Soil quality and trace element dataset trend analysis (revised version)

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Summary

Project and Background

The Ministry for the Environment (MfE) has requested delivery of regional soil quality, trace element, and site metadata to assess soil quality trends at a national scale for the Land 2021 report. Sampling frequency and land use classes sampled for each sampling period differs across regions. Additionally, maintaining a cohesive and up-to-date dataset for national reporting has proved difficult as there is currently no unified council approach to collating and updating data across regions. The dataset includes data for the seven core soil quality indicators (plus the C:N ratio), trace element data, site identifiers, and land use category for the period 1995–2018. This report summarises temporal trends in the soil quality and trace element dataset for the period 1995–2018.

Methods

A generalised linear mixed effects model (GLMM) using adaptive Gaussian quadrature (built into the “GLMMadaptive” library in R), was used for model fitting. The site identifier “nsdridentifier” is used as an additive random effect to account for correlation. The fixed effects include the sine of the topographic slope, and the interaction between the land use class and the sampling year.

Summary and Conclusions

We are now confident that the statistical models adequately fit the data; however, we would still advise a degree of caution in assessing indicator temporal trends for the Land 2021 report as these trends could be associated with a variety of factors. Because each site within a land use class is managed differently, the degree of variation of individual sites is high and the slopes (where significant) are often only slightly different from 0. Individual indicator trends should be considered within the context of the other statistics associated with that indicator (e.g. what is the median value for that indicator, where does the median value lie within the target range and whether the trend is moving toward or away from midpoint of the target range).

For pH, there was a slight positive increasing trend for the cropping land use. Total carbon and total nitrogen showed decreasing trends in cropping and indigenous land uses. The soil C:N ratio displayed a decreasing trend in cropping, dairy, indigenous, and orchard/vineyard land uses. Olsen P displayed an increasing trend in cropping, drystock, and exotic forestry land uses. There were no significant trends for bulk density but macroporosity exhibited a decreasing trend in exotic forestry (macroporosity trends for dairy and drystock were not significantly different from 0, indicating no further declines on the one hand, but no improvement on the other. For trace elements, there was an apparent increase in arsenic under orchard/vineyards and generally decreasing trends in copper on cropping, drystock, exotic forestry, and indigenous land uses and decreases in cadmium for cropping, exotic forestry, indigenous, and orchard/vineyard. There was an overall increasing trend in chromium over time, but as a GLMM with a land use*date interaction could not be fitted, the slope and confidence intervals are the same across all land uses.

1 Project and Background

The New Zealand soil quality monitoring programme began in earnest with the '500 Soils' programme in 1997 (though precursor studies date back to 1995) and has continued to the present. Maintaining a cohesive and up-to-date dataset for national reporting has proved difficult as there is currently no unified council approach to collating and updating data across regions. Details of curation of the current data set including the land use classification scheme were given in the previous report to MfE (LC3857). Though there have been efforts to report on trends over time on data within a region (e.g., Drewry et al. submitted; Curran-Cournane 2015; Taylor et al. 2017), lack of standardised site naming schemes and changes in site naming schemes within councils over time have hampered creation of a dataset suitable for trend analysis at a national level. Here we utilise the current data set to ascertain temporal trends in the data.

2 Dataset and Methods

Detailed methodology and steps taken to clean, transform, and analyse the data are found in the R markdown (Rmd) file included as a separate file. Note: the report contains only those analyses specifically relevant to State of the Environment reporting. A slightly expanded set of analyses is contained in the Rmd file in order to test some of the assumptions of the current data set. Here we present a brief overview of the statistical methodology:

The data are loaded from a tab-separated text file "SL2019_NSDR_RawData.csv" in directory "../data/". There are 2761 rows in this dataset. The land use class is taken from the field "curated.landuse". The soilorder is taken using the field "curated.soilorder", but is augmented using "nzsc_order_reclass" or "nzsc_order.y" if possible. Once this is done, a total of 14 rows of data do not have a soil order, from 1065 different sites. Of the soilorders in the dataset, a total of 32 are Anthropic, from 19 different sites. These sites are removed from the dataset. The total number of samples per region is indicated in Table 1.

Given the relatively small number of samples in the "Misc", "nomatch", "Scrub", "Lifestyle", and "Tussock" land use classes, these samples are removed before analysis. Probability density plots of each indicator were examined, and the data log transformed to meet assumptions of normality.

Table 1: New Zealand regions and the number of samples with valid locations in each region

Region	Num. samples	Num. sites	First year	Last year	Unknown locations	Missing soilorder	Missing land use
Auckland	443	169	1996	2017	0	0	0
Bay of Plenty	288	82	1999	2017	0	0	0
Canterbury[1]	154	88	1996	2019	10	0	0
Hawke's Bay	223	109	2000	2019	0	0	0
Manawatu-Wanganui	55	55	2015	2018	0	0	0
Marlborough	328	89	2000	2018	0	0	0
Nelson	15	15	2018	2018	0	0	0
Northland	102	29	2001	2016	4	0	1
Southland	57	57	2010	2015	0	0	0
Taranaki	108	59	1999	2017	0	0	0
Tasman	42	31	2001	2015	0	0	0
Waikato	492	156	1996	2017	9	0	0
Wellington	408	118	2000	2018	0	0	0

[1]Canterbury has a larger dataset of samples, but those additional samples were taken using different methodology and sampling depths, so are not included here.

Detailed description of the modelling process is given in the Rmd file, but, in summary, for model fitting a generalised linear mixed effects model (GLMM) using adaptive Gaussian quadrature (which is built into the "GLMMadaptive" library in R) was used. The site identifier "nsdridentifier" is used as an additive random effect, to account for correlation. The fixed effects include the sine of the topographic slope, and the interaction between the land use class and the sampling year. Soil order is not included since an early exploratory analysis showed that it had very little explanatory effect over and above that of the other explanatory variables. However, data from Anthropic soils are specifically excluded from the analysis.

