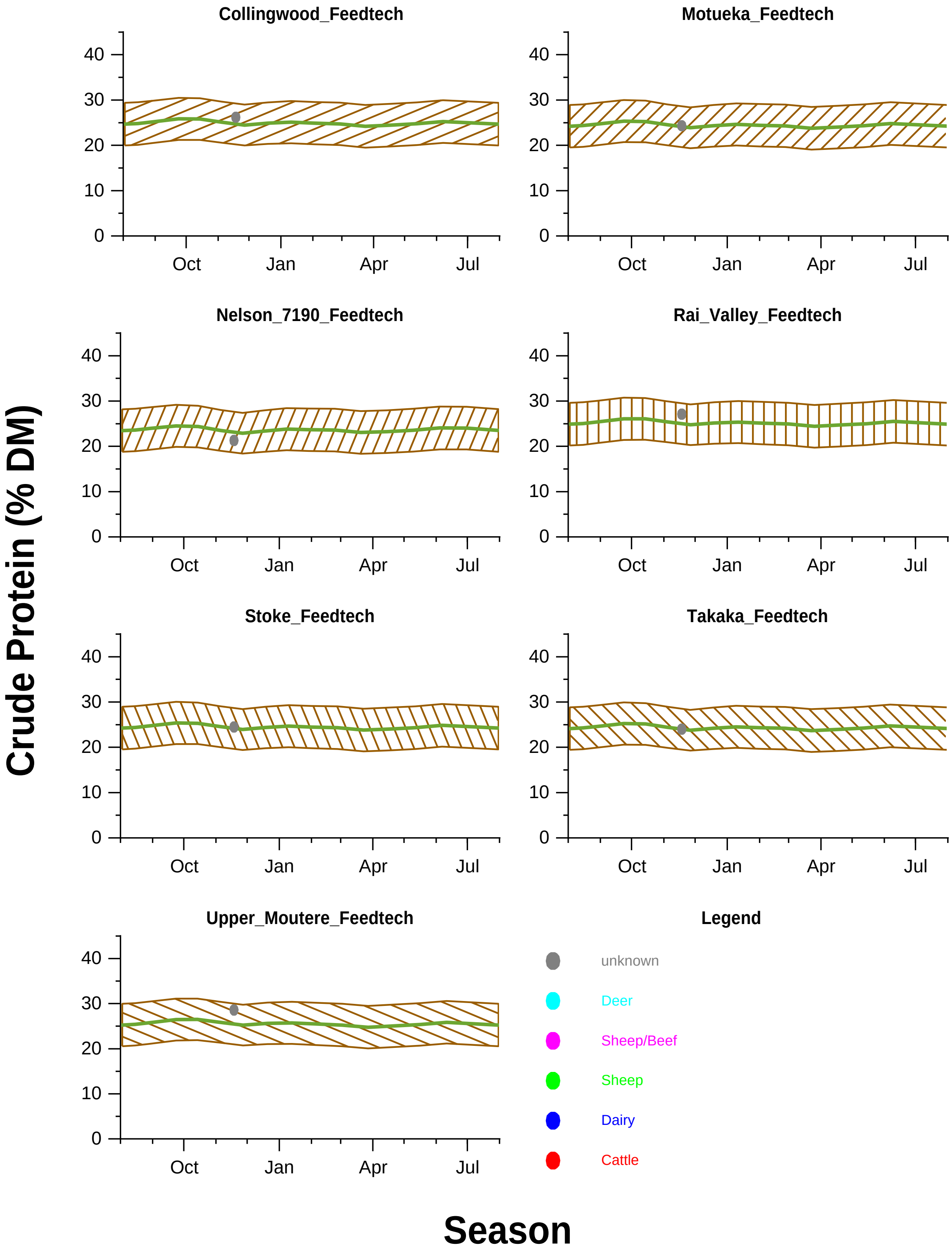
Crude Protein in Wellington



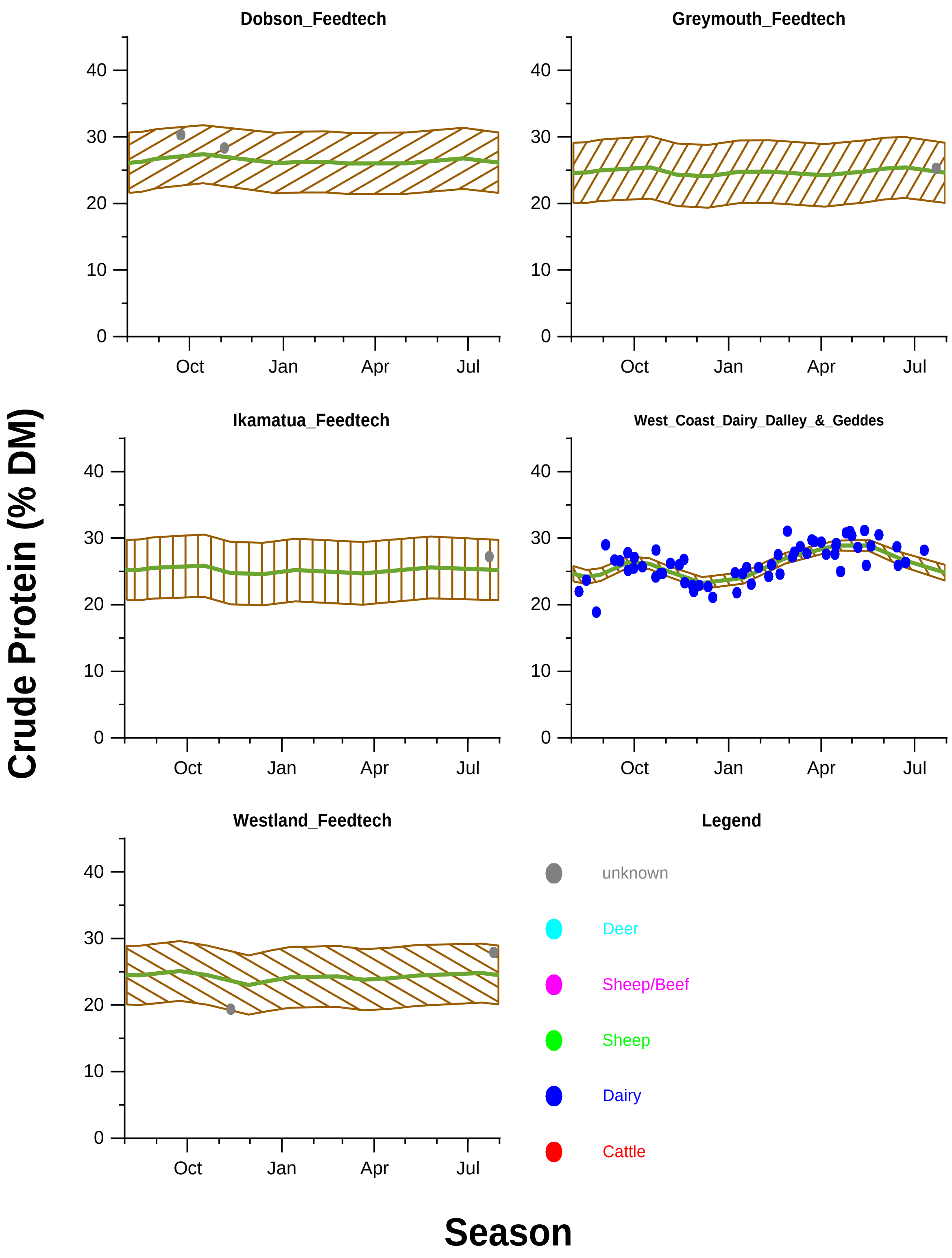
Crude Protein in Marlborough



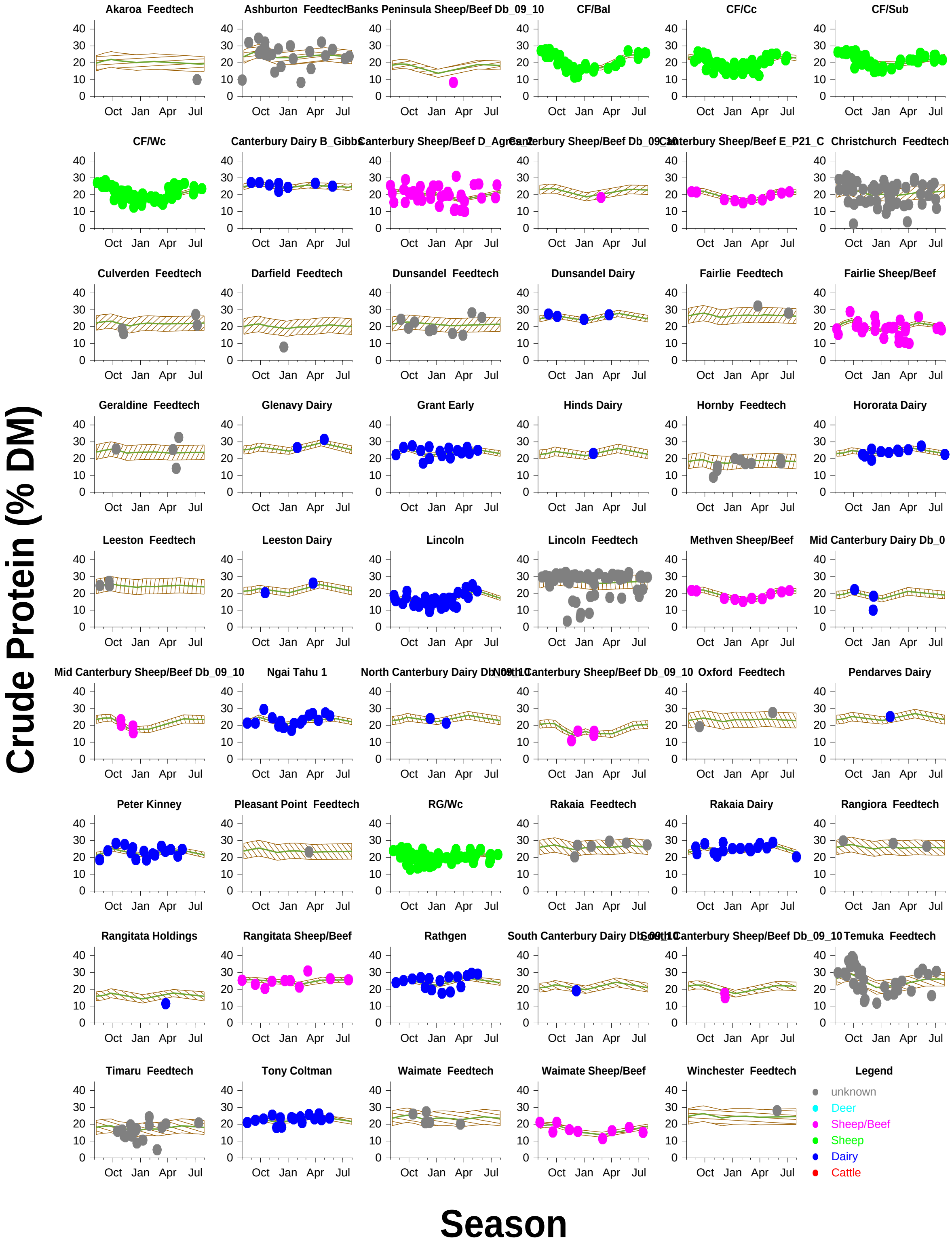
