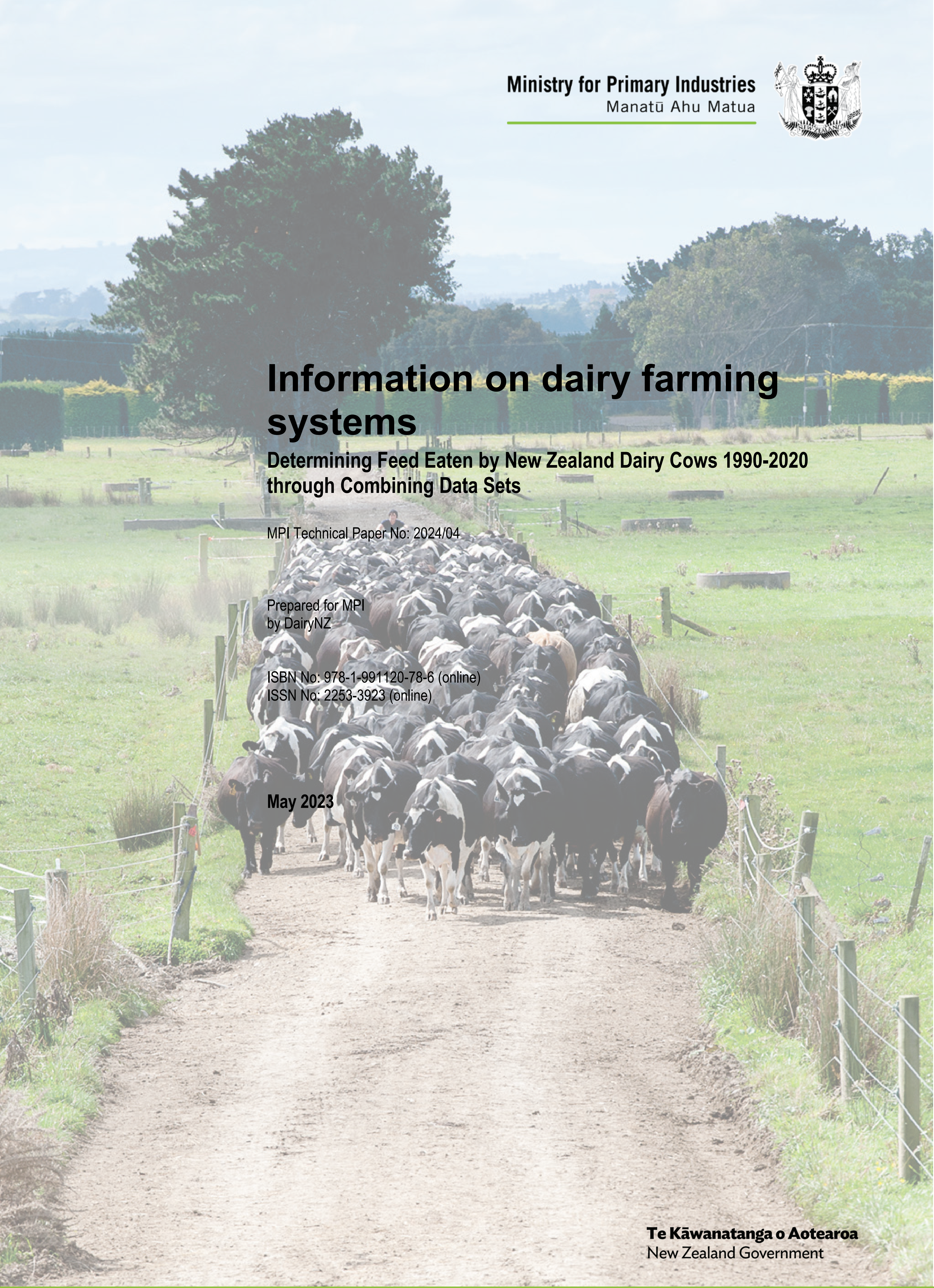

Ministry for Primary Industries
Manatū Ahu Matua

Information on dairy farming systems

Determining Feed Eaten by New Zealand Dairy Cows 1990-2020 through Combining Data Sets

MPI Technical Paper No: 2024/04

Prepared for MPI
by DairyNZ

ISBN No: 978-1-991120-78-6 (online)
ISSN No: 2253-3923 (online)

May 2023

Te Kāwanatanga o Aotearoa
New Zealand Government

Disclaimer

Contents

Page

1 Executive Summary

The dairy sector is responsible for a large proportion of New Zealand's methane emissions, and these emissions are largely driven by the amount and type of feed eaten. Older versions of the New Zealand GHG Inventory assumed feed eaten by dairy cows was 100% pasture, but recent improvements in the inventory now account (at a high level) for differences between pasture and other feeds. Within the dairy sector, several databases exist that have recorded farms, animals, and milk production over time, as well as feed use both through time and seasonally. In principle, this data can be combined at a farm system level to provide more accurate estimates of feed eaten (by month and region) and therefore methane emissions estimated by the GHG Inventory. This also provides a pathway for incorporating different emissions factors for different feeds (where this may not be reflected in how feeds are characterised currently) and for quantification of mitigation effects that may be differentially applied by region and farm system. We expect that other national inventories (e.g., Ireland) will be looking to consider these elements in the near future.

We assess the feasibility of combining these databases to provide monthly estimates of feeds (grown on farm and imported) eaten by dairy cows from 1990 to 2020 for different types of farm systems and regions of New Zealand. Main data sources included the "Dairy Statistics" series of reports, a 2019 DairyNZ report to MPI, DairyNZ's "DairyBase" database, anonymous farm data from "Farmax" software, and NZAEL's "DIGAD" national animal database. These databases lacked sufficient documentation (including metadata) and combining them was also hampered by a lack of unified data standards.

We combined the Dairy Statistics and DairyNZ (2019) data to provide 1990-2020 timeseries of cow and herd numbers, farm area, milksolids production and annual supplement use, for each region. Pasture continues to provide upwards of 70% of annual feed in all regions, with maize silage, PKE (palm kernel expeller) and fodder beet also having become important regionally since the mid 2000s.

More recent data sets such as DairyBase (2005-) and Farmax (2009-) were used to give examples of more detailed feed use data, but these are based on self-selected respondents and are not necessarily representative of regional or national farms. The lack of interoperability between data sets prevented attempts to debias these data, so the effect of the self-selection bias on feed use remains unquantified.

New Zealand's dairy industry data sets represent an invaluable resource whose value cannot be fully realised until issues of data standards, documentation and access are addressed. The design and funding of these data sets must also more intentionally support a wider range of potential applications such as this project.

There has been a trend on dairy farms towards higher use of imported feed on average, though the proportions in each farm system back to 1990 have been difficult to estimate. Additionally, the feeds within a farm system have evolved, with some feeds becoming less common (e.g., cereal silage), and others increasing in prevalence (e.g., maize silage, PKE, fodder beet), with much of this structural change occurring before DairyNZ has reliable farm-level records. These issues present difficulties for estimating robust time series, particularly for the earliest periods. Regardless, the current work represents what is likely to be more accurate estimates than the existing inventory for the recent timeframes and has the capacity to be updated for future years. It also has value for forecasting emissions and modelling the adoption of different potential mitigation approaches (e.g., the use of feed-based inhibitors). However, this is likely of more value for understanding adoption and forecasting than for reconstructing practices historically.

In our conclusions, we propose a choice between three options: keep the current Inventory method; use an approach based on dairy farm systems as developed in this paper; or develop a more comprehensive and integrated method.

2 Glossary

AI	Artificial Insemination
APS	Agricultural Production Statistics (administered by StatsNZ)
DIGAD	Dairy Industry Good Animal Database (administered by NZAEL)
DM	Dry Matter
GHG	Greenhouse Gas
LIC	Livestock Improvement Corporation
MFE	Ministry for the Environment
MPI	Ministry for Primary Industries
NAIT	National Animal Identification and Tracing
NZAEL	New Zealand Animal Evaluation Limited, a subsidiary of DairyNZ
NZMS1	New Zealand Map System 1
MS	Milksolids
PKE	Palm Kernel Expeller
Proliq	A liquid stockfood
TLA	Territorial Local Authority

3 Acknowledgements

Many thanks to our partners who provided us with data extracts for this work: the Farmax team, NZAEL's DIGAD team, and DairyNZ's DairyBase team.

4 Objective

The Enteric Fermentation section of the New Zealand's Greenhouse Gas Inventory (MFE, 2022) currently assumes that each kilogram of dry matter eaten by dairy cows (including calves, heifers and bulls) results in 21.6 grams of methane emitted (MPI, 2022, Equation 6.1, page 118). However, dairy emissions are calculated on a sub-national regional area basis to take into account regional differences in productivity (MFE, 2022, page 159).

Improving information regarding dairy farming systems in New Zealand, particularly types, quantities and seasonality of feed eaten in sub-national regions, could improve the accuracy and reduce uncertainty of emissions reporting and forecasting. Other national inventories are also likely to be considering methods to improve the accuracy of emissions from feed. For example, Teagasc will be proposing to update to the inventory to reflect the latest science on emissions by time of year and feed source (Morrissey, 2023). Our current report tests the feasibility of combining current industry databases to more accurately describe the quantity of feed eaten by dairy livestock in New Zealand from 1990 to 2020.

The scope of the analysis is:

- Time frame – from 1990-91 to 2020-21, monthly.
- Regions – for all dairy regions of New Zealand.
- Farms – for all dairy farm system types 1 to 5 (DairyNZ, 2010).
- Animals – for dry and lactating cows (not including calves, heifers and bulls).
- Feeds – quantity of all home-grown and bought-in feeds eaten per cow by month (but not quality or nutritional composition of feeds).

5 Data Sources

The project used a large number of dairy industry data sets to obtain the required information on historical numbers of cows and farms, and feed use. Data sets included:

- LIC's "Dairy Statistics" national historical herd data (1990-present, continuing, transitioning to DairyNZ administration).
- The DairyNZ (2019) national historical dairy feed report (1990-2019, one-off, with updates as contracted by MPI).
- NZAEL's "DIGAD" data set giving detailed historical cow and herd data (1990-present, continuing, voluntary, though 92-99% of herds and 82-90% of animals are recorded, Edwards, 2017).
- StatsNZ (2023) Agricultural Production Statistics (APS) of cow numbers (5-yearly national census, with sample surveys and imputation between census events).
- DairyNZ's "Milksolids" national milk levy data set (2008-present, continuing).
- DairyNZ's "DairyBase" data set giving detailed descriptions of about 5% of farms (2005-present, continuing, voluntary).
- "Farmax" data giving detailed feed use on about 2% of farms (2009-present, continuing, voluntary, proprietary).
- Several additional datasets giving farm geographic location data, such as AgriBase and DairyNZ's farm information system.

Edwards (2017) provides further details on the Dairy Statistics and DIGAD data. As noted, participation in several data sets is voluntary, which means that they do not provide complete or unbiased information about the industry. Furthermore, the DairyNZ (2019) data set comes from a commissioned report, and so updating requires work to be done in the future outside the scope of the current project. No other long term, national, animal or herd data sets are available that we know of.

Collation of these data sets highlighted issues of access, documentation and data standards. Negotiating access to data sets can be time consuming, even when these are non-proprietary. The availability of accurate documentation is also generally poor and attempts to link across data sets (interoperability) was complicated by a lack of data standards, such as common definitions of variables and common identification fields.

5.1 Farm Definition Differences

One complication of working across multiple data sets is that different data sources have different definitions of several key variables. These are summarised in Table 1.It should be noted that the New Zealand's current agricultural greenhouse gas (GHG) emissions calculation is based on an animal population model, and does not track herd numbers (MPI, 2022). In addition, milk production in these databases only includes milk picked up for processing. Any milk used for calf rearing is not included.

Table 1: Variable definition differences across the different data sources.

Data Source	"Cow"	"Herd"	"Area"	"Milk"	"Feed"
Dairy Statistics	All cows lactating in a season. Before 1992, only cows lactating on 31 December	By geographic location and herd number. Excludes herds < 50 cows	Milking platform with support block excluded. Before 1990, based on factory supply herds only	Before 1998, town milk supply was excluded	Not included
DairyNZ (2019)	Mature milking cows, excludes heifers prior to first lactation	Not included	Effective area, including crops	From Dairy Statistics	Estimated from seed sold and feed imported into NZ
DIGAD	"Breeding cows" in each month (heifers excluded)	AI or Herd Testing customer	Not included	Not included	Not included
Milksolids	Not included	Dairy Processor Supplier ID	Not included	Milk picked up per month	Not included
DairyBase	Peak cows milked in a season	DairyBase customer	Effective area of milking platform	Milk picked up year total	Imported feed, and estimated home grown feed eaten
Farmax	Lactating and dry mixed age cows on the milking block in each month (excludes grazing off)	Farmax customer	Effective milking area, and additional crop areas	Milk picked up per month	Pasture, crop and supplements offered/eaten in each month
StatsNZ	Pregnant or lactating animals on 30 June	Not included	Not included	Not included	Not included

A key complication was that "herd" was not always synonymous with dairy farm, and indeed, there is no universally accepted definition of a dairy farm. This is an issue that was previously highlighted in the DataLinker and the Farm Data Standards projects (Rezare, 2020). For example, a physical farm entity can be considered from operating, land management, biophysical and legal viewpoints (Figure 1), and these may not completely match spatially. A farm may also have multiple herds. These spatial conceptualisations are also related to non-spatial concepts such as legal and management entities (Figure 2).

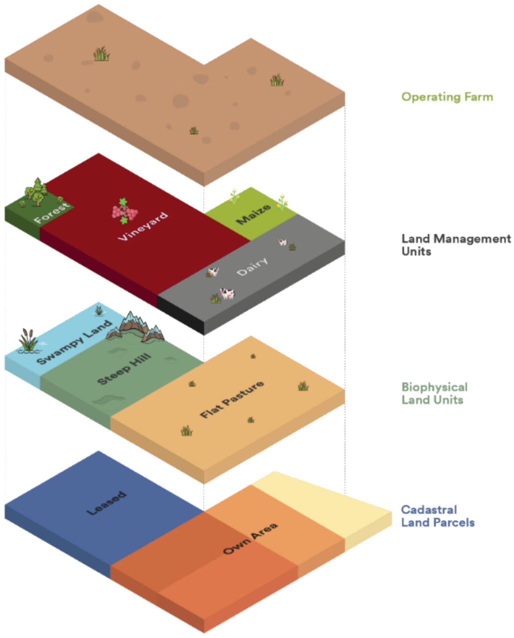

Figure 1: Spatial features may occupy similar spatial area while not being completely related (Rezare, 2020).

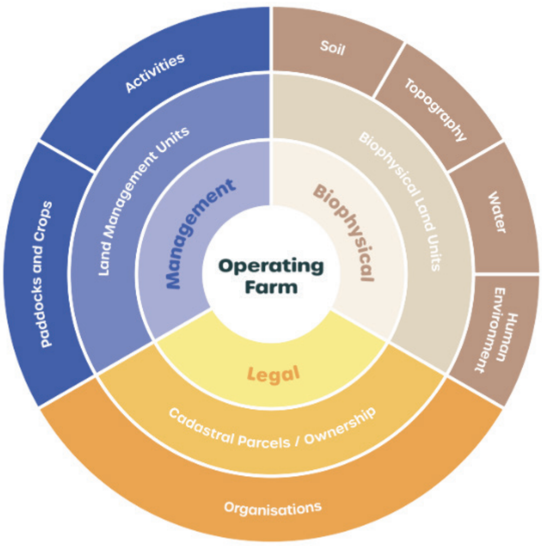

Figure 2: Spatial entities may have relationships with non-spatial entities (Rezare, 2020).

6 Looking Backwards

In order to determine feed eaten by dairy cows from 1990 to 2020 we first need to establish basic information on the size of the dairy industry through time, including numbers of farms, numbers of cows, farm area, feed use and milk production.