Table 2: Summary of the models used for modelling each of the soil properties. The formula is given using Wilkinson notation

Property	Type	Formula
Gravimetric Olsen P	GLMM	OlsenP_ug_g ~ sin(slope) + landuse*syear
Total carbon concentration	GLMM	TotalC_pct ~ sin(slope) + landuse*syear
Total Nitrogen concentration	GLMM	TotalN_pct ~ landuse*syear
Carbon-to-Nitrogen ratio	LMM	CN_Ratio ~ sin(slope) + landuse*syear + (1|nsdridentifier)
pH	LMM	pH ~ sin(slope) + landuse*syear + (1|nsdridentifier)
Bulk density	GLMM	Bulk_density_t_m3 ~ sin(slope) + landuse*syear
Anaerobic mineralisable Nitrogen	LMM	AMN_ug_g ~ landuse*syear + (1|nsdridentifier)
Macroporosity (5 kPa)	GLMM	Macroporosity_5kPa ~ sin(slope) + landuse*syear
Cadmium concentration	GLMM	Cd ~ sin(slope) + landuse*syear
Macroporosity (airfilled porosity 10 kPa)	GLMM	Macroporosity_Airfilled_porosity_10kPa ~ sin(slope) + landuse*syear
Zinc concentration	LMM	Zn ~ sin(slope) + landuse*syear + (1|nsdridentifier)
Copper concentration	GLMM	Cu ~ sin(slope) + landuse*syear
Lead concentration	GLMM	Pb ~ sin(slope) + landuse*syear
Arsenic concentration	GLMM	As ~ sin(slope) + landuse*syear
Chromium concentration	GLMM	Cr ~ sin(slope) + landuse + syear
Nickel concentration	LMM	Ni ~ sin(slope) + landuse*syear + (1|nsdridentifier)

3 Results

Table 3 summarises the slope and confidence intervals for each indicator and land use. If the confidence interval is inclusive of 0, the slope of the trend line is not significantly different from 0. Figures for temporal trends for each indicator (by land use) are shown in the appropriate indicator subsections.

Table 3: Table of 95% confidence intervals of slope for each model and land use. Confidence intervals that are significant (i.e. confidence intervals that do not include zero) are highlighted in yellow

Property	Cropping	Dairy	Drystock	Exotic Forestry	Indigenous vegetation	Orchard/Vineyard
Gravimetric Olsen P	[0.023,0.257]	[-0.069,0.229]	[0.021,0.306]	[0.016,0.400]	[-0.485,0.150]	[-0.144,0.198]
Total carbon concentration	[-0.247,-0.040]	[-0.145,0.078]	[-0.105,0.099]	[-0.221,0.135]	[-0.317,-0.060]	[-0.233,0.019]
Total Nitrogen concentration	[-0.204,-0.024]	[-0.062,0.126]	[-0.071,0.135]	[-0.235,0.179]	[-0.222,-0.004]	[-0.165,0.031]
Carbon-to-Nitrogen ratio	[-1.016,-0.006]	[-1.508,-0.221]	[-1.203,0.044]	[-0.959,0.685]	[-2.077,-0.641]	[-1.414,-0.045]
pH	[0.010,0.197]	[-0.070,0.169]	[-0.132,0.099]	[-0.203,0.099]	[-0.126,0.140]	[-0.165,0.088]
Bulk density	[-0.005,0.082]	[-0.024,0.077]	[-0.053,0.046]	[-0.040,0.125]	[-0.009,0.121]	[-0.047,0.059]
Anaerobic mineralisable Nitrogen[1]	[-24.626,0.780]	[-23.454,9.104]	[-24.686,6.779]	[-21.099,20.246]	[-42.127,-5.937]	[-26.982,7.384]
Macroporosity (airfilled porosity 10 kPa)	[-0.222,0.081]	[-0.313,0.083]	[-0.262,0.079]	[-0.452,-0.071]	[-0.354,0.041]	[-0.249,0.151]
Cadmium concentration	[-0.204,-0.049]	[-0.200,0.039]	[-0.171,0.039]	[-0.611,-0.013]	[-0.502,-0.159]	[-0.247,-0.066]
Zinc concentration	[-8.216,0.436]	[-2.160,8.844]	[-9.224,1.448]	[-12.407,1.679]	[-12.247,0.003]	[-7.791,3.945]
Copper concentration	[-0.162,-0.015]	[-0.085,0.084]	[-0.217,-0.024]	[-0.400,-0.017]	[-0.273,-0.020]	[-0.090,0.187]
Lead concentration	[-0.083,0.030]	[-0.075,0.055]	[-0.125,0.035]	[-0.124,0.125]	[-0.172,0.076]	[-0.112,0.049]
Arsenic concentration	[-0.060,0.088]	[-0.098,0.082]	[-0.093,0.144]	[-0.142,0.123]	[-0.058,0.221]	[0.078,0.263]
Chromium concentration[2]	[0.012,0.074]	[0.012,0.074]	[0.012,0.074]	[0.012,0.074]	[0.012,0.074]	[0.012,0.074]
Nickel concentration	[-0.614,0.845]	[-0.625,1.214]	[-0.369,1.432]	[-1.286,1.114]	[-1.207,0.839]	[-1.673,0.305]

[1] The model for anaerobically mineralizable N was difficult to fit, consequently confidence intervals were large.

[2]A GLMM with the land use effect could only be fitted as an additive affect for chromium, therefore though values do differ between land uses, the temporal slope (i.e. the coefficients associated with "syear") does not vary and, consequently, the confidence intervals across all land uses are the same.

3.1 Soil pH

There was a slight positive increase in pH under cropping, no other land use trends were significant for pH.