Crude Protein in Tasman



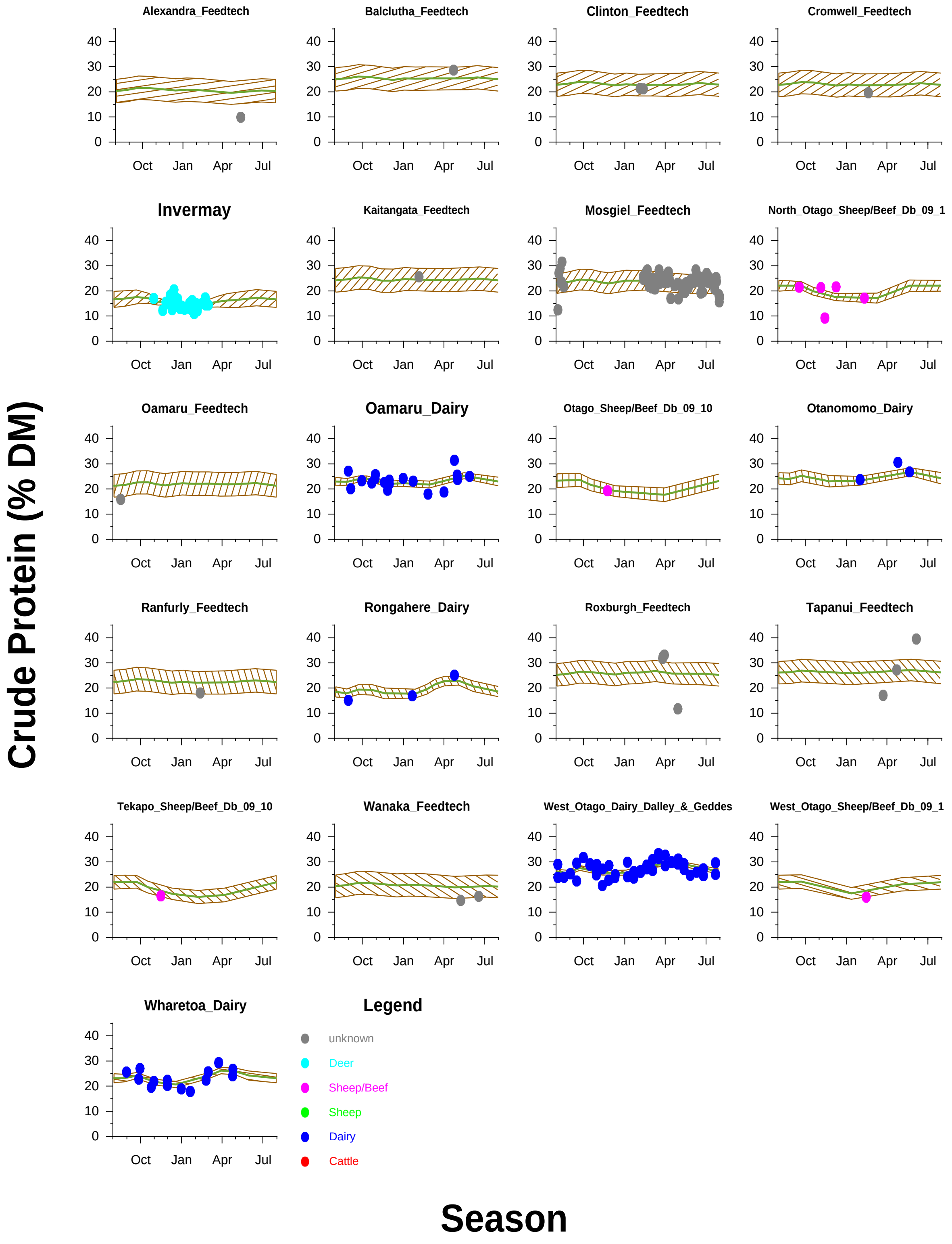
Crude Protein in West_Coast



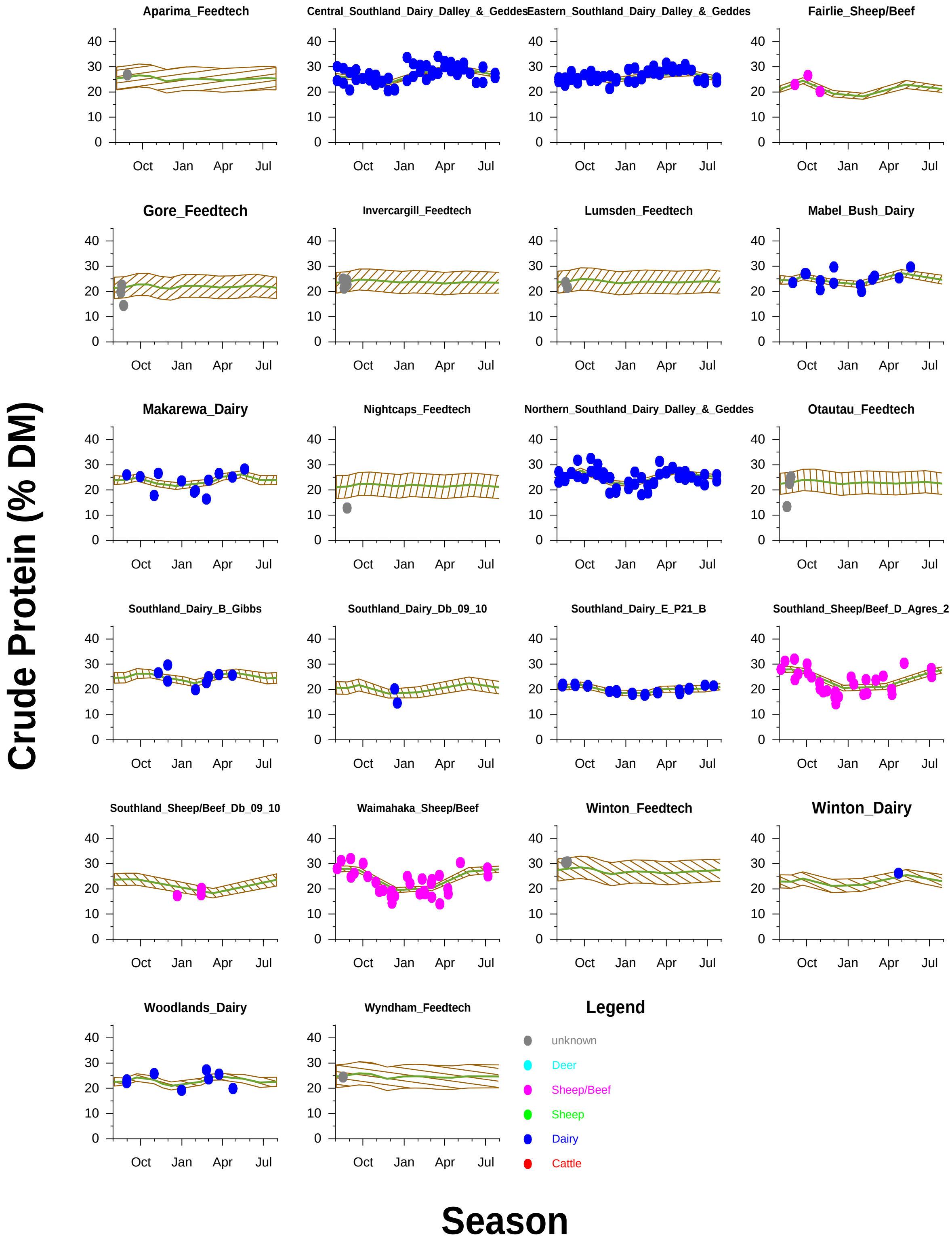
Crude Protein in Canterbury



Crude Protein in Otago



Crude Protein in Southland



22 Appendix 4. Research vs commercial sites

The scientist uses the method given in Table 8 to collect the sample to preserve the integrity of the metabolisable energy in the sample that the farmer does not. Sugars in the sample can be depleted by respiration if the sample is not handled correctly. This lowers the value of metabolisable energy and raises the apparent value of crude protein by reducing the total amount in the sample to which it is compared.