However, the availability of historical dairy industry data is variable and often limited. For example, Fonterra, the largest dairy processor and a key driver of current data recording, was only formed as a result of the Dairy Industry Restructuring Act 2001. While national summary statistics are available prior to 2000, they lack the level of detail required to help determine feed use differences between farms as precisely as would be desirable.

6.1 Dairy Statistics (DairyStats)

The annual LIC "Dairy Statistics" report estimates the number, size and production of dairy herds in each region and district (territorial authority) of New Zealand. The reports combine and clean data from a range of sources, including milk processors, herd recording companies, etc. (Edwards, 2017; Burggraaf et al., 2021). Some expert judgement is involved in the process of producing the final numbers. Production of the report is being passed to DairyNZ from 2023, retaining the same methodology. We abbreviate this database as "DairyStats".

For example, the total milking cows, total herds, total effective hectares, and total milksolids production in each region are shown in Figure 3. These data are also available at a district level, although there are some districts that overlap regions, depending on the chosen regional classification layer. The geographic distribution of dairy herds in the last decade is shown in Figure 4, with the following notes:

- The number of cows used to calculate the average herd size since 1992/93 includes all cows lactating in that season, whereas in earlier years the number of cows used to produce the average herd size was based only on those cows lactating on 31 December. This change in method has had a small effect on reported cow numbers.
- Herds less than 50 cows are likely to be omitted from the herd count.
- Total effective hectares (milking platform with support block excluded) between 1981/82 and 1999/00 are estimates. Average effective hectares and average cows per hectare for 1981/82 to 1990/91 are based on factory supply herds only. Factory supply farms whose milk was used for manufactured products (the vast majority of farms), as opposed to town milk farms, who milk was used for local liquid milk supplies.
- Prior to 1998/99, total milksolids consisted of milk production statistics that were processed into export products (i.e., town milk supply was excluded). These statistics on milk, milkfat, protein and milksolids processed were provided by the New Zealand Dairy Board. Consequently, totals from 1998/99 include all milk processed by New Zealand dairy companies, including milk for the domestic market.

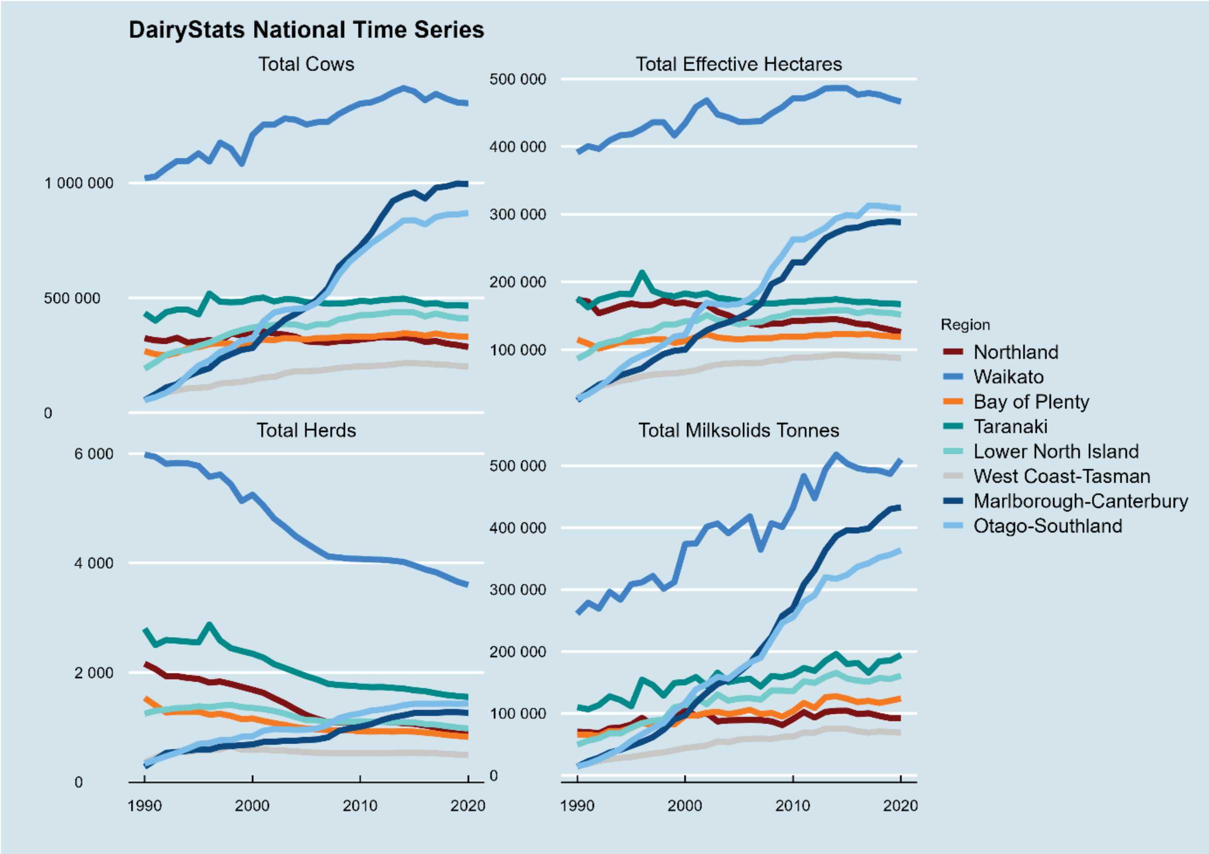

Figure 3: Regional time series for the NZ dairy herd (LIC, 2021).

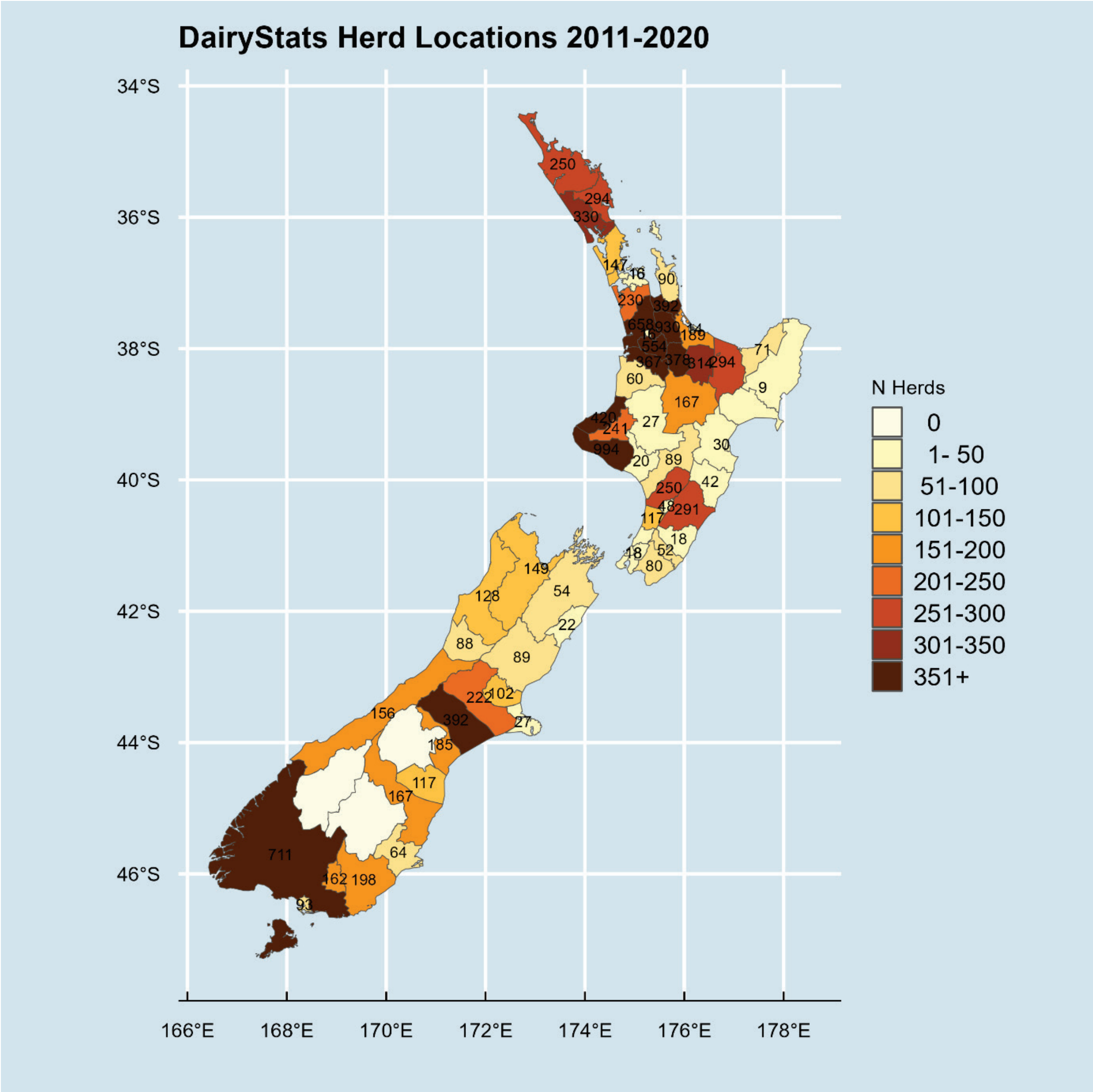

Figure 4: Location of dairy herds (average per district) for the decade 2011-2020 (LIC, 2021).

Derived quantities such as herd size are shown in Figure 5. Almost all of these metrics have been steadily increasing since 1990, although stocking rate has plateaued since 2000 in all regions except Canterbury.

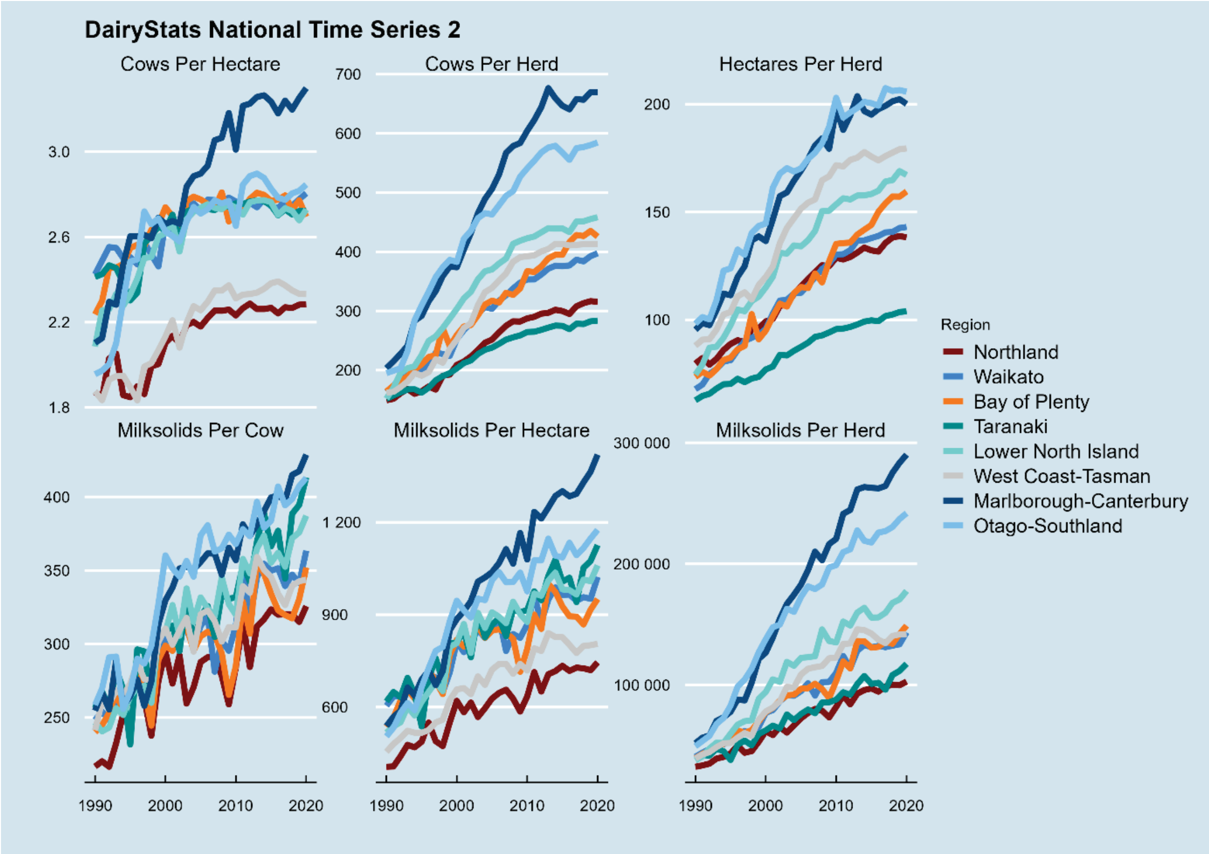

Figure 5: Regional derived time series for the NZ dairy herd (LIC, 2021).

6.2 DIGAD

In parallel, the NZAEL "DIGAD" database maintains detailed records of most dairy animals and herds in New Zealand. The core database was established by LIC and transferred to NZAEL in 2014. These data are provided by herd fertility and herd milk testing agencies (LIC and CRV). All herds in the database have a "farm gate identifier", which provides an approximate geographical location (an NZMS1 map number), and a "herd number", which differentiates herds at the same approximate location.

In theory, total animals and herds recorded in DIGAD should closely match animal and herd numbers in DairyStats. After removing herds with less than 50 milking cows in any given year, the comparisons are shown in Figure 6, Figure 7 and Figure 8. These show differences in cow and herd numbers between the two data sets. DIGAD cow numbers were 5% less than those in DairyStats on average (standard deviation 9%), DIGAD herd numbers were 4% less than those in DairyStats on average (standard deviation 6%), and DIGAD cows per herd were 1% less than those in DairyStats on average (standard deviation 10%).

One source of this discrepancy may be that the definition of a herd is not the same between the different data sets. Another possible source of error could be processing of the DIGAD data that may double count some animals (e.g., where identifiers are lost or used inconsistently, and possibly if a cow's milking status changes during a month).

DIGAD is the only historical information available that describes individual farms, providing the number of cows in each individual herd. This is potential useful for inferring the proportions of cows and herds belonging to different types of farming systems in different regions. However, DIGAD focuses on animal breeding, and accompanying data such as farm area, feed eaten or milk production was not historically included. Therefore, DIGAD does not provide sufficient data to fully characterise individual farms.