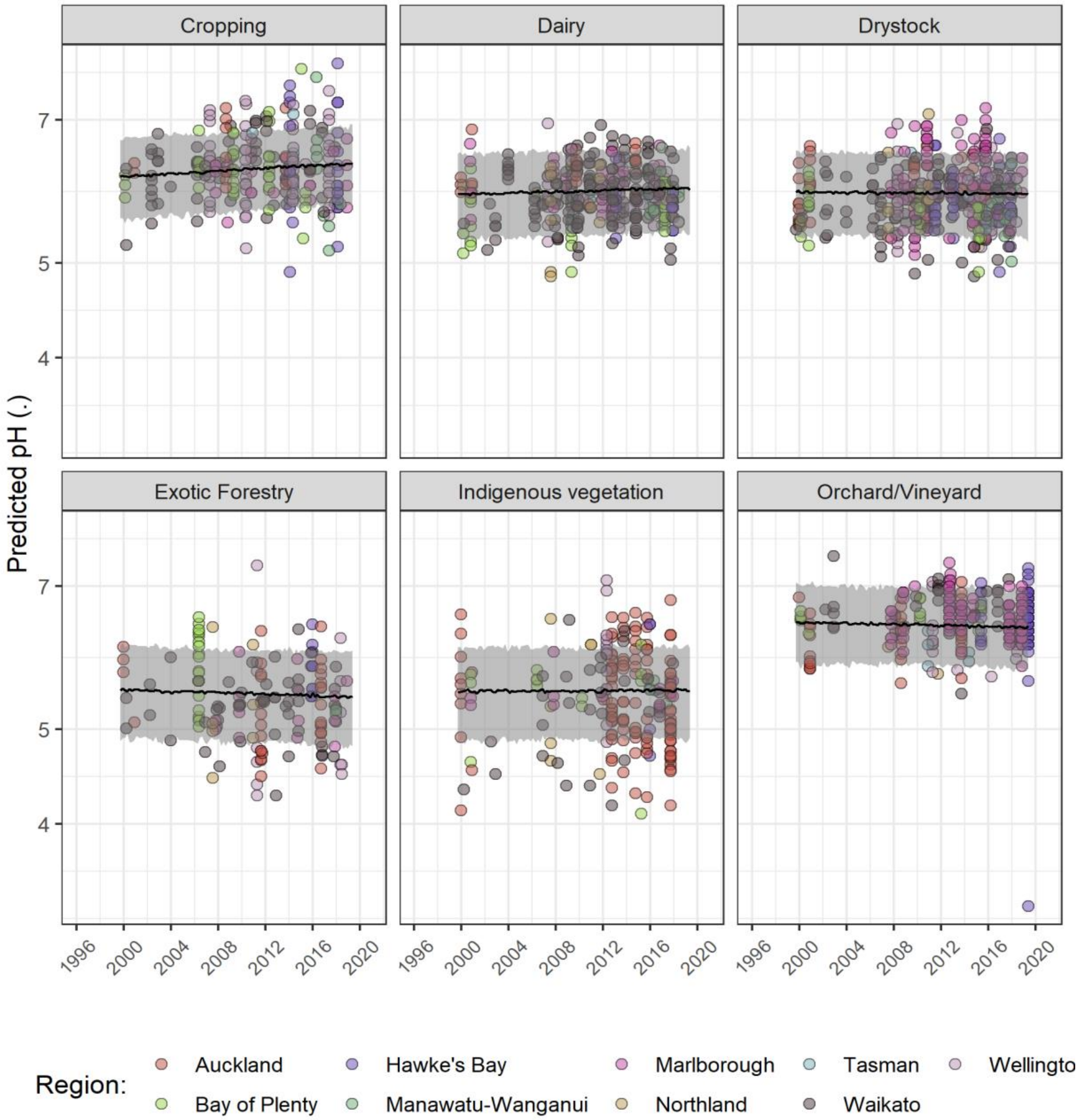

Figure 1: Plot of measured pH over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in pH for each land use class over time. The shaded area is the 95% confidence interval. Note that the pH values are shown on a log-scaled axis.

3.2 Total Carbon

There was a decrease in soil carbon under cropping and indigenous vegetation. The trend in the indigenous land use appears to be driven primarily by the relatively large number of samples from the Auckland region which were resampled one time.

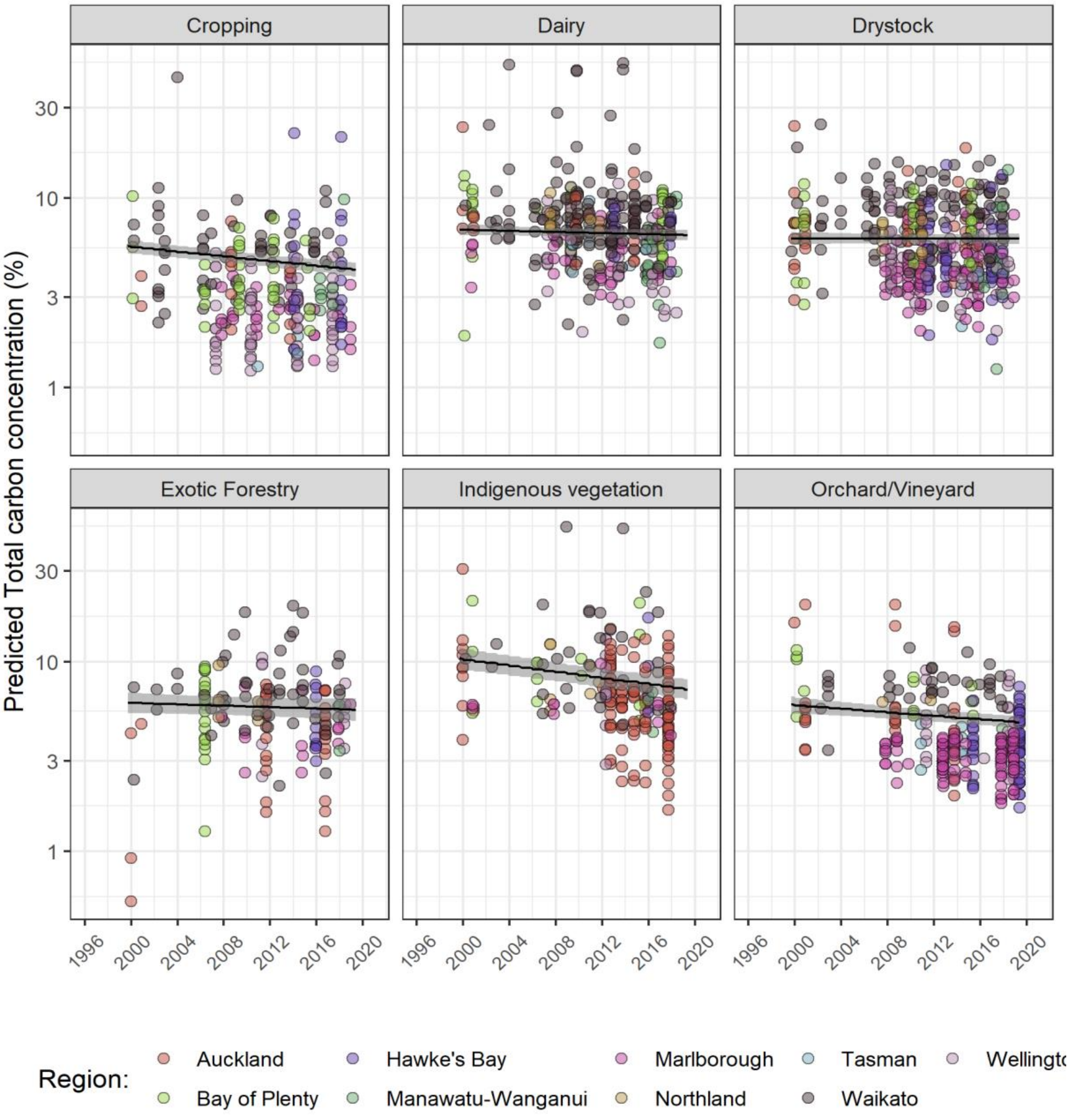

Figure 2: Plot of measured % total carbon over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in % Total carbon for each land use class over time. Note that the Total carbon concentration values are shown on a log-scaled axis. The shaded region (if shown) is the estimated 95% confidence interval of the trend line.

3.3 Total Nitrogen

The trends for total N were very similar to total C, there was a decrease in total nitrogen for both cropping and indigenous land uses.