The two sets of samples from a wide range of sites are the Bown and AgResearch data sets. In both of these data sets the sites are classified into either Dairy or Sheep / Beef. The other stock classes come from research farms and differences may be due to the method of sample collection. The difference in metabolisable energy in samples collected by the scientist vs. the farmer is 0.5MJME/kg DM which is half the difference in values between the Sheep farms which are on research stations and Sheep / Beef farms which are on commercial farms (Figure 8).

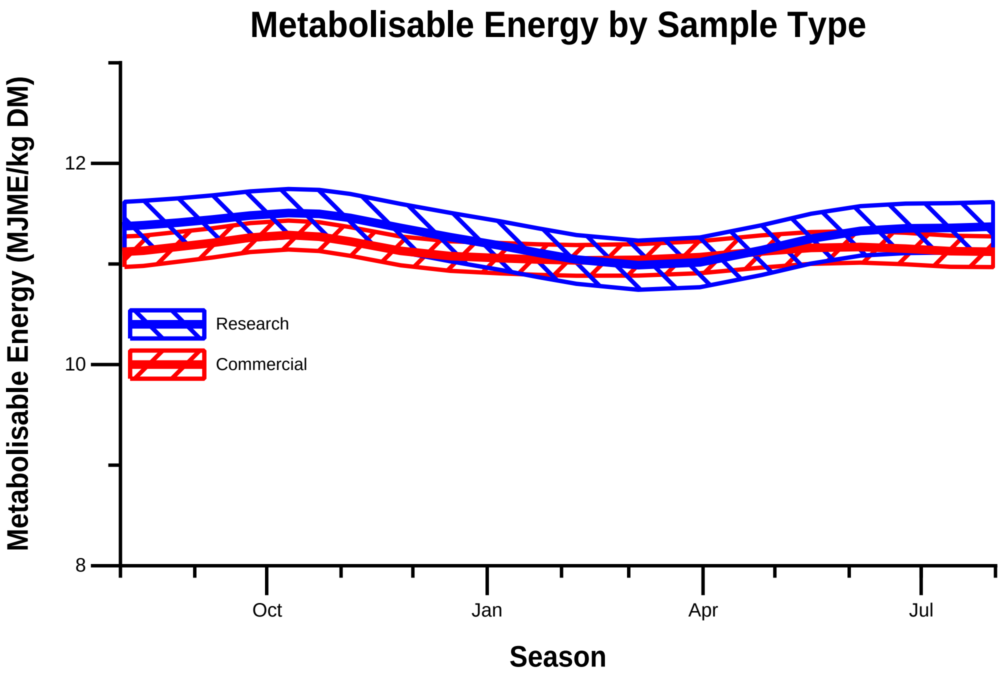
Table 8: Scientist's collection method

1	Sample collection started at midday and was completed by 1pm NZ Standard Time, with the schedule adjusted for day light saving. This timing was assumed to provide a balance between low morning sugar concentrations and higher values in the late afternoon.
2	In each paddock we walked a transect and cut "toe of boot" samples every five paces. The samples were put in a plastic bag, and at the end of the transect the bag of grass was put into a small polystyrene chilly bin. Liquid nitrogen was immediately poured over the sample and the chilly bin lid was replaced. The total elapsed time between cutting the first sample in the transect and freezing the samples was about 3-4 minutes.
3	The frozen samples were transferred to a larger chilly bin and kept frozen with freezer pads and generous additions of liquid N.
4	After all the paddocks had been sampled, all the remaining liquid N was poured into the large chilly bin and it was transported back to Ruakura – about a two hour drive.
5	At Ruakura the samples were transferred to a minus 20C freezer. Many bags contained visible liquid N but this was not removed and it went away quite quickly.
6	The samples were transferred from the freezer to the freeze drier using a chilly bin, and dried.