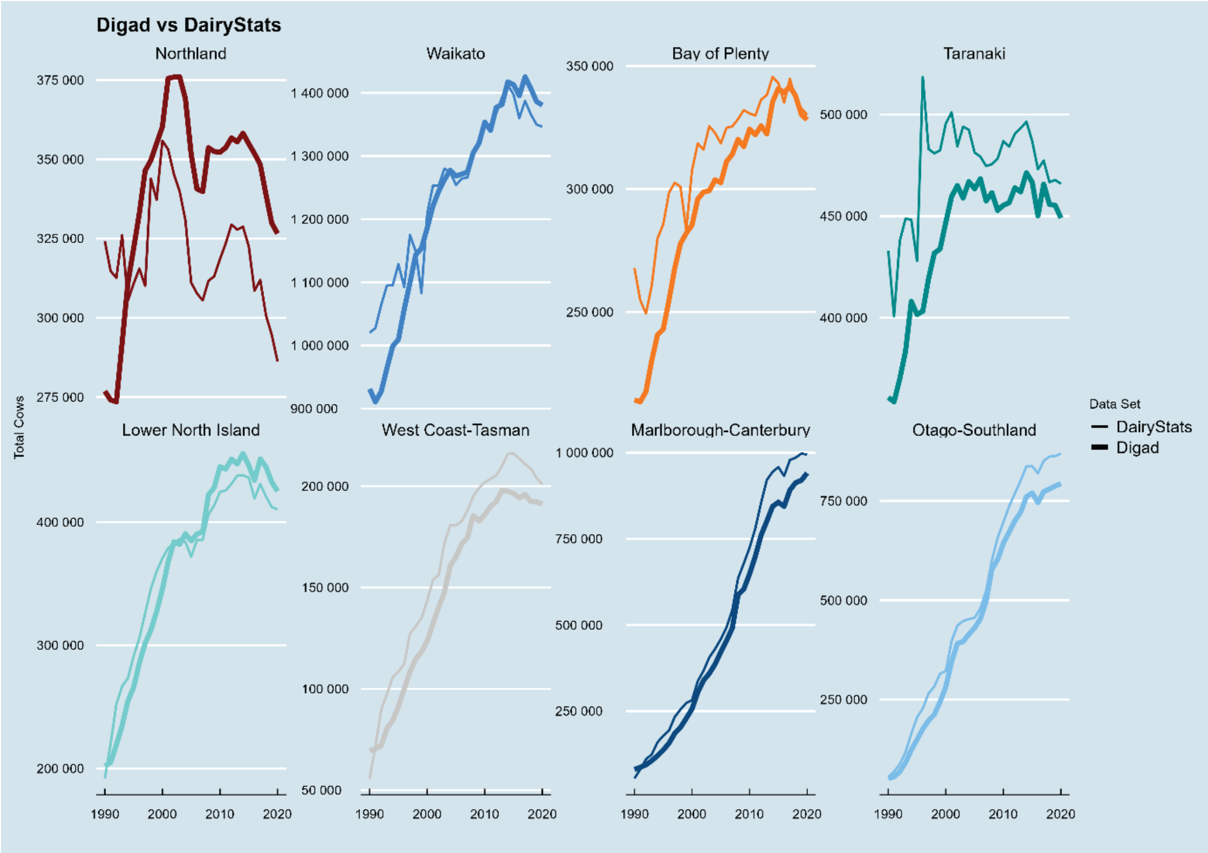

Figure 6: Regional cow numbers from DairyStats (LIC, 2021; thin line) and DIGAD (DairyNZ, 2023; thick line).

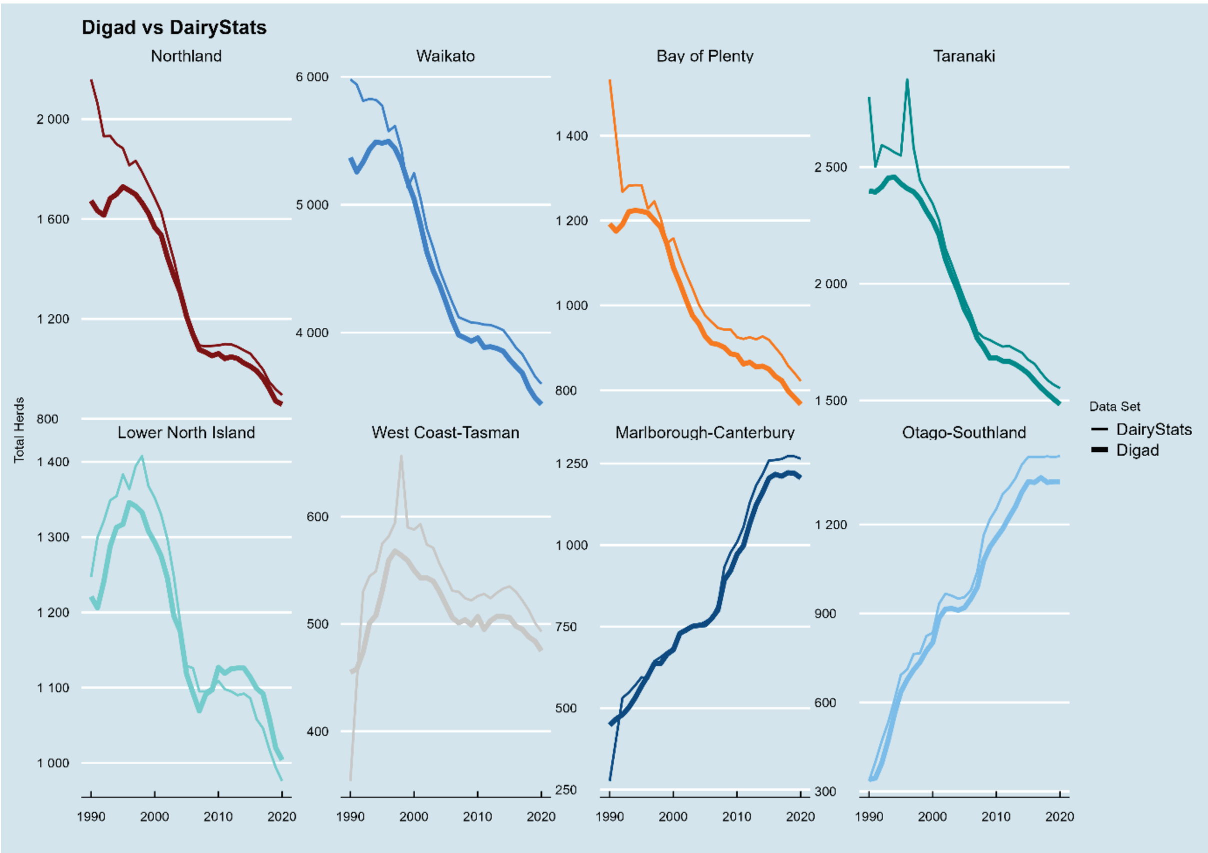

Figure 7: Regional herd numbers from DairyStats (LIC, 2021; thin line) and DIGAD (DairyNZ, 2023; thick line).

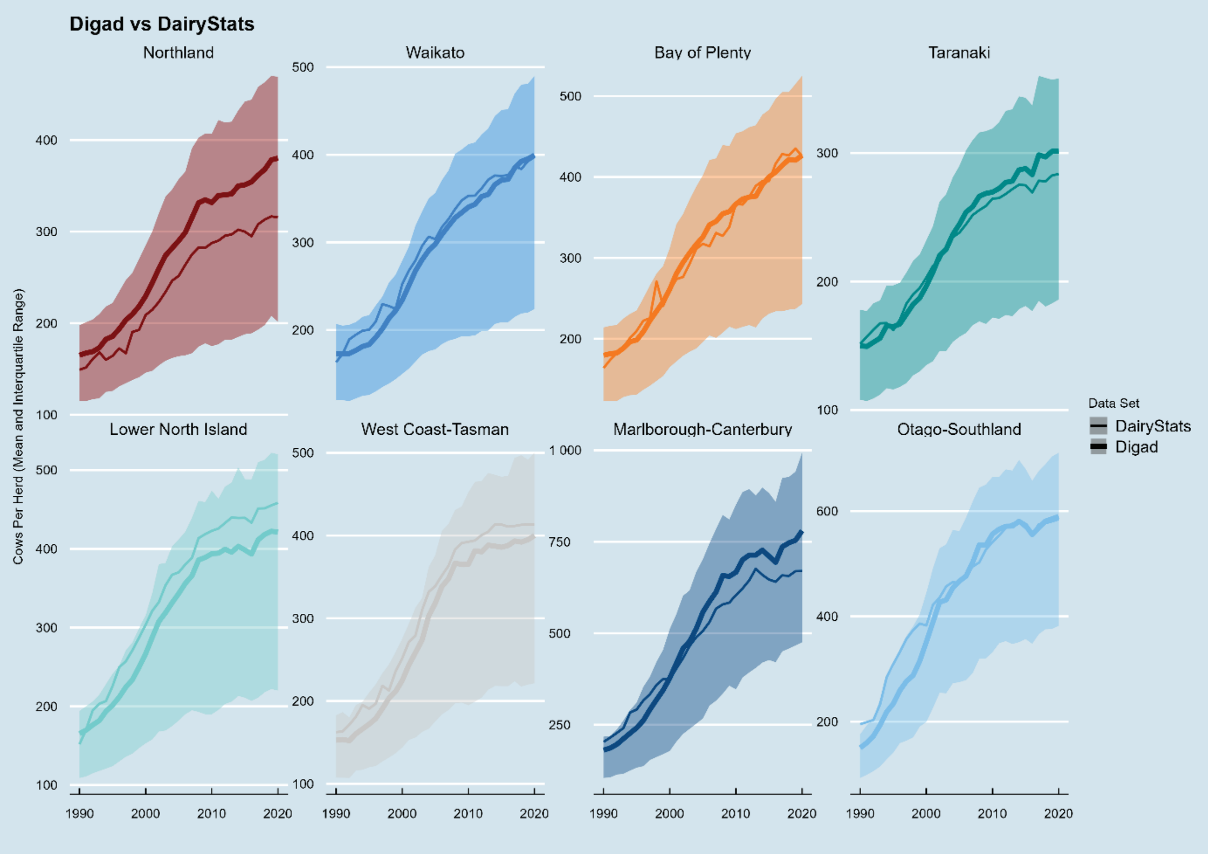

Figure 8: Regional average herd sizes from DairyStats (LIC, 2021; thin line) and average and interquartile herd size from DIGAD (DairyNZ, 2023; thick line and shaded region, respectively).

6.3 StatsNZ

The Agricultural Production Statistics (APS) collected by StatsNZ (2023) records populations of four categories of dairy animals on 30 June each year, the key category being “Dairy cows/heifers over 1 year in milk or in calf”. This is a key data source forming the basis of cow numbers in the current inventory. In general, the data tracks other measures (e.g., DIGAD, DairyStats) (Figure 9). In absolute terms, it is similar to the DairyStats numbers, with discrepancies in 2016 and 2018.

Geographic regions in the APS use different aggregations of New Zealand’s Territorial Local Authorities (TLA) compared with other data sets. However, DairyStats numbers are collected at district (TLA) level, and so can be re-aggregated to match the region definitions in APS, though some minor areal mismatches can occur on certain boundaries (e.g., near Taupo). These numbers approximately match, although some data are missing from the StatsNZ records, and some noise and divergence is observed for some regions (Figure 10). Plausibly the DairyStats estimates are more accurate as these are compiled and checked by dairy industry experts each year, compared with APS data which is collected every 5 years and interpolated in between.

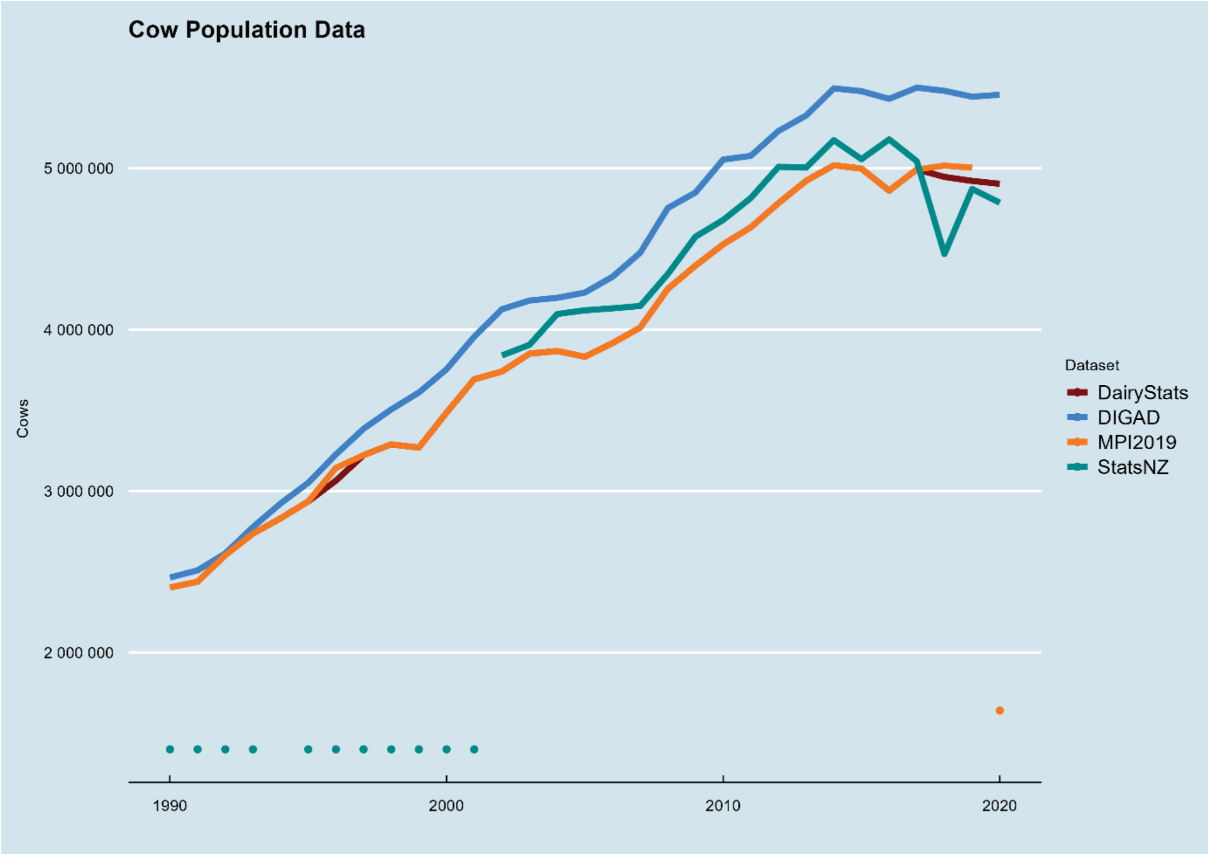

Figure 9: National dairy cattle population comparison. Missing years of data are indicated by dots. DairyStats data matches MPI2019 except where shown.

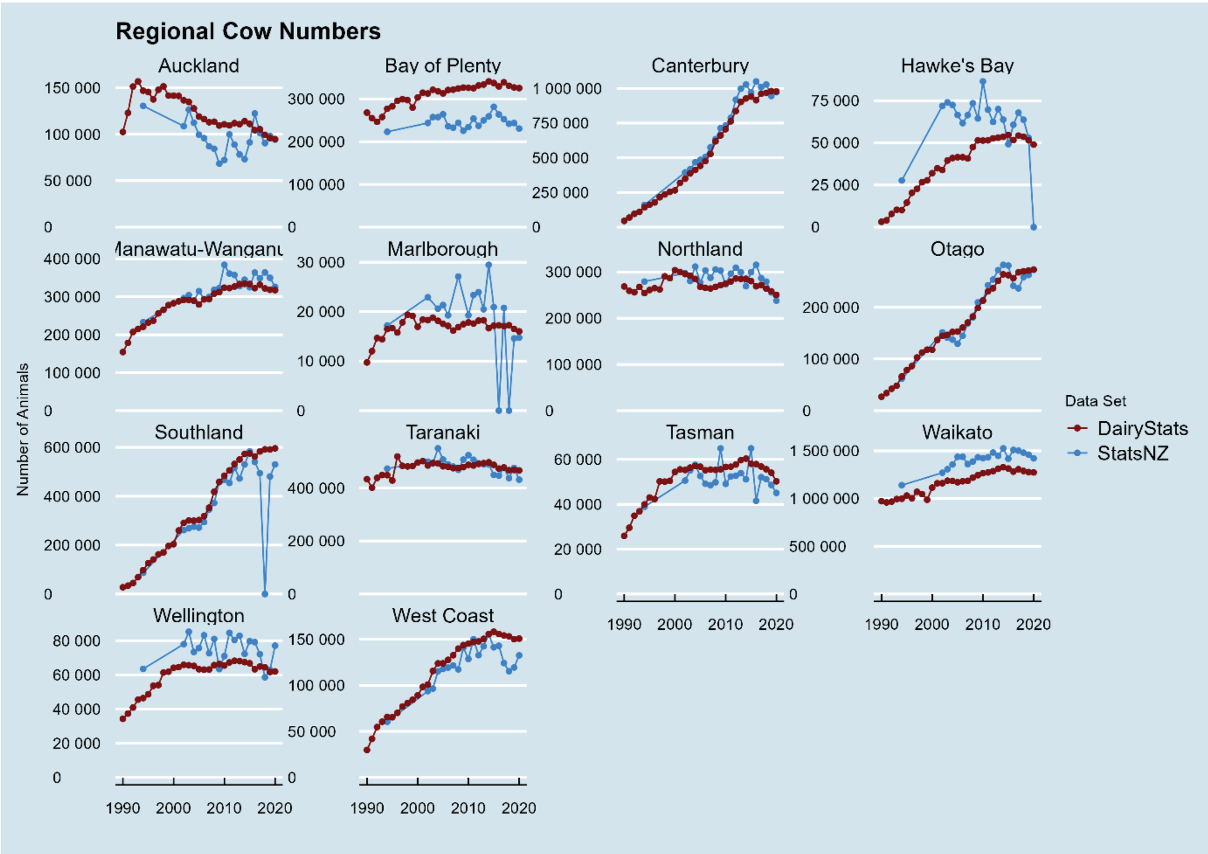

Figure 10: Regional dairy cattle population comparison. Missing years of data are indicated by zeros.