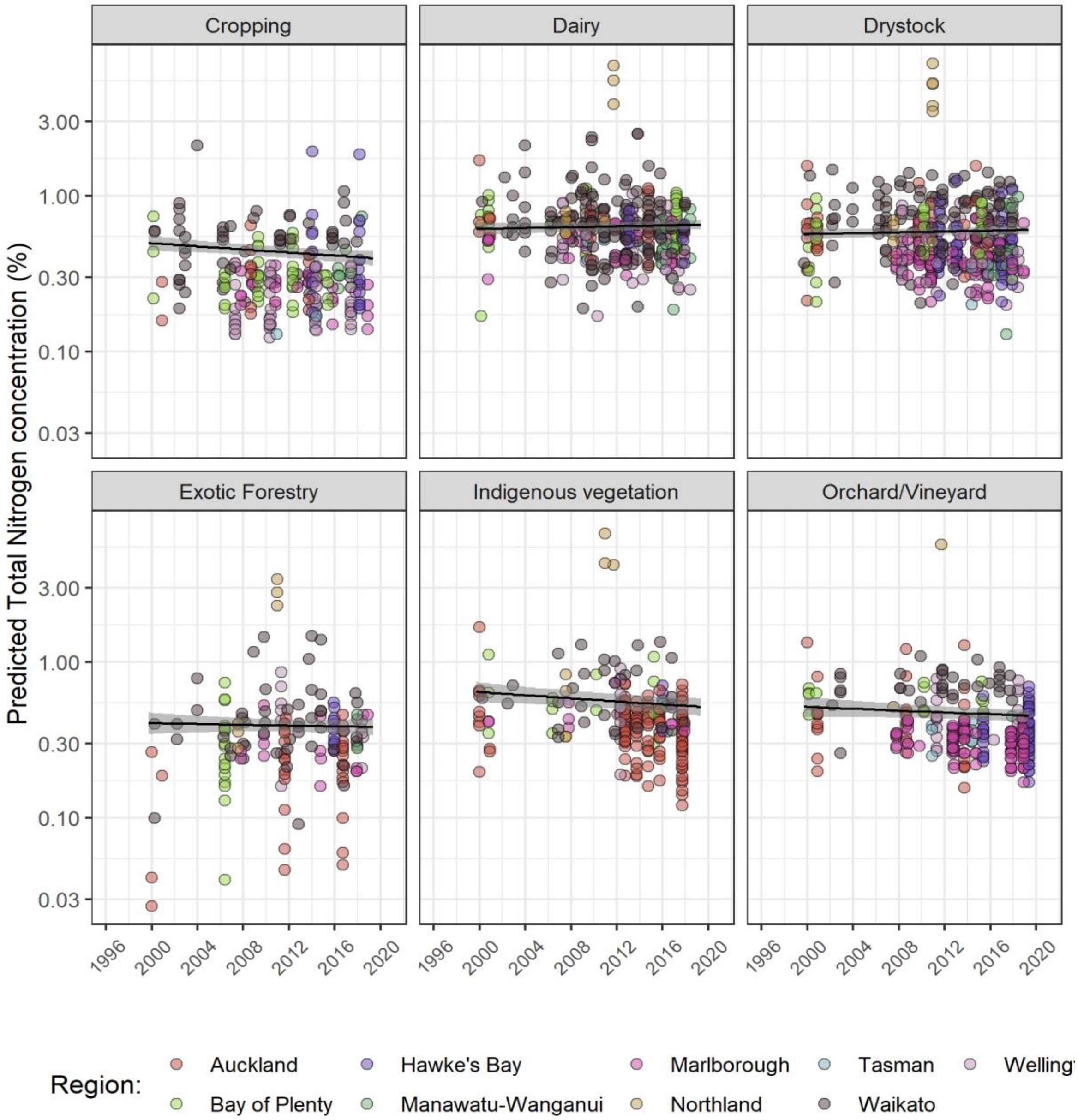

Figure 3: Plot of measured % total nitrogen concentration over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in % Total Nitrogen for each land use class over time. Note that the Total Nitrogen concentration values are shown on a log-scaled axis. The shaded region (if shown) is the estimated 95% confidence interval of the trend line.

3.4 Carbon to nitrogen ratio

The carbon to nitrogen ratio decreased in cropping, dairy, orchard/vineyard, and indigenous land uses.