To further test whether the differences between the two data sets in the Taupo catchment project are due to differences in data collection techniques between farmers and scientists, a separate term for whether the sample was from a Research or Commercial project was entered and the model rerun. All sites coming from known research compilations were classified as research. Samples coming from private bags in the Bown dataset were also classified as research. The majority could be matched to either AgResearch postal addresses or Massey University postal address. All other sites were classified as commercial. This resulted in 16% of the samples being classified as research and 84% as commercial. The resulting plots of the effect of sample collection are given in Figure 22 and Figure 23 for metabolisable energy and crude protein, respectively. The Least Significant Intervals overlap, indicating that we cannot be sure whether the anomaly at the Taupo site is due to sample collection method or some other factor.

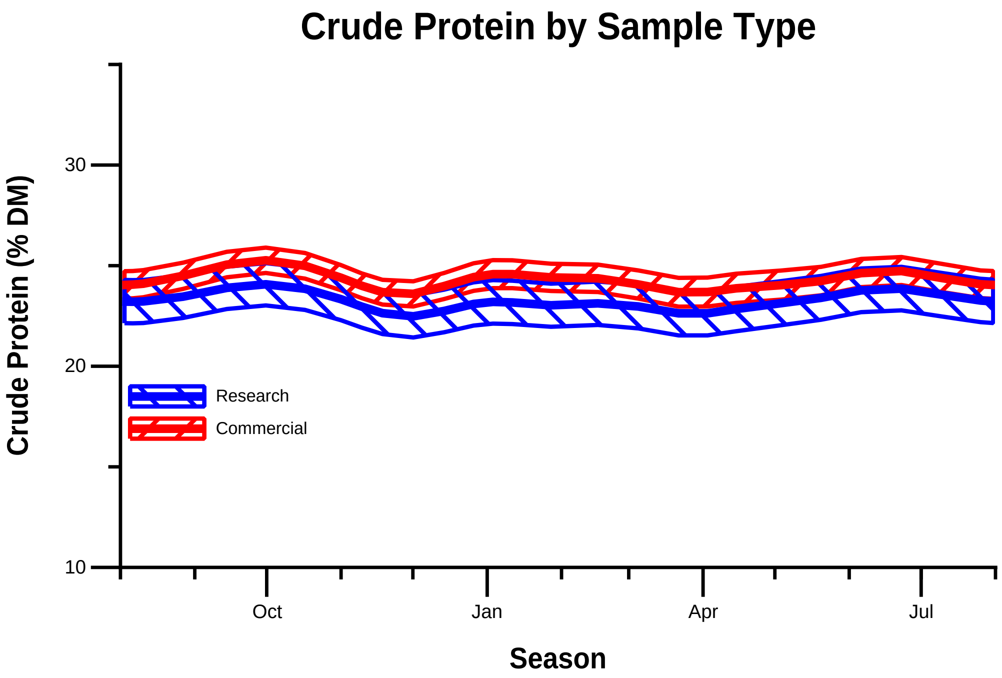
Sampling method was not included in the model.

Figure 22: Metabolisable energy by collection method



Effect of sample collection method on metabolisable energy. The bands are 95% Least Significant Intervals for comparing the two curves. Two curves are significantly different at the 5% level where their bands do not overlap. The blue curve are the predictions from sites known to be research farms. The red curve are from other sites, presumed commercial.

Figure 23: Crude protein by collection method



Effect of sample collection method on crude protein. The bands are 95% Least Significant Intervals for comparing the two curves. Two curves are significantly different at the 5% level where their bands do not overlap. The blue curve are the predictions from sites known to be research farms. The red curve are from other sites, presumed commercial.