6.4 MPI Report (DairyNZ, 2019)

The MPI-commissioned reports by DairyNZ (2016, 2019) surveyed feed volumes consumed by New Zealand dairy cows nationally and regionally from 1990-2019. The reports used data from a range of sources, including DairyStats, DairyBase, DairyNZ Facts and Figures (2017), and the StatsNZ APS for grain production, along with energy demand equations from Nicol and Brookes (2007) and expert knowledge. Pasture, hay and silage made from pasture, and any other forage herbs such as chicory, plantain and lucerne were included as "pasture", whether grown on the farm or purchased. All other feeds were categorised as (non-pasture) "crops, harvested supplements or imported supplements". Based on feed imported and crops grown, regional totals of feed use were estimated as shown in Figure 11.

Although the analysis only provided regional averages, it does highlight several changes in the industry especially c. 2005:

- The introduction and increased use of maize silage, PKE and fodder beet.
- Declines in the use of cereal silage.
- Decline in pasture use in the North Island, associated with the increases in cropping.

On individual farms the patterns may be more complex, especially when differences in farm management strategies are considered, as described in Section 7.2.

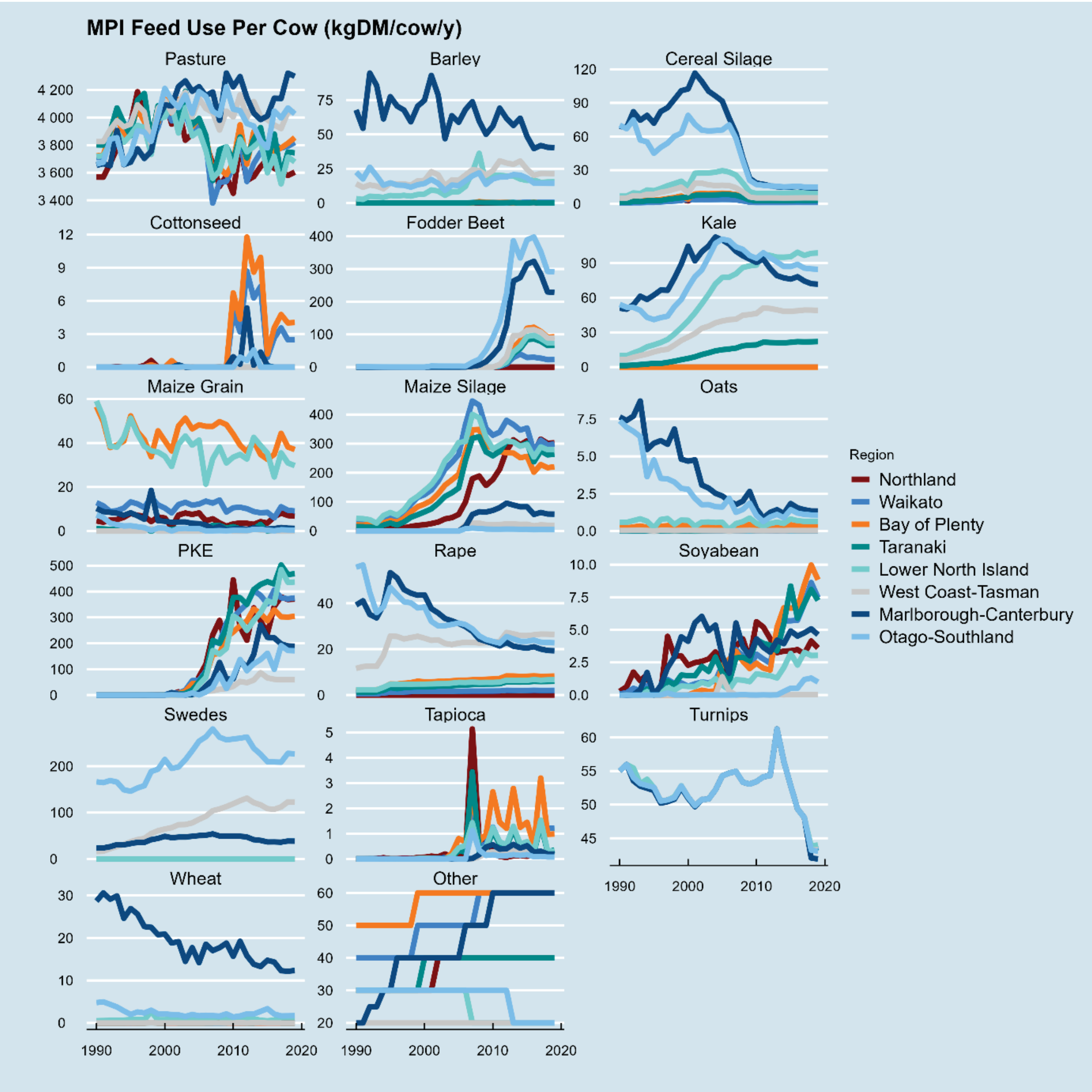

Figure 11: Feed eaten from 1990-2019 (DairyNZ, 2019).

6.5 Conclusions

Apart from the individual cow and herd records in Digad (Figure 8), the long term historical data provides only regional averages (e.g., cows per herd in DairyStats, feed eaten per cow in DairyNZ (2019)). This means that limited conclusions can be drawn about dairy cow diets. Average pasture and supplement eaten annually per cow has been estimated (Figure 11) but this is not available at district or monthly resolution or differentiated by the type of farm system. Furthermore, since this is primarily based on the one-off report of DairyNZ (2019), continuing the estimates into the future would require additional data collection to be established.

In broad-scale summary, we can estimate changes in the proportion of imported feed eaten (consistent with the DairyBase definition) in each region. From expert opinion and estimated energetics, assuming 10% of pasture is imported onto the milking platform (e.g., as grazing off), 90% of crop and maize silage is imported onto the milking platform, and 100% of all other feeds are imported onto the milking platform, then the trend in imported feed estimated from the DairyNZ (2019) report is given in Figure 12. This suggests that imported feed use increased substantially between 2000 and 2010, in all regions of the North Island. Imported feed use also increased in the South Island, although this was less marked in the West Coast-Tasman.

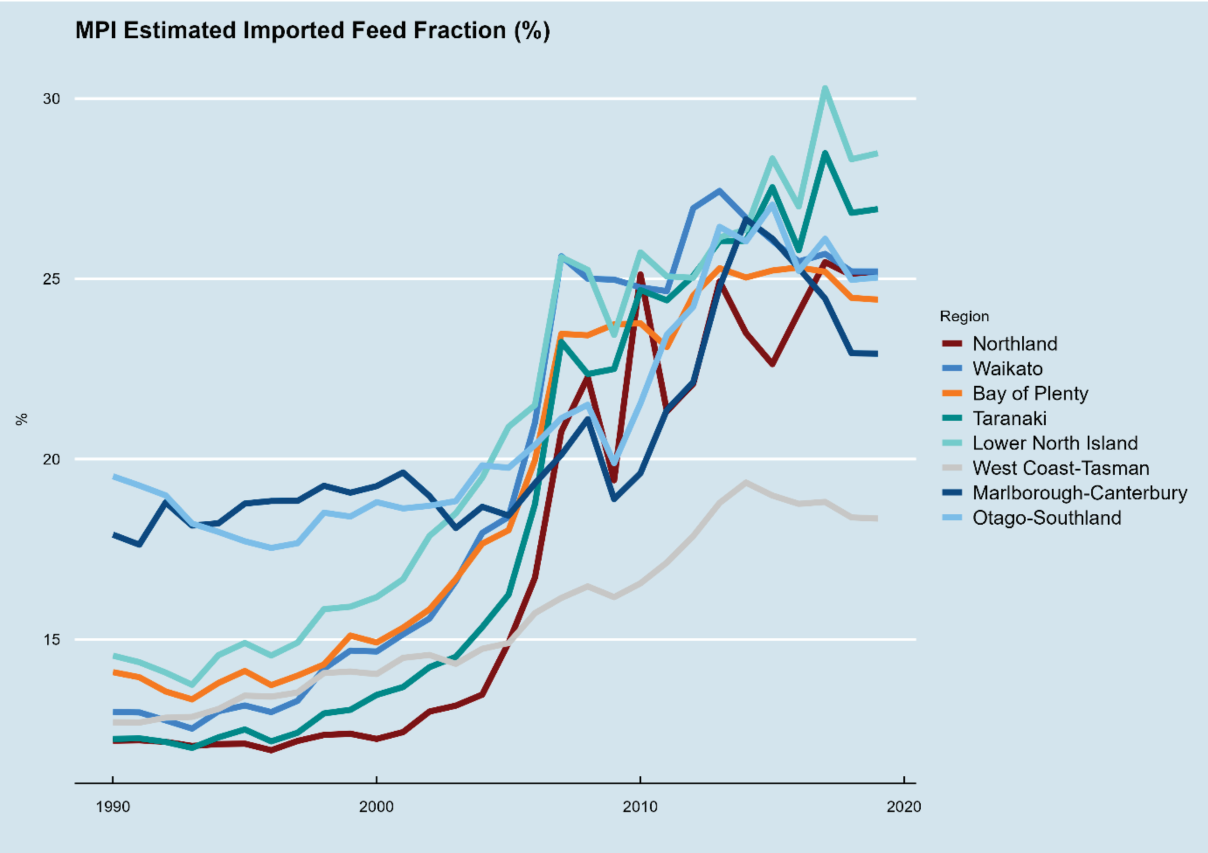

Figure 12: Estimated percentage of feed imported onto the milking platform from 1990-2019 (DairyNZ, 2019).

7 Current State

While the historical data mainly provides national and regional totals, newer data sets such as DairyBase and Farmax have started to record information on individual farms and give greater resolution within seasons. However, these data sets are based on voluntary participation, and so do not provide a representative sample of farms as well as a census or random sampling would achieve.

7.1 DairyBase

DairyBase is an annual survey of about 5% of New Zealand dairy farms which capture farm physical and financial data on an annual basis. Among these is the farmer's assessment of which of DairyNZ's 5 farm systems they operated in (DairyNZ, 2010, 2021), as well as actual feed purchases in that year.

7.1.1 Farm System Type

The 5 farm systems represent, in a simple way, how feeding of dairy cows varies by farm, and farm systems and feed types vary across the different regions of New Zealand. In Waikato (and most other regions), for example, adult cattle are typically wintered on the dairy platform, whereas in Canterbury and Southland cows are more often wintered off, and a higher proportion of crops are used either for grazing or conservation. Furthermore, different supplements are available and commonly used in different regions, such as kiwifruit byproduct in the Bay of Plenty or arable crops in Canterbury. These regional variations naturally affect enteric methane emissions (MFE, 2022; MPI, 2022). Pasture and crop eaten in DairyBase is estimated through a back-calculation approach, where energy demand is subtracted from energy supply from imported feed to determine pasture and crop eaten.

DairyNZ (2010) defined 5 types of dairy farm systems in New Zealand, based on the amount of imported feed used:

- **System 1 – All grass self-contained, all stock on the dairy platform**
  No feed is imported. No supplement fed to the herd except supplement harvested off the effective milking area and dry cows are not grazed off the effective milking area.

- **System 2 – Feed imported, either supplement or grazing off, fed to dry cows**
  Approximately 4 – 14% of total feed is imported. Large variation in percentage values as in high rainfall areas and cold climates such as Southland, most of the cows are wintered off.

- **System 3 – Feed imported to extend lactation (typically autumn feed) and for dry cows**
  Approximately 10 – 20% of total feed is imported. For Westland, feed to extend lactation may be imported in spring rather than autumn.

- System 4 – Feed imported and used at both ends of lactation and for dry cows
  Approximately 20 – 30% of total feed is imported onto the farm.

- System 5 – Imported feed used all year, throughout lactation & for dry cows
  Approximately 25 – 40% (but can be up to 55%) of total feed is imported.

Note 1: Farms feeding 1-2kg of meal or grain per cow per day for most of the season will best fit in System 3.

Note 2: These definitions were changed slightly in DairyNZ (2021) (to 0%, 1-10%, 11-20%, 21-30% and 31-50%, respectively), and DairyBase changed their questionnaire accordingly. Care is therefore required when combining data before and after this change in definitions. In the current report we used the original DairyNZ (2010) definitions.

Figure 13 shows the distribution of self-reported farm system type (1-5) across the eight dairy regions of New Zealand as recorded in DairyBase for the 2012-2020 period. Duplicate records were removed to leave one remaining for each supplier id (e.g., if an owner and a sharemilker record coexisted, or a single supplier id and a combined supplier id record coexisted, the latter was removed).

Figure 13 also shows the reported proportion of actual imported feed used by these farms in different years; this is often outside the intended range for the self-reported farm system type, reflecting year to year variations in home grown feed supply, where a shortfall in pasture grown leads to higher levels of imported feed. The data may also reflect that farmers could have intensified their system gradually over years, without updating their reported farm system to match the decisions made on farm.

Alongside this, Figure 14 shows the distribution of herd size corresponding to the farm system types in Figure 13. Average herd size varies widely between regions, but surprisingly, less so between farm system types. The largest herds occur in most developed regions of Waikato, Marlborough-Canterbury and Otago-Southland, with lower herd sizes in the other regions.