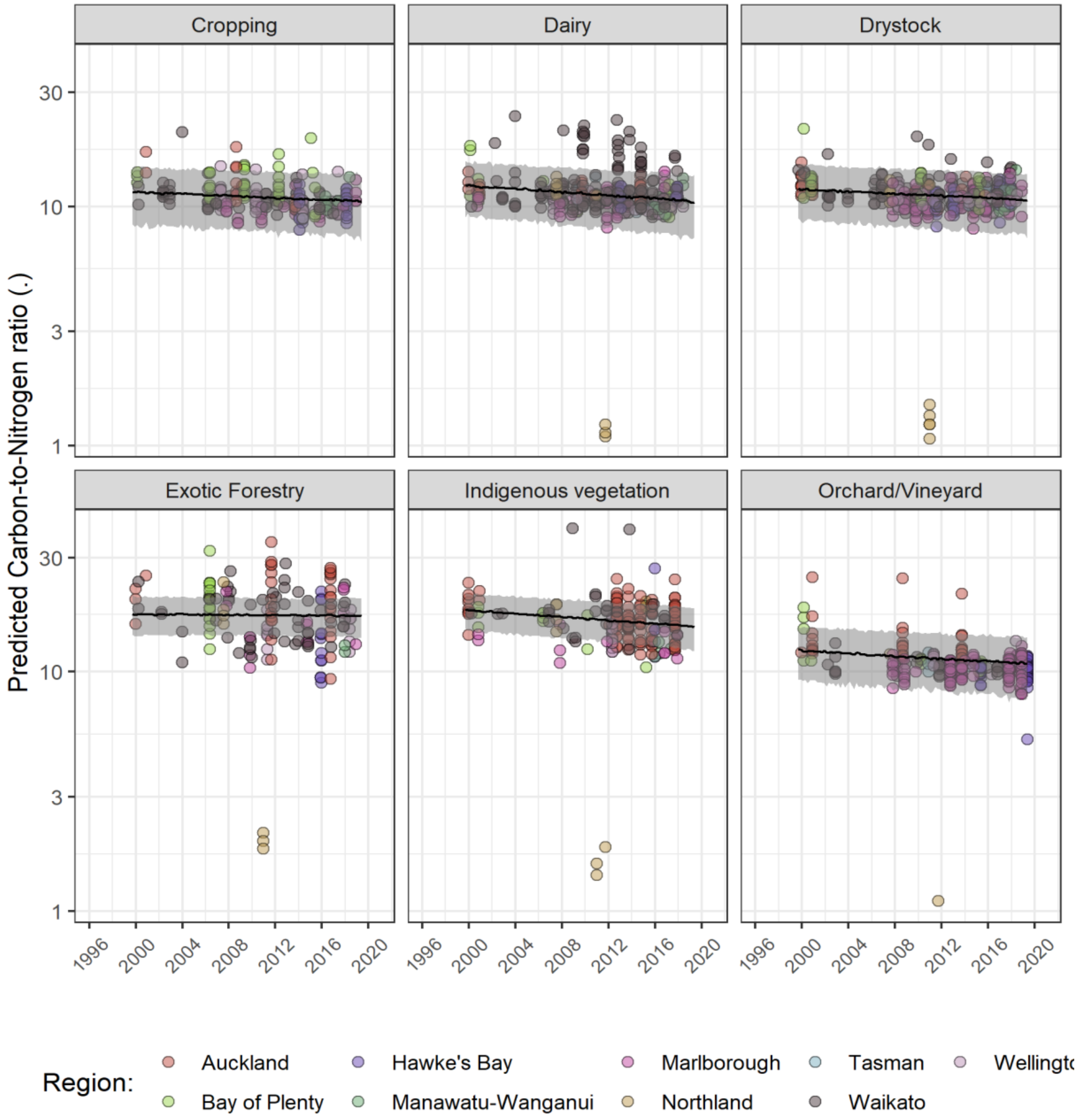

Figure 4: Plot of the carbon to nitrogen ratio over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in the C to N ratio for each land use class over time. Note that the C to N ratio values are shown on a log-scaled axis. The shaded region (if shown) is the estimated 95% confidence interval of the trend line.

3.5 Olsen P

Olsen P increased slightly under cropping, drystock, and exotic forestry.

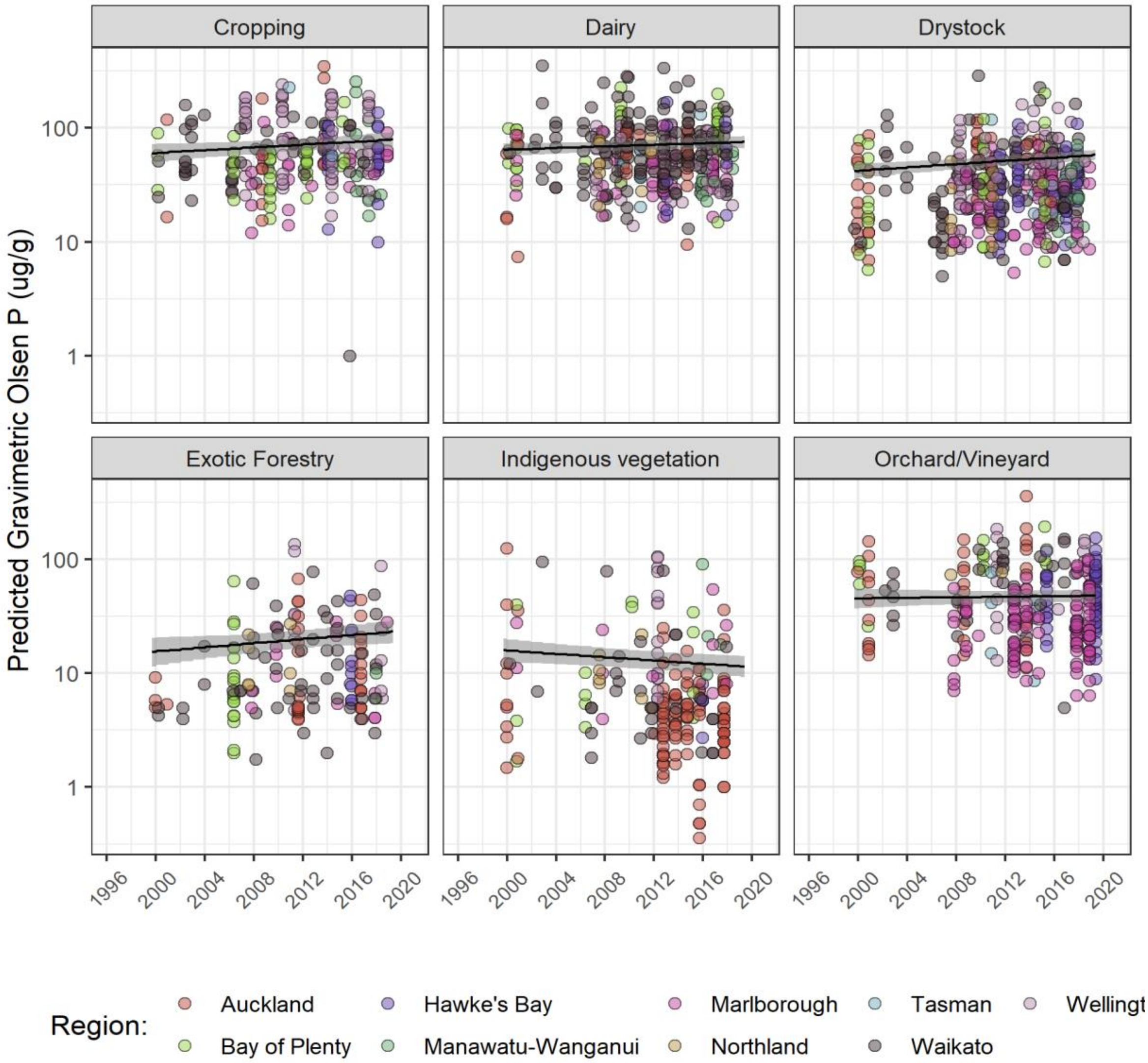

Figure 5: Plot of gravimetric Olsen P over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in Gravimetric Olsen P for each land use class over time. Note that the Gravimetric Olsen P values are shown on a log-scaled axis. The shaded region (if shown) is the estimated 95% confidence interval of the trend line.

3.6 Mineralisable N

Mineralisable N exhibited a poor model fit, consequently the 95% confidence intervals were large. Indigenous vegetation did however show a negative trend.

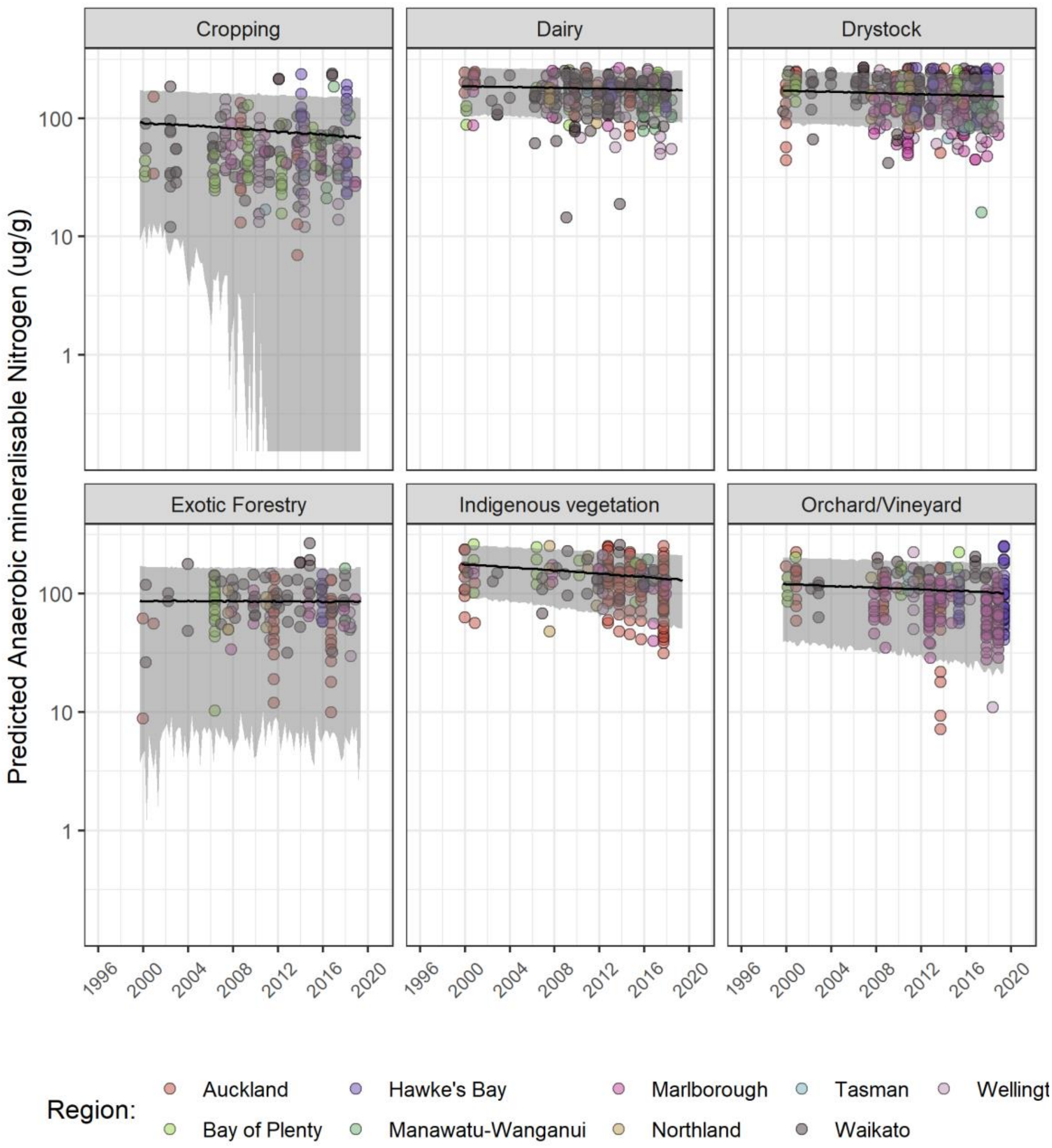

Figure 6: Plot of measured anaerobic mineralisable Nitrogen over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in anaerobic mineralisable Nitrogen for each land use class over time. Note that the anaerobic mineralisable Nitrogen values are shown on a log-scaled axis. The shaded region (if shown) is the estimated 95% confidence interval of the trend line.

3.7 Bulk Density

No significant changes in bulk density were observed.

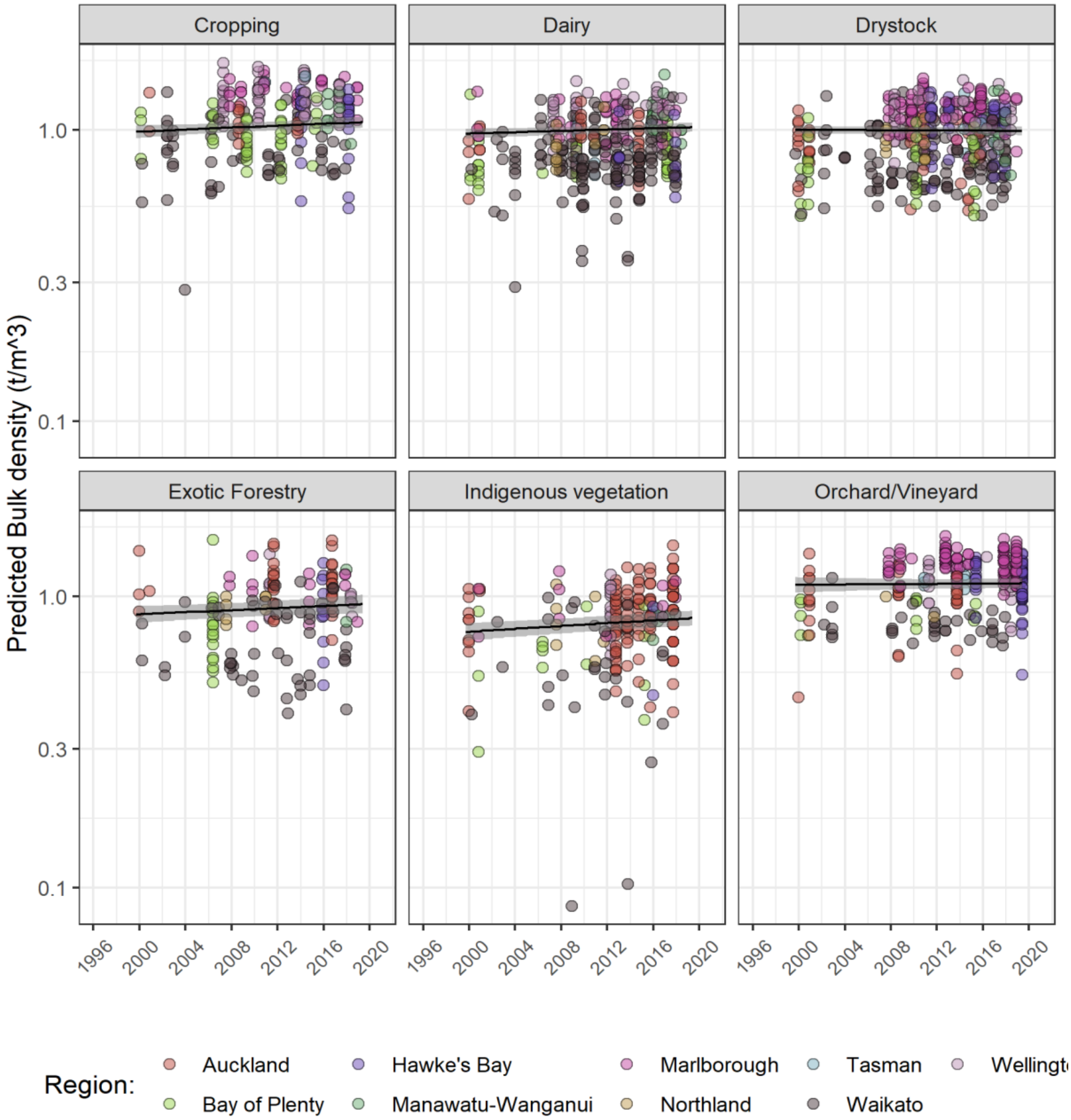

Figure 7: Plot of measured bulk density over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in bulk density for each land use class over time. Note that the bulk density values are shown on a log-scaled axis. The shaded region (if shown) is the estimated 95% confidence interval of the trend line.