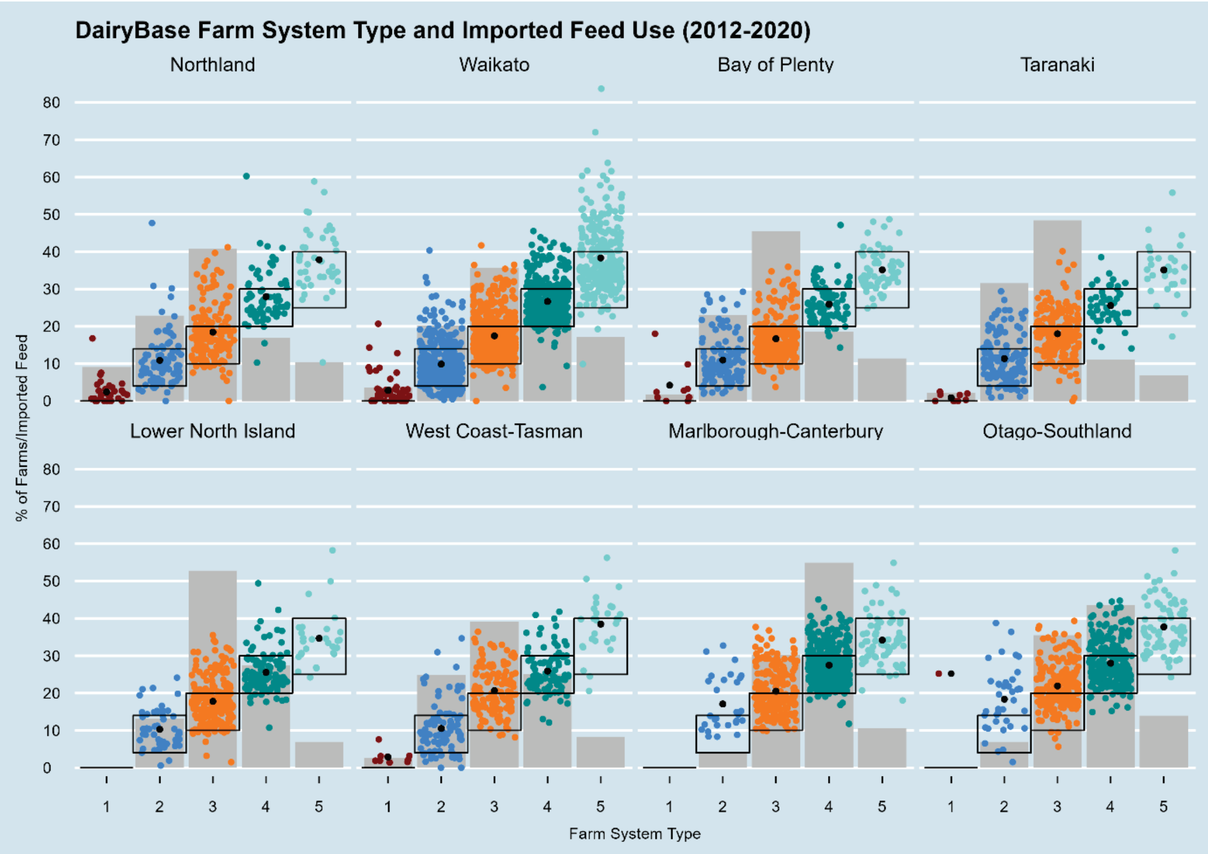

Figure 13: Regional frequency of (self-reported) farm system type (1-5) (grey bars) and imported feed use (coloured dots, black dot shows the mean), from DairyBase 2012-2020 data. Nominal imported feed ranges for system types 1-5 are shown as black rectangles (0, 4-14, 10-20, 20-30, 25-40) (DairyNZ, 2010). Feed exported from the milking platform is not considered as intake. The calculation of intake from young stock is included in pasture eaten on the platform, but not accounted for in imported feed.

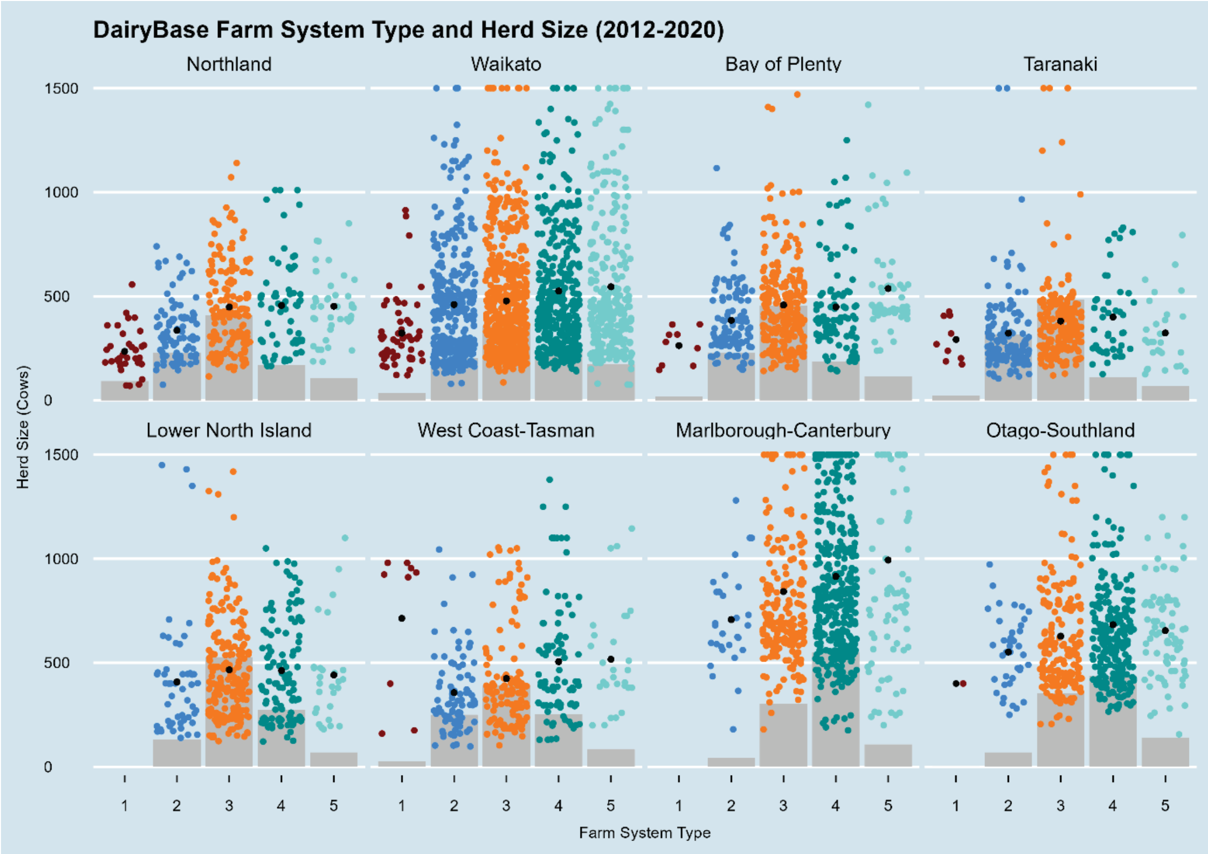

Figure 14: Regional frequency of (self-reported) farm system type (1-5) (grey bars) and herd size (coloured dots, black dot shows the mean), from DairyBase 2012-2020 data.

7.1.2 Bias

When interpreting this data, it is important to remember that DairyBase is a voluntary data set capturing data from about 5% of farms, and these tend to be larger and more productive than the average farm. For example, Figure 15 shows the difference in herd size distribution between farms in DairyBase and those in DIGAD (approximately all herds in New Zealand), and Figure 16 shows the difference in milk production between farms in DairyBase and those in the DairyNZ Milksolids data set (approximately all suppliers in New Zealand).

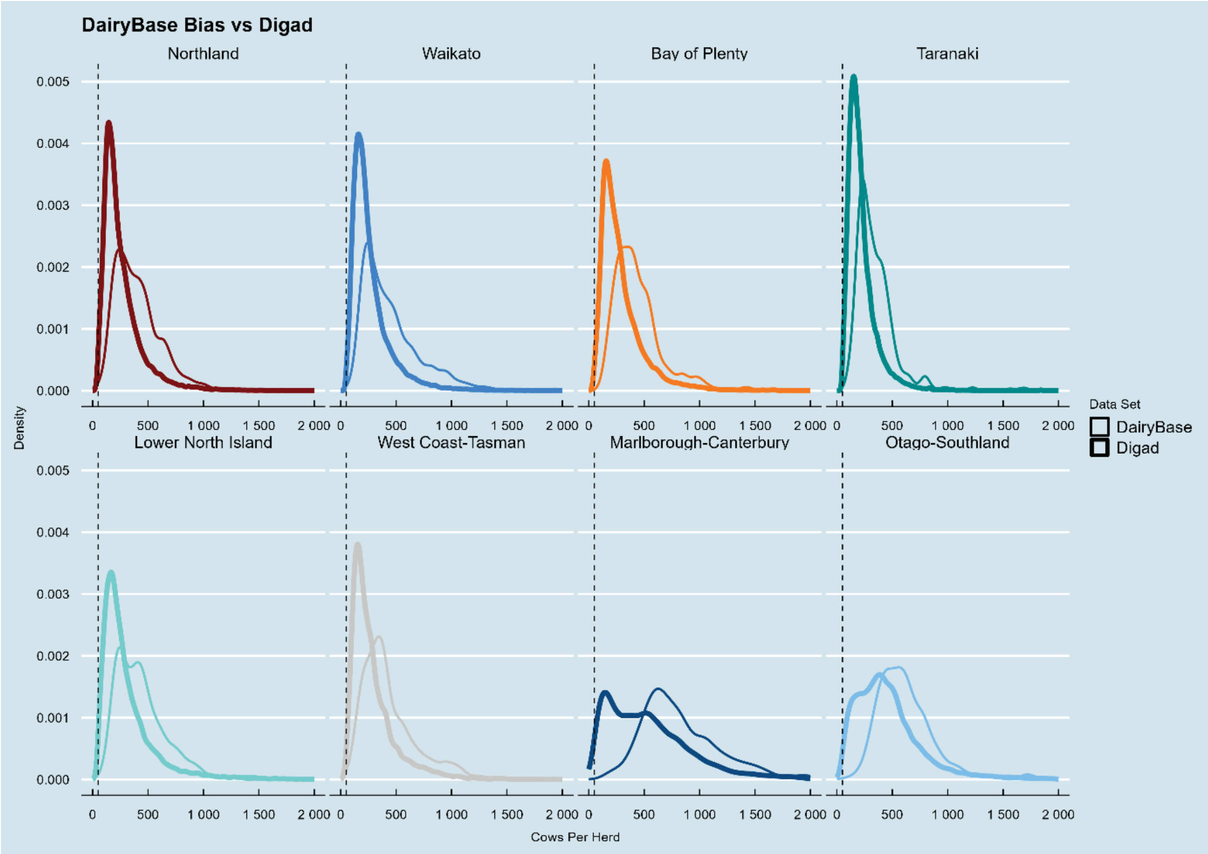

Figure 15: Comparison of Herd Size Distribution in DairyBase and DIGAD.

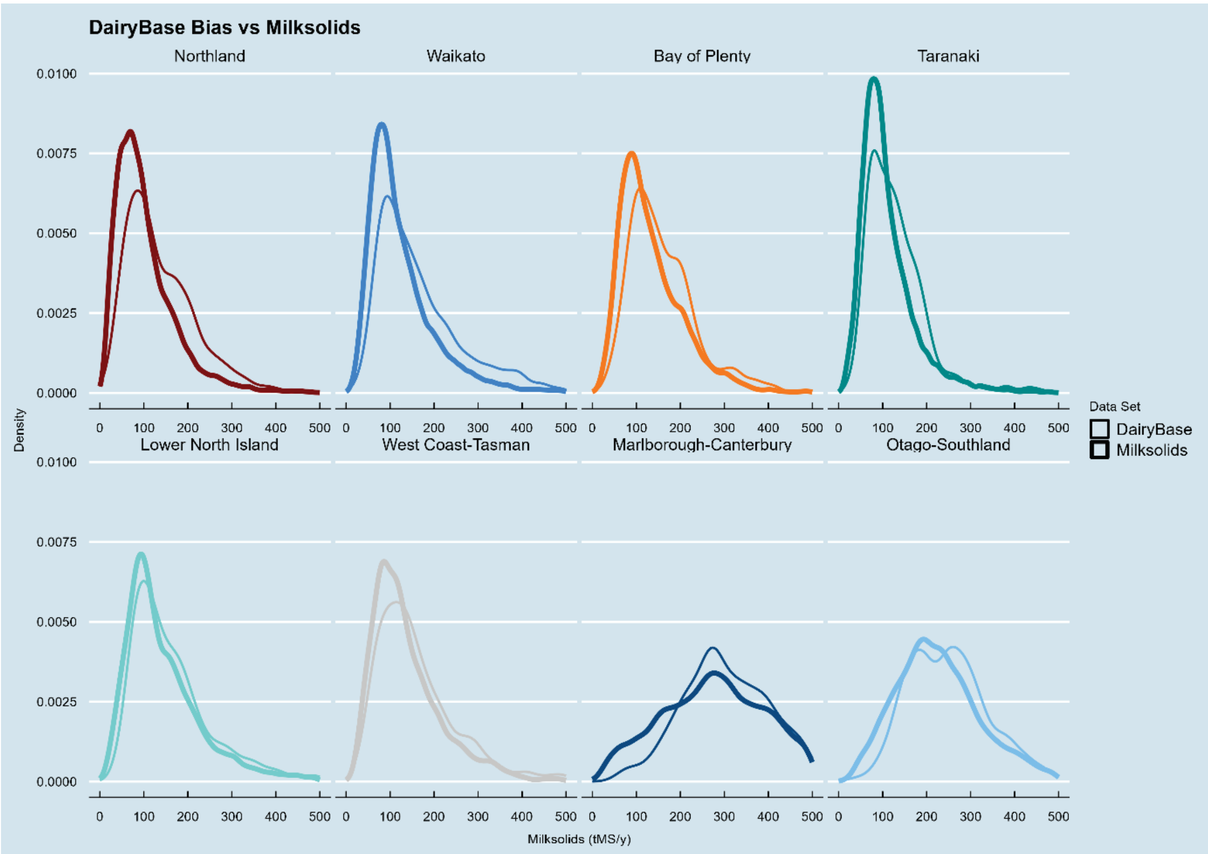

Figure 16: Comparison of Annual Milk Production in DairyBase and Milksolids dataset.

7.1.3 Liveweight Trends

An important structural difference that affects feed demand across regions and farm systems, is that of animal liveweight. DairyBase allows for farmer-reported liveweight estimates, but it is not a compulsory field, and so is not always reported, and when they are, are not particularly accurate. This is for a range of reasons, but primarily because few farmers regularly weigh dairy cattle, and if they did, the time of year would affect the liveweight dramatically. However, aggregating at region or farm system level can be considered indicative across the data set. While there appear to be only modest differences comparing across regions (**Error! Reference source not found.**), there is some divergence in some regions from the numbers estimated by DairyNZ (2019). More importantly, the farm system effect is quite marked, with liveweight increasing as farms import more feed, partly through higher average condition score, but primarily due to different animal genetics (**Error! Reference source not found.**).

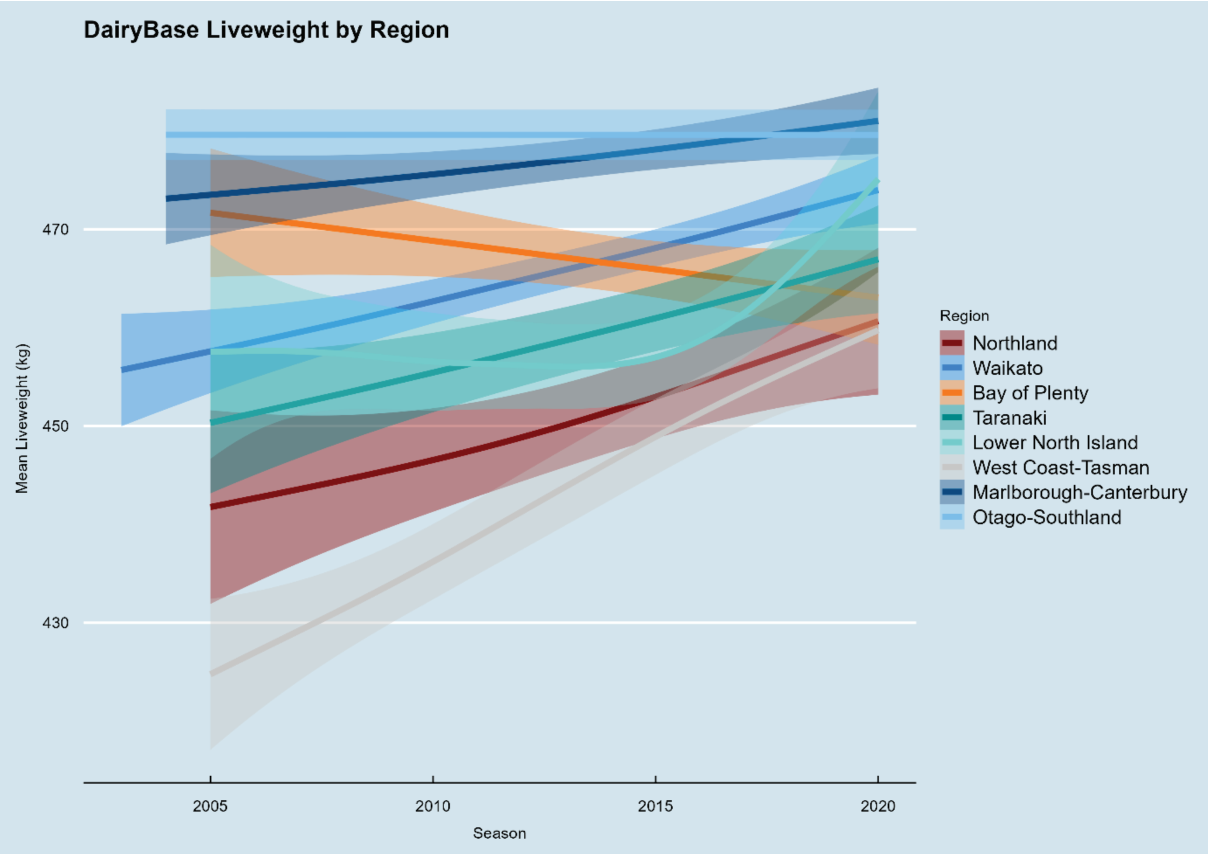

Figure 17: Comparison of trends in mean liveweight by region.

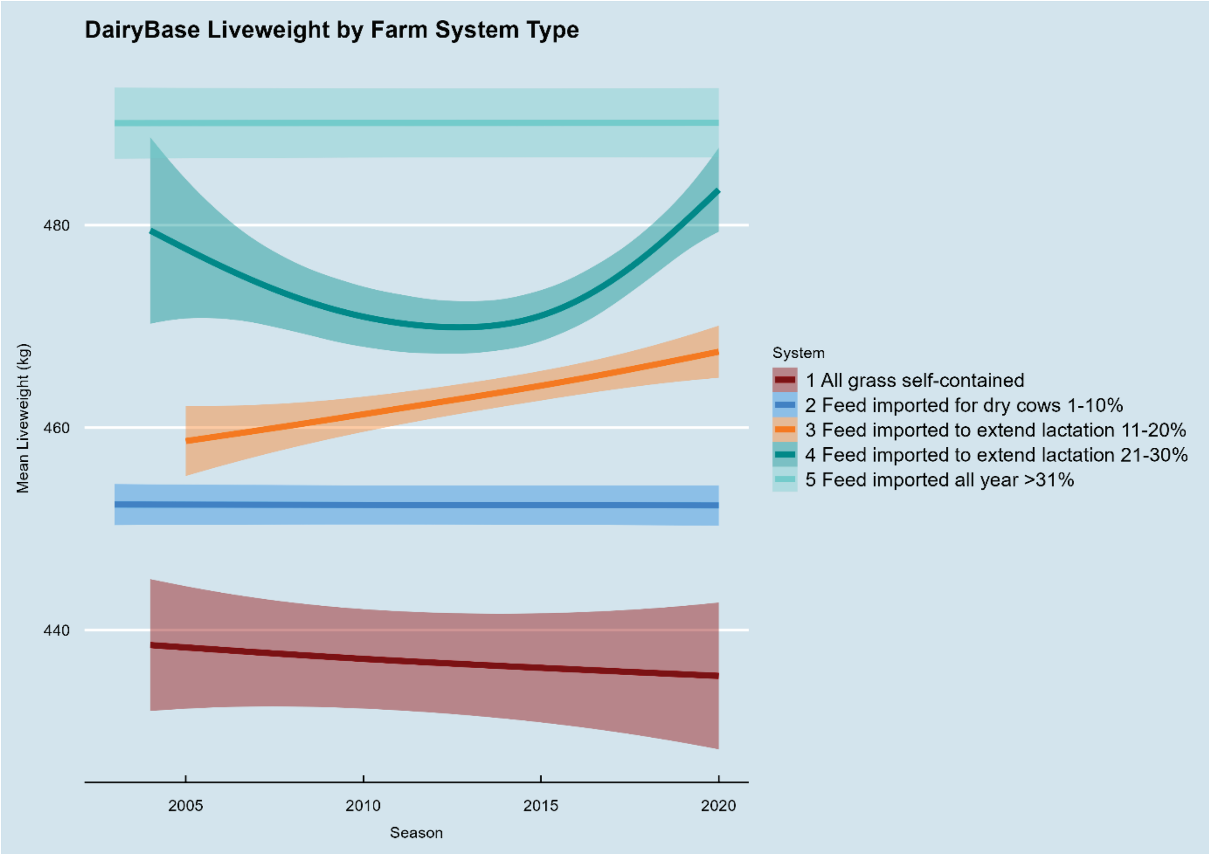

Figure 18: Comparison of trends in mean liveweight by farm system type.

7.2 Feed Definition Differences

DairyBase includes calculated estimates for the amount of home-grown pasture and crop eaten on farm, and also records imported feeds. These feeds are recorded on a dry matter (DM) basis only. However, the feeds included differ from those estimated in DairyNZ (2019) (Section 6.4), and from those recorded in the Farmax data (Section 7.4). That is, although feeds eaten are reported in several data sets at the national, regional, district and farm level, there is no standard feed list. The livestock classes included, and the method of defining and measuring feed use, differs between data sets, and is difficult to reconcile.

Table 2 compares the feed definitions between several of the key data sets, and attempts to define a "Master" delineation (based on Farmax) that can be used to reconcile across data set. These are capitalised where they refer to database filed, and lower case otherwise.

Note that the feeds included under "Pasture" could evolve over time. For example, plantain is not currently explicitly recorded in any of the data sets, but has different nutritive characteristics, and could become important in the near future (for example, when adopted at scale to reduce nitrate leaching).

Table 2: Feed definition differences across the different data sets. Includes feeds that are fed to (all) all animals or (cows) mixed age cows only, as indicated.

Master[1] (cows)	DairyNZ (2019)[2] (cows)	DairyBase[3] (all)	Farmax[4] (all)
Concentrate	Barley	Barley Grain	Concentrates
Concentrate	Wheat		Concentrates
Concentrate	Oats		Concentrates
Concentrate	Cottonseed		Concentrates
Concentrate	Maize Grain	Maize Grain	Concentrates
Concentrate		Meal	Concentrates
Concentrate		Broll	Concentrates
Concentrate	Soyabean	Soyabean Meal	Concentrates
Concentrate	Tapioca	Tapioca	Concentrates
Hay		Cereal Straw	HayStraw
Hay		Hay	HayStraw
Hay		Lucerne Hay	HayStraw
Cereal Silage	Cereal Silage[5]	Cereal Silage	
Imported Silage		Baleage	
Imported Silage		Pit Silage	
Maize Silage	Maize Silage	Maize Silage	Maize Silage
Maize Silage		Sweetcorn Silage	
PKE	PKE	PKE	PKE
Crop	Fodder Beet		Crop
Crop	Kale		Crop
Crop	Rape		Crop
Crop	Turnips		Crop
Crop	Swedes		Crop
Other		Proliq	Other
Other		Molasses	Other
Other		Brewers Grains	Other
Other		Potatoes	Other
Other		Kiwifruit	Other
Other		Carrots	Other
Other	Other	Other	Other
Pasture/Silage	Pasture[2]	Pasture[3]	Pasture[4]
Pasture/Silage			Silage[4]

[1] Master covers feed types eaten by dairy cows, from any source (milking platform, support block, bought in).

[2] DairyNZ (2019) covers feeds eaten by dairy cows, primarily from imported feeds and sown crops (whether grown on the milking platform or not). "Pasture" includes hay, pasture silage, chicory, plantain, lucerne, etc. (and not fodder beet, kale, rape, turnips and swedes) and is inferred from an

energy balance. Byproducts are included under “Other Supplements”. Sangster (2022) also adopted this definition of supplementary feed.

[3] DairyBase covers feed imported onto the milking platform (both from the support block and bought in) for adult animals and young animals while on the milking platform. Pasture, hay and crops grown, possibly conserved, and consumed on the platform are classed together as “Pasture and Crop Eaten” (a.k.a., “Pasture”). In particular, forage crops on the milking platform are not separated from pasture in the back-calculation approach.

[4] Farmax covers feed types eaten by dairy cows and young livestock on the milking platform only, from any source (milking platform, imported from the support block, bought in). Pasture, hay, silage and forage crops are listed separately. This data set therefore does not include grazing off, and we have excluded cases where the support block appears to included or where significant numbers of non-dairy stock affect overall demand.

[5] Cereal Silage is ensiled triticale, barley, or wheat, and is typically of lower quality (de Ruiter, 2019).

7.3 DairyBase Feed Use

Figure 19 shows the average proportion of pasture, grazing off and imported supplements used from 2012-2020 in DairyBase farms of the five different system types (as self-reported) in different regions of New Zealand. Subsets with less than 10 farm-years of data were excluded.

As expected, supplement use increased from System 1 to System 5 farms. In the North Island additional feed was primarily imported supplement, whereas in the South Island a larger amount of Grazing Off was used, and the proportion was quite consistent from System 2 to System 5. Pasture remains the dominant feed across all farm system types.

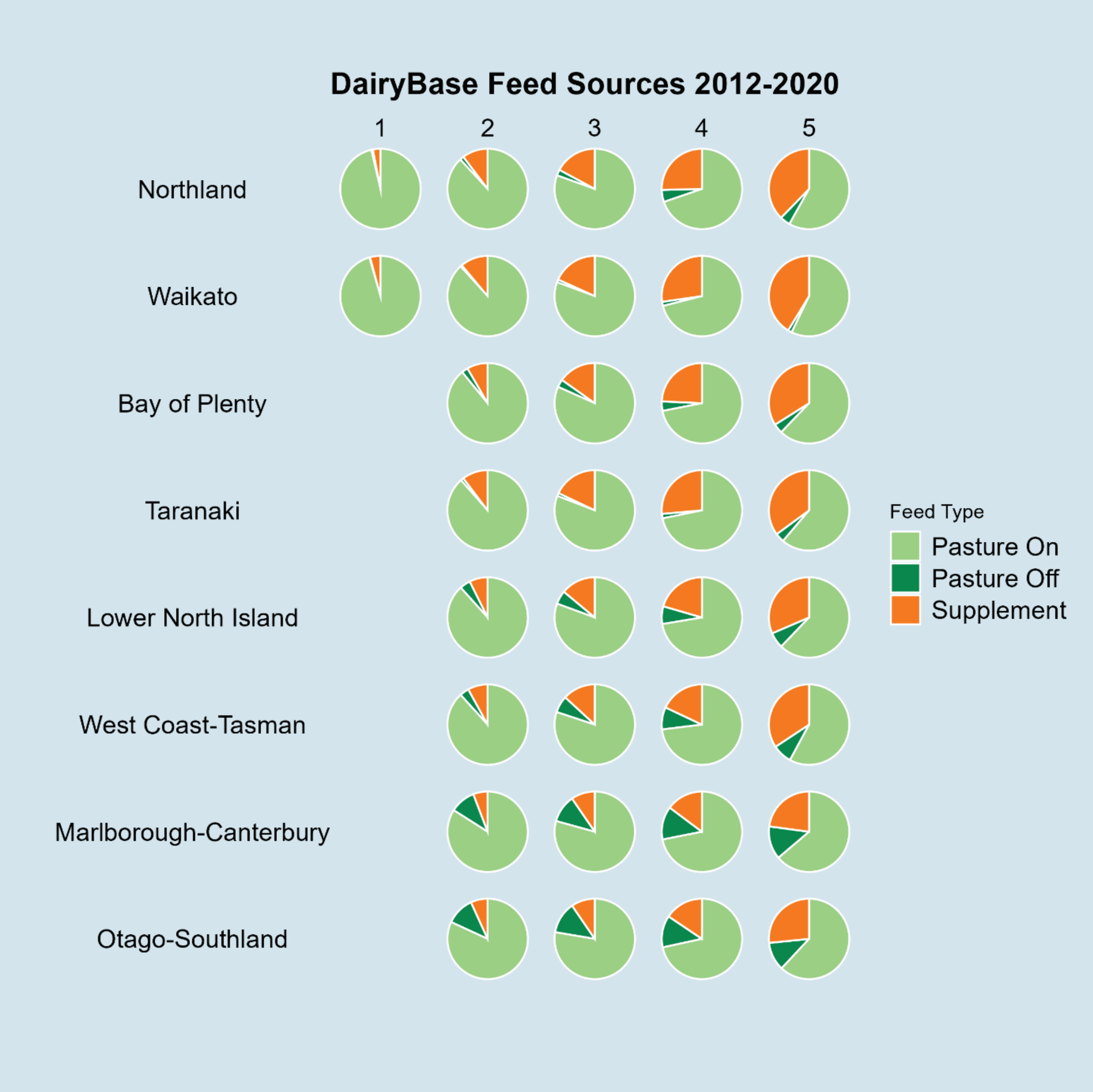

Figure 19: Average Pasture and Crop grown On Farm, Pasture and Crop from Off Farm, and Imported Supplement use by region and farm system type, for the DairyBase farms from 2012-20. Systems with less than 10 data points were omitted. Feed exported from the milking platform is not considered as intake. The calculation of intake from young stock is accounted for in pasture eaten on the platform, but not accounted for in imported feed.

To give more detail, Figure 20 shows the breakdown of imported supplement types used (eaten) in different regions of New Zealand. Palm Kernel was used the most, with Pasture Silage and Maize Silage also being popular. Usage varied across regions with greater amounts of Palm Kernel in the North Island compared with greater usage of Pasture Silage in the South Island. Other regional differences were the use of Hay in the lower intensity systems in the North Island, Meal in the Waikato and West Coast-Tasman, Proliq in Taranaki, and Barley Grain in the central and southern parts of the South Island.

Assuming the sampled farms are typical of farms in each region, these differences could result in differences in Greenhouse Gas emissions across regions associated with different feed types, especially in systems using a high proportion of imported feed and motivate a more accurate accounting of feed use.