3.8 Macroporosity

There was a slightly negative trend under exotic forestry for macroporosity (measured at –10 kPa).

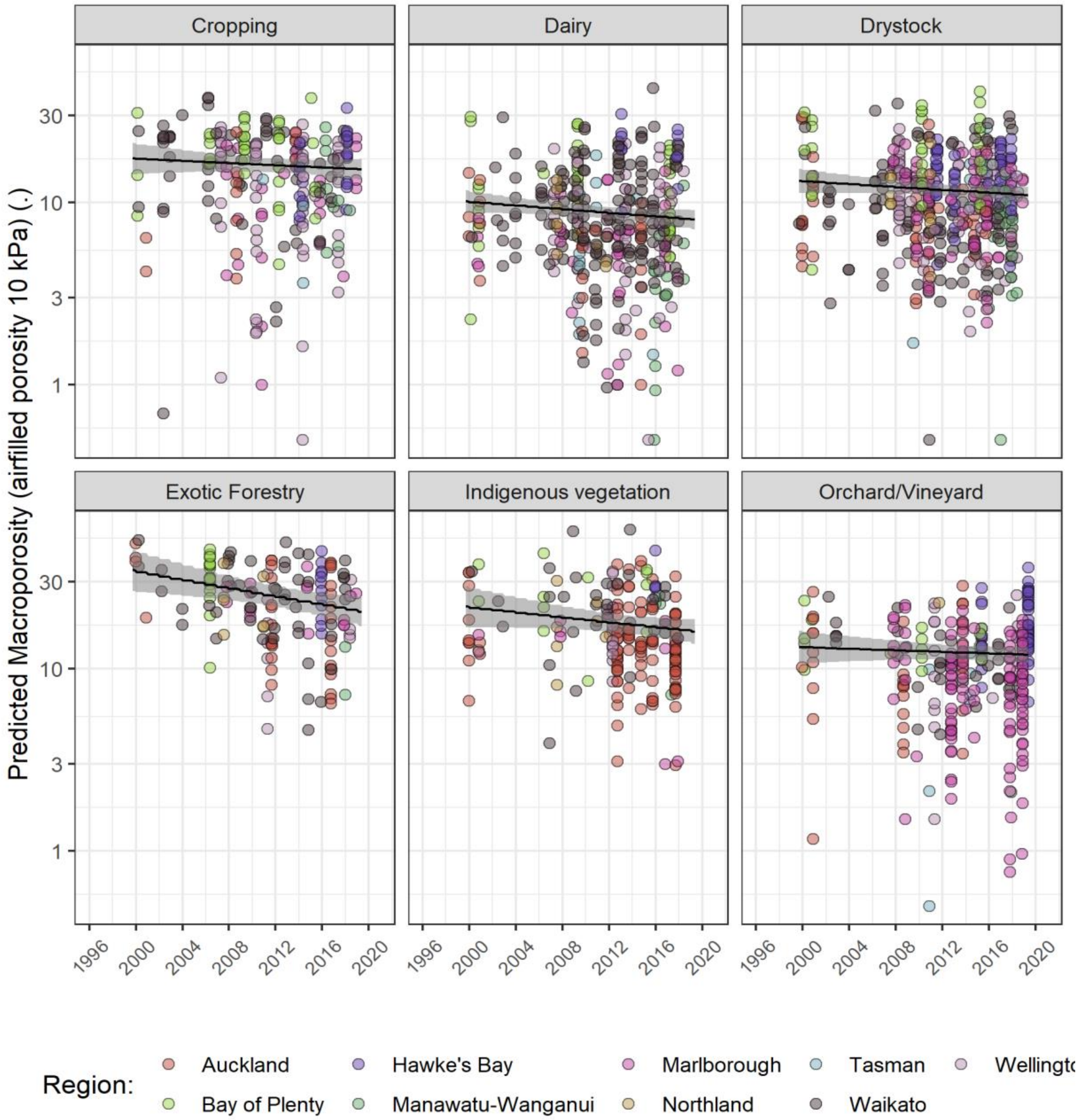

Figure 8: Plot of measured Macroporosity (air-filled porosity 10 kPa) (% v/v) over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in Macroporosity (air-filled porosity 10 kPa) for each land use class over time. Note that the Macroporosity (air-filled porosity 10 kPa) values are shown on a log-scaled axis.

3.9 Trace Elements

There were some significant trends for trace elements (e.g., an apparent increase in arsenic under orchard/vineyards and generally decreasing trends in copper on cropping, drystock, exotic forestry and indigenous land uses and decreases in cadmium for cropping, exotic forestry, indigenous and orchard/vineyard). There was an overall increasing trend in chromium over time, but a GLMM with land use*date interaction could not be fitted so the slope and confidence intervals are the same across all land uses. Other trace element figures are included in the RMD file.