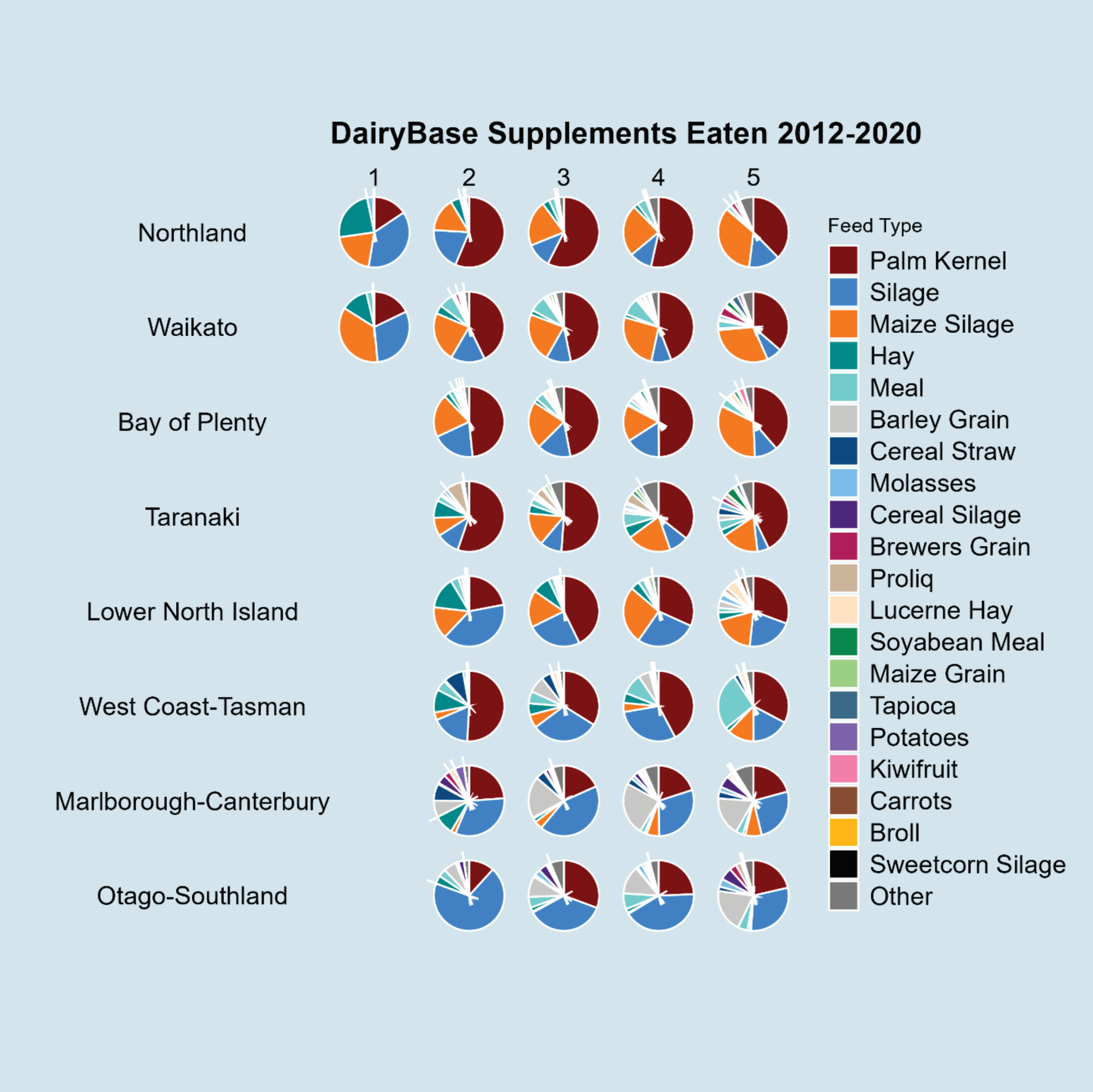

Figure 20: Breakdown of average imported supplement types used by region and farm system type, for the DairyBase farms from 2012-20. Systems with less than 10 data points were omitted.

7.4 Farmax Feed Use

Apart from the seasonal feed use patterns estimated in DairyNZ (2019) for 2017-2018, the only data of feed use within the season (year) is provided by data collected for use in the Farmax software. This was provided as anonymous farm-level data, with monthly feed usage. This data represented a small number of farms (approximately 200 records in each year), and mostly the 2015-2021 period. Farmax differs from other data sets described here, in that feed is aggregated for all animal types (including replacements and male animals) but grazing off is excluded.

The timing of feed use varies between regions. The data from Farmax shows the different seasonal patterns of feed use between regions (Figure 21). To estimate farm system type (1-5), we assumed that 0% of pasture was imported onto the milking platform, 10% of hay-straw and silage was imported, 90% of crop and maize silage was imported, and 100% of all other feeds was imported. This can later be checked for consistency with DairyBase, where percentage of area cut for hay and silage, and areas of winter and summer crops are recorded, though yields would still need to be estimated based on expert opinion. Farm system type was then inferred as per the revised definitions in DairyNZ (2021) which uses the imported feed percentages ranges 0-10,10-20, 20-30, 30-50, and 50-100 to define the five farm system types.

Figure 21 highlights the differences in data availability between regions, with Northland, Taranaki and West Coast being poorly represented. This results in a poor estimate of these regional averages. This reflects the commercial nature of the tool where regional support and familiarity may vary. The tool is also less likely to be used in smaller, low intensity farms, and possibly also in more intensive farms where pasture makes a smaller percentage of the diet, and so pasture management may be considered less important.

Farmax also differs from other data sets in that only the milking platform is represented, and all animal classes on that platform (including young stock and bulls). Furthermore, wintering off feed and stock are not included (as clearly seen in the South Island data), making it difficult to compare with data with other data sets.

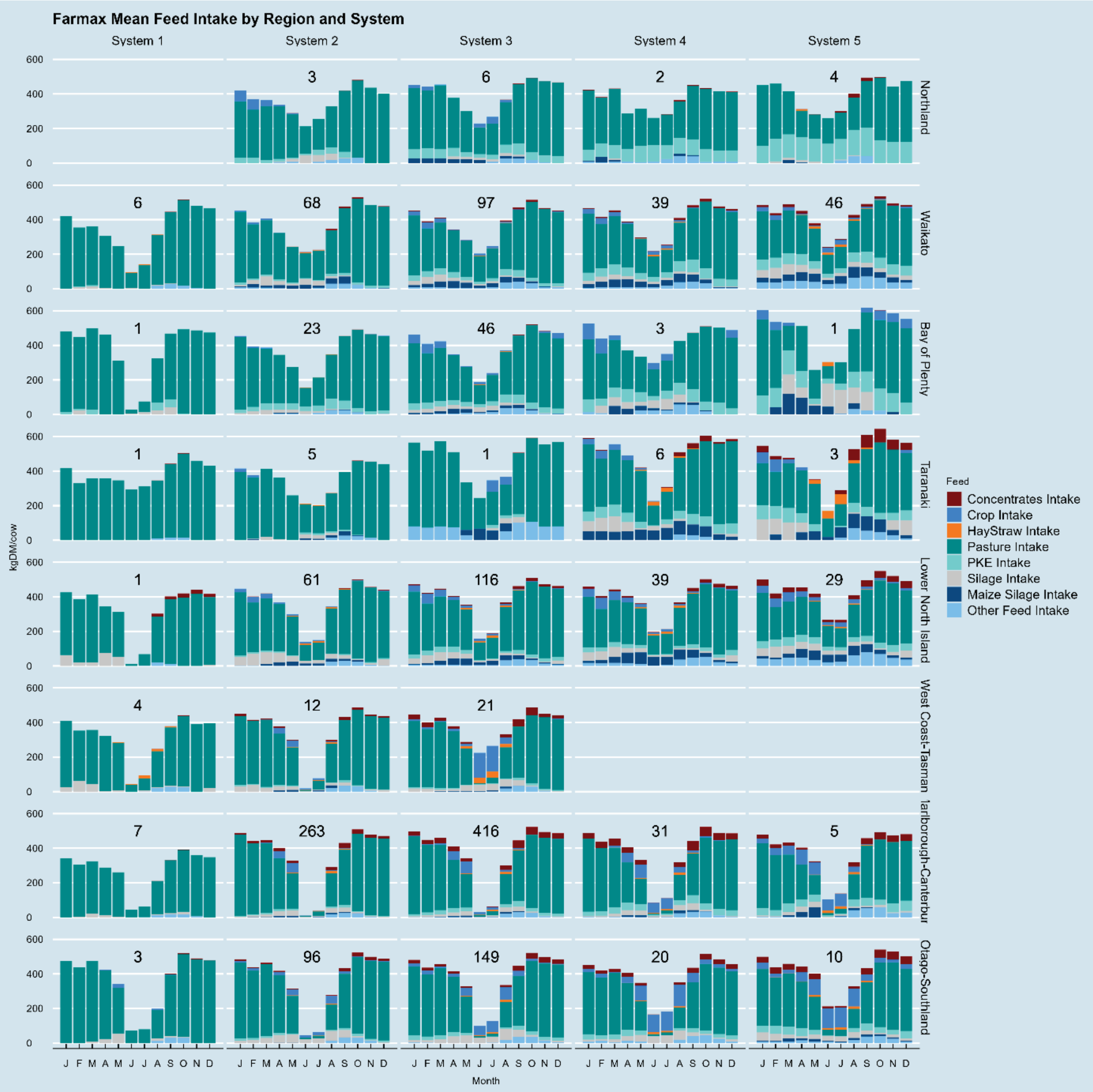

Figure 21: Average feed components eaten in each month by region and farm system type, from Farmax. The number within the plot facet refers to the number of farms represented in the data.

7.5 Conclusions

Current data sets established since the 2000s offer a lot more resolution and detail than previous periods but are some are presently not assured to be representative. DairyBase in particular captures a wealth of farm physical and financial information on an annual basis, and gives good national coverage, although the sample of farms surveyed is biased towards larger farms. DairyBase also does not provide any within-season information, and the energy balance model used to determine pasture and crop eaten may benefit from a review, for consistency with other methods, including Farmax and the wider GHG Inventory approach.

Debiasing this data to make national assessments is currently an open problem. To produce the annual Economic Survey (e.g., DairyNZ 2022), DairyNZ uses a statistical process to censor the DairyBase sample, with the aim of more closely matching farm size, herd size and production per cow at a regional level. While this could feasibly be used to reduce some sources of bias, it is not necessarily guaranteed to reduce bias in the type of most relevance to this report, being feed amounts. Additionally, the sample size of Farmax data is likely to be too small to effectively apply this process in some regions.

The farm system type definitions developed by DairyNZ (2010) and revised In DairyNZ (2021) (Section 7.2) have provided extremely valuable for simplifying discussions of alternative farm systems relying on different amounts of imported feed. However, they do mask some differences in feeding. For example, the types and timing of imported feed use has changed significantly since 1990 (Figure 11), so that a System 3 farm in 1990 is likely to have been very different from a System 3 farm in 2020. The timing within the year of feed use of different types also varies between regions for farms of the same system designation (Figure 21).

The Farmax data also provides very rich information on seasonal feeding on individual farms. This is commercial data that is specific to Farm clients and is not collected for the intention of informing national assessments. Since the data is primarily used for annual feed planning, the data quality and completeness may also be variable. Due to the different basis for the farm definition, wintering off feed data is not included, an issue particularly for South Island farms (Figure 21).

Overall, despite increasing interest in dairy industry data collection, coordination between the different data sources (DairyStats, DIGAD, StatsNZ, DairyBase, DairyNZ Milksolids, AgriBase, Farmax, etc.) is poor. Each data set is administered independently and for different purposes, so that connecting them is not routine, requiring considerable relationship and technical effort. Detailed pasture and feed use information in particular is relatively sparse, DairyBase being the only database that collects this on a regular basis, and not for all farms, and not at a monthly level. There is likely to be useful processor level data collected for more recent years, though access would need to be negotiated. Anonymised data from other sources (e.g., Overseer) may also be possible to access in the future.

There exist tradeoffs when approaching finer levels of categorization using sample data. For example, within a year, a region, and a farm system, there are fewer observations in each category, and so variation due to fixed effects reduces, but sample size variation increases. This is likely to occur with a number of the sample data sets. One approach is then to average or model within a group of years, which may capture slow moving trends (e.g., feed intensification over time), but smooths year to year variation (e.g., due to drought, economic conditions, etc.). Further work and discussions would be required to quantify these tradeoffs, and determine which approaches provide the best possible outcome.

8 Looking Forwards

8.1 The Value of Feed Information

The Agricultural Inventory Model for the New Zealand Greenhouse Gas Inventory primarily focuses on modelling the populations of animals to determine feed demand (Burggraaf et al., 2021). More detail around feed types and feed quality is still being developed and requires improved data (Sangster, 2022). The aim of the current project was to assess the feasibility of using existing dairy industry data sets to provide a more nuanced picture of feed use within the industry, with dairy farm systems as an informative category between micro and regional/national level data. This would allow us to answer questions such as:

- What are the dominant feeds in terms of enteric and non-enteric emissions?
- How do feed use and emissions vary throughout the year, and how does this relate to the feed quality of the diet?
- What feeds need further science to give confidence that the inventory is as accurate as possible?
- What data are required in the future to support more accurate emissions estimation?

8.2 Data Sources

The following data sets will continue to provide useful data in the future:

- DairyBase
- DairyNZ Milksolids
- DIGAD
- Dairy Statistics (DairyStats)

Note that from 2023 data collation and aggregation for the Dairy Statistics publication will be conducted primarily by DairyNZ (previously this was done primarily by LIC). Additionally, due to improvements as a result of the review of the Herd Test Standard, NZAEL (a DairyNZ subsidiary) will have improved interoperability of DIGAD with additional data sources. As an example, we understand at least one major dairy processor has recorded annual feed types at farm level for most of a decade.

It is also likely that as freshwater farm plans are implemented, as well as the likely farm-level reporting requirements for GHGs (through He Waka Eke Noa or alternative scheme), that improved standards for data recording, and lower friction permission systems will emerge, which could improve inventory estimates. Other datasets that exist and could potentially accessed with further negotiations, including Overseer or Processor data that may be anonymised.

8.3 Filling the Gaps

There are some methods for using the existing data could be used to fill out the picture of feed eaten from 1990-2020, though more work would be required to determine the chance of success. The key issues are how one might correct for the bias in the DairyBase and Farmax data.

In the first method, we would establish a set of bins that describe the farms in the national data sets. The bins would give ranges of key variables, e.g., farm size, cow numbers, milk production, feed use. We could then weight the farms in DairyBase and Farmax to match these frequencies in the bins. However, this method requires that we know the distributions of the variables describing the national farms, whereas most of the historical data only provides regional averages or totals. Therefore, the bins cannot be easily specified.

In the second method, we group the DairyBase or Farmax farms into bins and then assign and calibrate weights for each bin, so that the resulting regional and national statistics match the historical data. This is a more flexible but computationally demanding approach. Furthermore, it will still only give a partial result, since DairyBase or Farmax probably do not contain enough (or any) farms in certain classes that were important in the past (e.g., farms using a large amount of cereal silage or oats, supplementary feeds that were popular prior to the establishment of these data sets. Also, farm systems are influenced by their environment (weather, product availability, prices, etc), and past environments may not have any analogue in the recent data, so that the differences between recent and older farms may not be simply a matter of numbers.

Nevertheless, the approach is illustrated here. From DairyBase (2012-2020) (Figure 13), we can calculate the mean and standard deviation of imported feed fraction per cow in each region. The average mean is 0.217 and the average standard deviation is 0.095. Assuming that the distribution of imported feed per cow can be modelling using a truncated normal distribution (Wikipedia, 2023), and that a fixed standard deviation of 0.095 is suitable, we can use the average proportion of feed imported in each season and region estimated in Figure 12 to infer the proportion of cows in the five farm system types (as defined in DairyNZ, 2021, with System 5 as 40%+ imported feed) in each season and region (Figure 22).

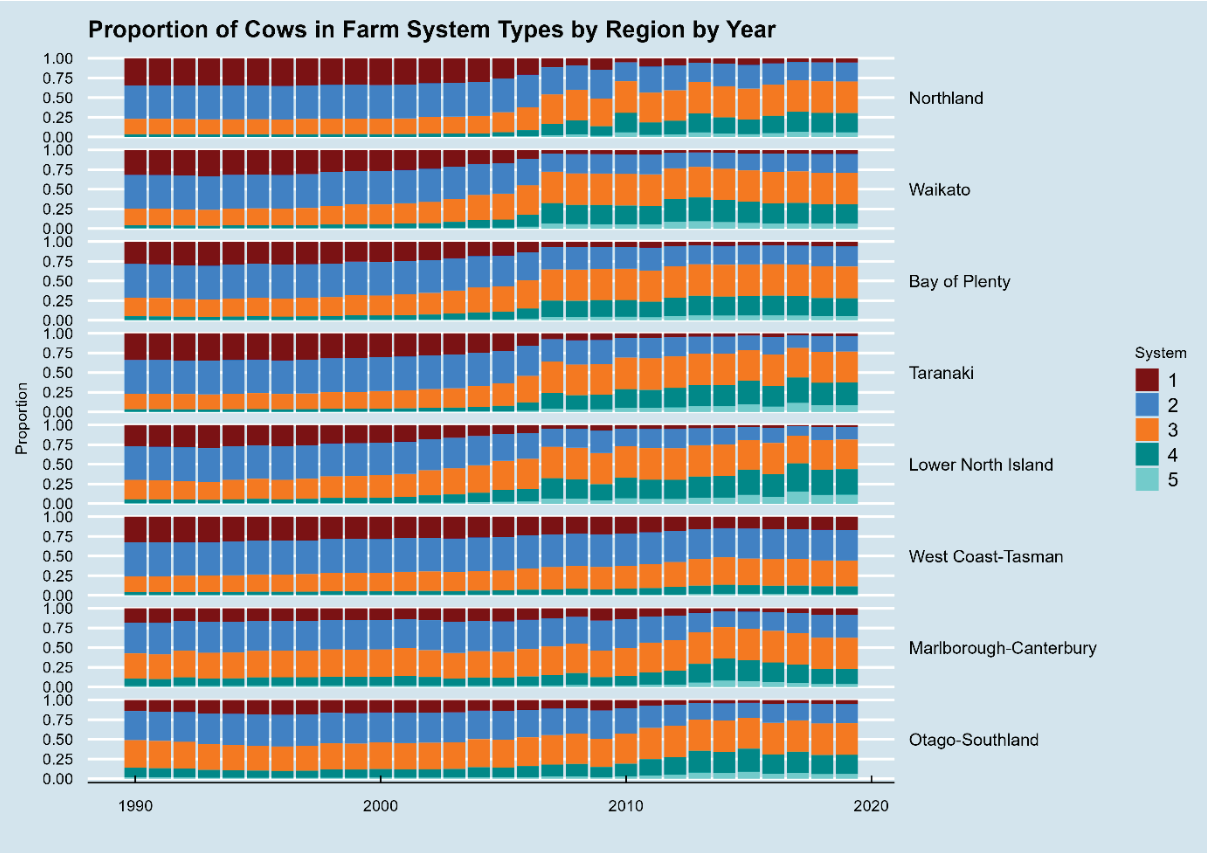

Figure 22: Model of cows in each farm system in each region based on DairyNZ (2019) feed import data (Figure 12).

Based on this distribution, feeds per cow can be inferred from the Farmax data as in Figure 21, but with the updated farm system definitions used in Figure 22, as shown in Figure 23. The data for doing this is currently quite limited however and it requires further work to develop a robust model which can be maintained into the future. There are some region-system combinations without data, though they could be approximated by the same farm system in the nearest region.

The data used to generate Figure 22, in combination with the data from Figure 23, can be multiplied through by the number of cows per region, per year, to generate the amount of feed (of each type) eaten in each month, in each region, in each farm system, in each year. The resulting data can then be aggregated a number of ways, allowing for emissions factors that could vary based on any of these parameters (i.e., feed type, month, year, region and farm system). We consider this the best currently available option that could be developed within the data, time and budget constraints of this project.

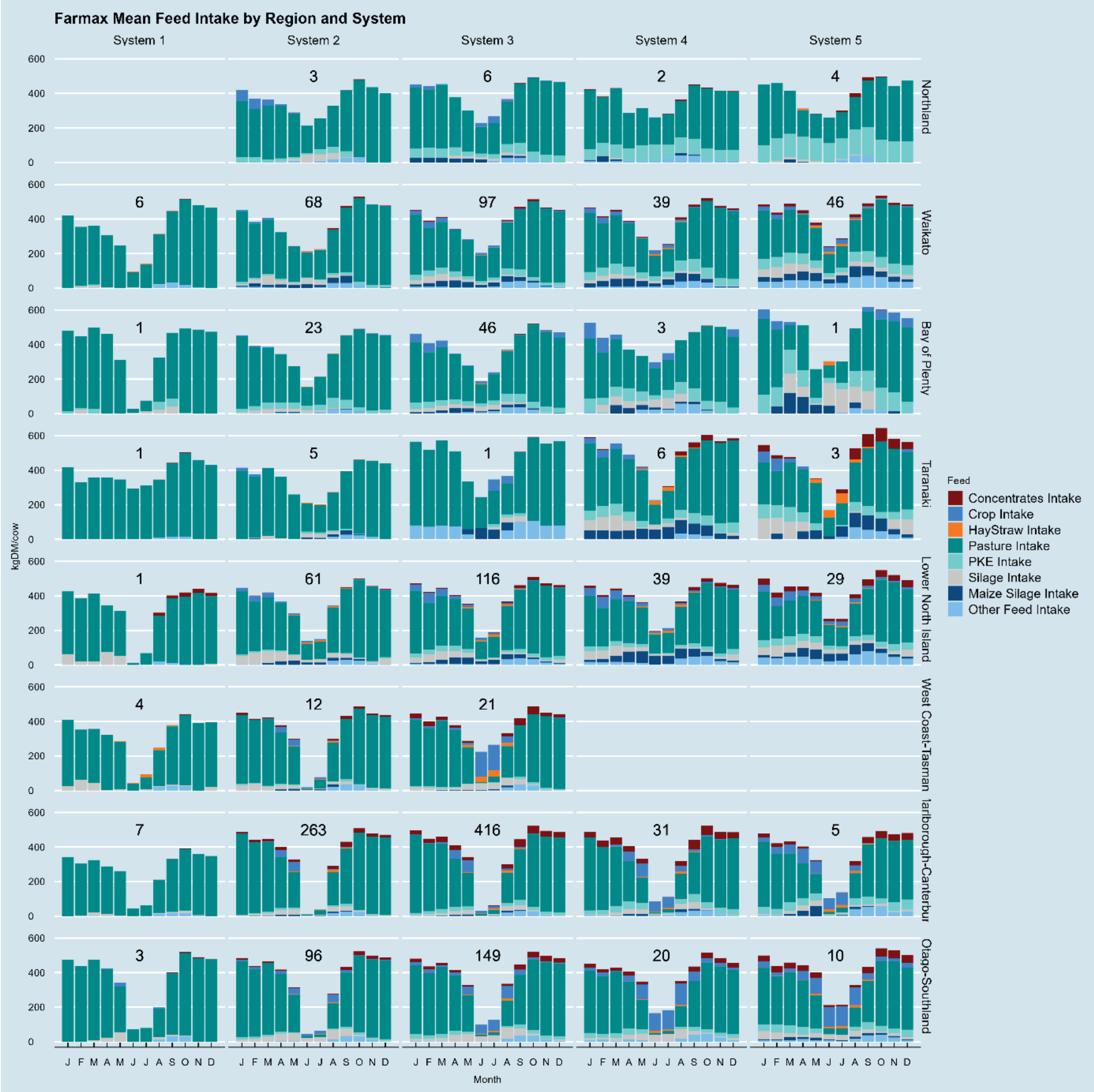

Figure 23: Average feed components eaten in each month by region and farm system type, from Farmax, using the updated farm system type definitions from Figure 22. The number within the plot facet refers to the number of farms represented in the data.

A third method is to use existing data to simulate key variables for farms, based on the population means and distributional data where available. Relationships between key variables are maintained based on correlations in the DairyBase data. This approach has been used by DairyNZ previously (e.g., Doole et al., 2021), though would need additional adjustment to deal with the variety of distributional data now available to ensure greater accuracy. Feed demand can then be built up with an energetics model, taking monthly pasture supply distributions from Farmax data and supplementary feed type and timing informed by Farmax data. Additional modelling for the pasture curve in areas with gaps would likely be needed, and DairyNZ has substantial experience in this space (e.g., Beukes et al. 2022; Harris-Wight et al., 2022). Modelling the historical period would allow for the effect of N fertiliser use to be incorporated consistently, incorporating expert opinion and national fertiliser use statistics. Care needs to be taken to ensure that there is a consistent understanding of land area (e.g., effective milking platform) to allow for interoperability. Aggregating feeds to a few high-level categories may allow for the changes within categories over time (e.g., cereal silage to related feeds) to be determined after the overall feed budget is calculated on an energetics basis.

8.4 Conclusions

A set of estimates for dairy cattle feeds, by month and by region was developed. At this point, three options are possible from an inventory perspective:

1. Keep (indefinitely) the existing inventory approach to feed eaten by dairy cattle (intake driven by animal class, supplementary feed included at high level).
2. Adjust the inventory to use regional and farm system herd size and feed profiles developed in this report (likely more accurate, though some bias may exist in recent years (2010-), and uncertainties in estimation for earlier years (1990-2010) remain).
3. Through additional work, develop more comprehensive and consistent understanding of feed use by dairy cattle taking into account:
   - Accurate cow numbers by region and month, with further cross validation of various sources.
   - Feed characteristics for pasture by region (dry matter, energy, nitrogen content) and month. This should likely include material changes such as proportion of plantain, and different forms of pasture eaten such as hay and silage. Related changes in the conversion of dry matter to methane, and dry matter to nitrogen excretion, would need to be consistent with these factors.
   - Energetics calculations, where these should be consistent between supply of feed, and demand, which in part is determined by liveweight and is shown to vary by farm system and region.
   - Nitrogen partitioning and loss (including spatial nitrogen loss, and the effects of soil type and slope).
   - Consideration of Whenua Māori as a category of emissions.
   - Accounting for differential adoption of inhibitor technology by region and farm system.

8.5 Action Points

Here we suggest some actions for consideration in respect of future work.

- Align DIGAD more closely with DairyStats to allow for population means, distributions and correlations to be better understood. Improve efforts to capture all animals and ensure accurate numbers, which may improve over time with NAIT and implementation of the Herd Test Standard.
- Improve liveweight data. A number of avenues to improve this are being considered, including improving access to on farm data and end of life data (i.e., from meat processors). This may then allow a genetic model of liveweights to impute at animal level back to 1990, which can then be aggregated up to regional and national levels on an annual basis.
- Record routinely national/regional feed use as part of an existing data collection framework.
- Establish ongoing relationship with Farmax for data provision or include monthly feed use (similar to Farmax) into DairyBase.
- Establish/modify farm system typology that is valid back to 1990, which could be more than a percent of imported feed but also what and when.
- Develop spatially and temporally specific feed estimates that could improve the ability to model the fate of nitrogen, and its interaction with feed quality, soils and slope.

9 References

Beukes, P., Chikazhe, T., Williams, I., 2022. A dedicated maize block as a nitrogen mitigation strategy for Waikato dairy farms, Australasian Dairy Science Symposium, Sunshine Coast, 28 December 2022.

Burggraaf, V., Benson, C., Rollo, M., 2021. Dairy cattle population model: Improving estimates of within-year population changes used in the inventory. Report for the Ministry of Primary Industries. https://www.mpi.govt.nz/dmsdocument/56077-A-review-of-the-report-Improving-estimates-of-within-year-dairy-cattle-population-change

DairyNZ, 2010. Facts and Figures for New Zealand Dairy Farmers, 1st Edition. DairyNZ Ltd, Hamilton, NZ.

DairyNZ, 2016. Feed Use in the NZ Dairy Industry. MPI Technical Paper 2017/53. Prepared for the Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/20897-feed-use-in-the-nz-dairy-industry

DairyNZ, 2019. Feed Consumed by NZ Dairy Cows: An update of feed volumes consumed by New Zealand dairy cows nationally and regionally since 1990-91. Prepared for the Ministry of Primary Industries. https://www.mpi.govt.nz/dmsdocument/46231-Feed-Consumed-by-NZ-Dairy-Cows

DairyNZ, 2021. Facts and Figures for New Zealand Dairy Farmers, 2nd Edition. DairyNZ Ltd, Hamilton, NZ.

DairyNZ, 2022. Economic Survey, DairyNZ Ltd, Hamilton NZ https://www.dairynz.co.nz/publications/dairy-industry/dairynz-economic-survey-2020-21/

DairyNZ, 2023. The Dairy Industry Good Animal Database (DIGAD). https://www.dairynz.co.nz/animal/animal-evaluation/animal-database/

de Ruiter, J.M., 2019. Cereal silage crop management: current state of knowledge. Confidential report for: Foundation for Arable Research (FAR). https://www.far.org.nz/articles/1278/cereal-silage-crop-management-current-state-of-knowledge

Doole, G.J., Romera, A.J., Leslie, J.E., Chapman, D.F., Pinxterhuis, I.J., Kemp, P.D., 2021. Economic assessment of plantain (plantago lanceolata) uptake in the New Zealand dairy sector. Agricultural Systems 187, 103012.

Edwards, P., 2017. Regional changes in the New Zealand Dairy Industry: 1995-2015. Report for the Kellogg Rural Leadership Programme. DairyNZ, Lincoln.

Glassey, C.B., Wills, G., McCahon, K., Dodd, M.B., Chapman, D.F., 2021. Long-term Central Waikato summer-autumn rainfall and pasture growth trends. Are conditions for pasture growth changing over time? NZGA: Research and Practice Series.

Harris-Wight, F., Pinxterhuis, J.B., Beukes, P.C., Maxwell, T.M.R., Al-Marashdeh, O., 2022. The effect of climate change on a New Zealand dairy system, Australasian Dairy Science Symposium, Sunshine Coast, 28 December 2022.

LIC, 2021. New Zealand Dairy Statistics 2020-21. https://www.dairynz.co.nz/publications/dairy-industry/new-zealand-dairy-statistics-2020-21/

MFE, 2022. New Zealand's Greenhouse Gas Inventory 1990–2020. Wellington: Ministry for the Environment. 500p. https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2020/

Morrissey, C., 2023. Methane models over-estimate what Irish cows produce. Irish Farmers Journal. 25 Jan 2023. https://www.farmersjournal.ie/methane-models-over-estimate-what-irish-cows-produce-745520

MPI, 2022. Methodology for calculation of New Zealand's agricultural greenhouse gas emissions. Version 8. MPI Technical Paper. https://www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation

Nicol, A.M., Brookes, I.M., 2007. The Metabolisable Energy Requirements of Grazing Livestock. In: Rattray, P.V., Brooks, I.M., Nicol, A.M. (Eds) Pasture and Supplements for Grazing Animals, Occasional Publication No. 14, New Zealand Society for Animal Production.

R Core Team, 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rezare, 2020. DataLinker and the Farm Data Standards. https://www.datalinker.org/overview

RStudio Team, 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA. http://www.rstudio.com/.

Sangster, C., 2022. Inclusion of supplementary feed in the Agricultural Inventory Model: For dairy, sheep and beef. MPI Technical Paper No. 2023/04. Prepared for MPI. https://www.mpi.govt.nz/dmsdocument/56395/direct

StatsNZ, 2023. Agriculture Production Statistics. https://datainfoplus.stats.govt.nz/item/nz.govt.stats/6362a469-f374-412e-ac25-d76fd0962003

Wikipedia, 2023. Truncated normal distribution. Accessed on 29 June 2023. https://en.wikipedia.org/wiki/Truncated_normal_distribution

Appendix 1: Plain English Summary

This report is about the dairy industry in New Zealand and how it contributes to greenhouse gas emissions, for example methane, which comes from the feed that dairy cows eat. There are several databases that record information about dairy farms, cows, milk production, and the food that cows eat. One of the methods to group farms is based on their farm system, and this refers to the amount of feed imported from outside the milking area. This information can be combined to get a more accurate view of how much feed cows eat and hence how much methane they produce. The researchers looked at whether it was possible to combine these databases to estimate how much feed cows have eaten every month between 1990 and 2020 in different regions of New Zealand. They used several different databases to do this, but there were some difficulties with getting the information to match up properly. They also found that there was not enough detailed information available for the earlier years in their study. Overall, this research is trying to figure out how to get a better understanding of the feed that cows eat and how much methane they produce, so that accurate estimates of greenhouse gasses can be constructed, and approaches to reduce greenhouse gas emissions can be better informed.

Appendix 2: Tables of Data to be Supplied

Tables were provided to MPI as Excel spreadsheets.

File Name	Referenced in this document
dairystatstimeseries.xlsx	Figure 3
mpireportfeedseries.xlsx	Figure 11
dairybasefeeddata.xlsx	Figure 19, Figure 20
mpireportsysmodel.xlsx	Figure 22
farmaxmonthlyfeed.xlsx	Figure 23