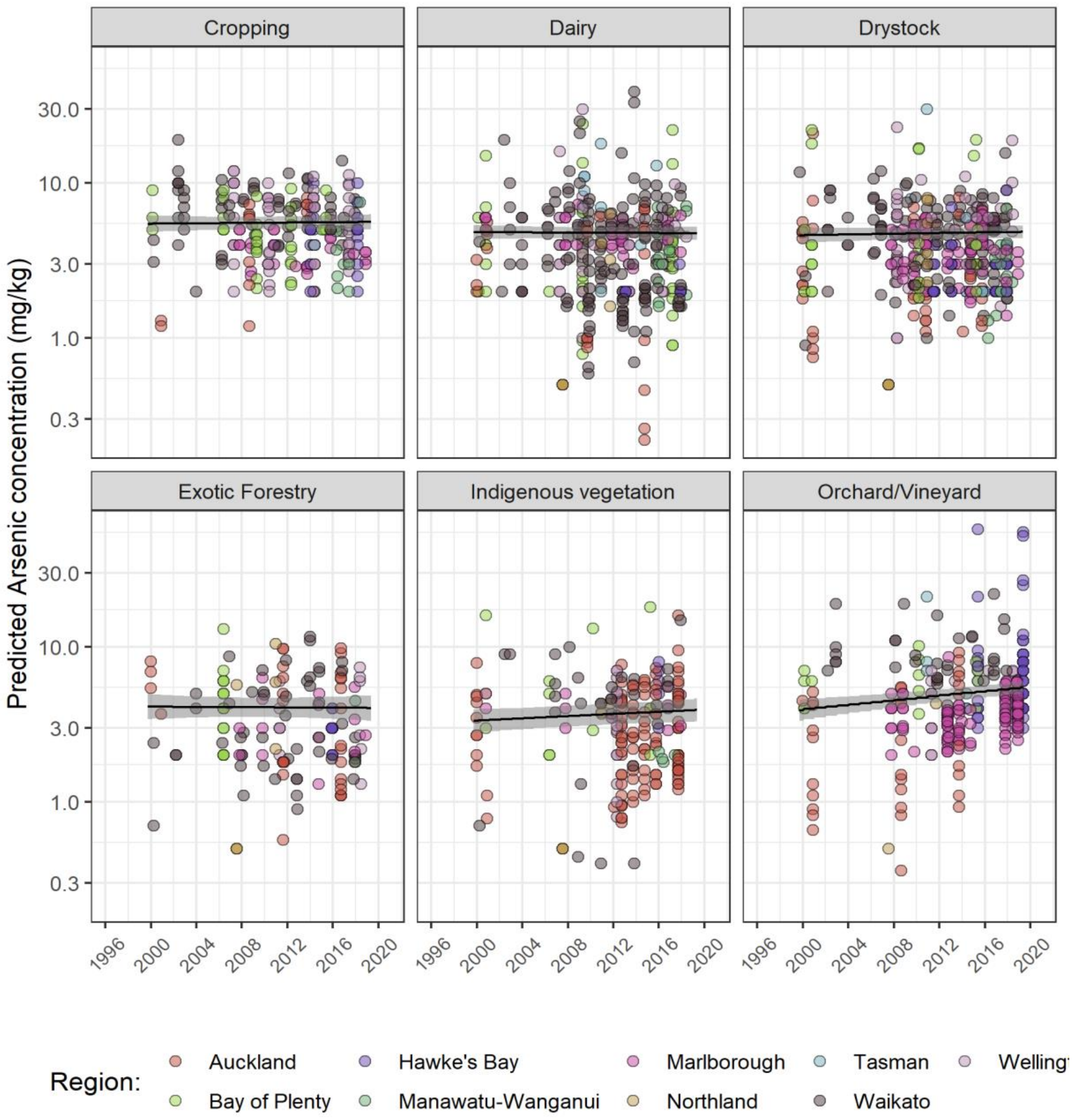

Figure 9: Plot of measured Arsenic concentration over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in Arsenic concentration for each land use class over time. Note that the Arsenic concentration values are shown on a log-scaled axis.

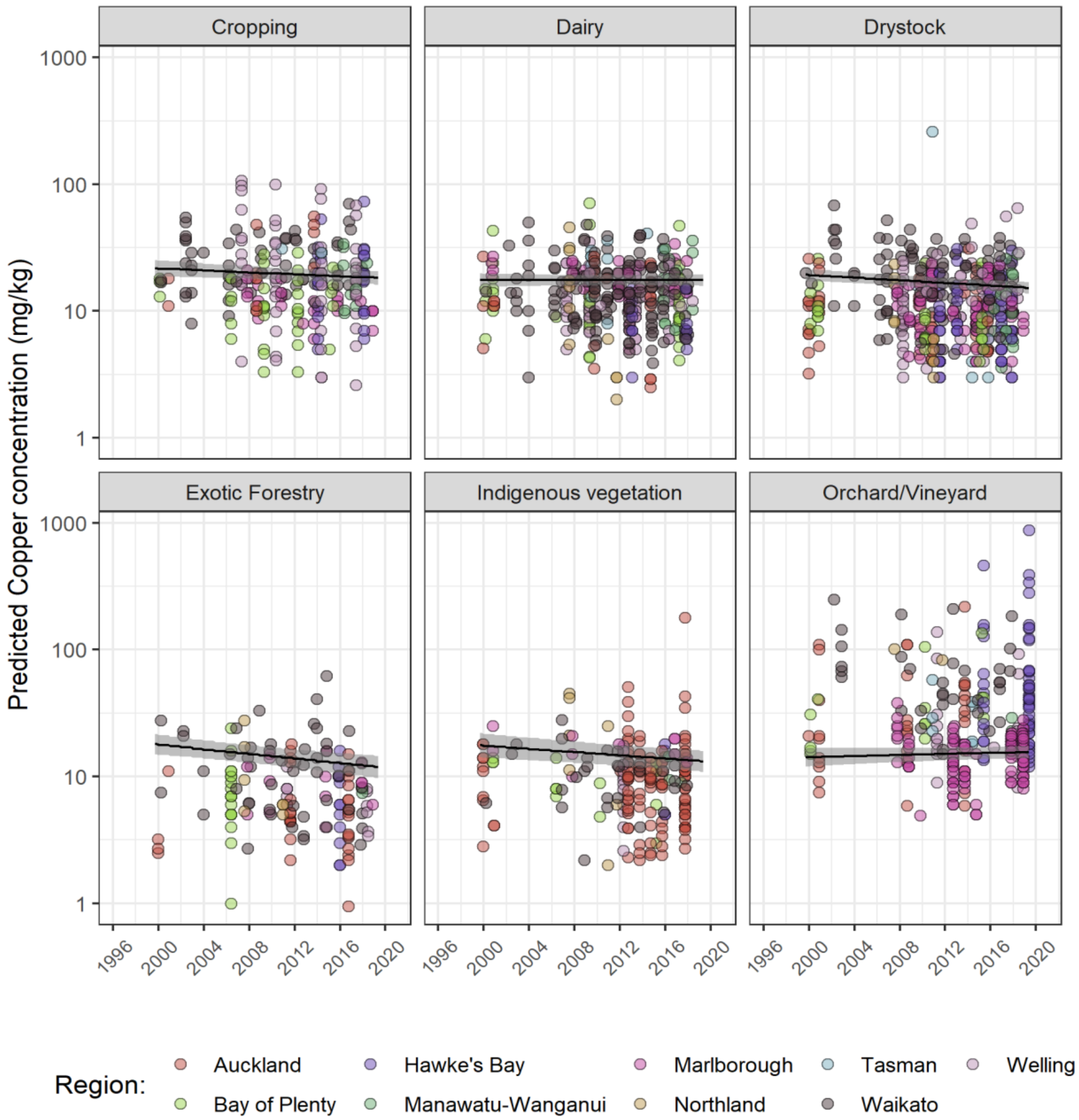

Figure 10: Plot of measured Copper concentration over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in Copper concentration for each land use class over time. Note that the Copper concentration values are shown on a log-scaled axis.

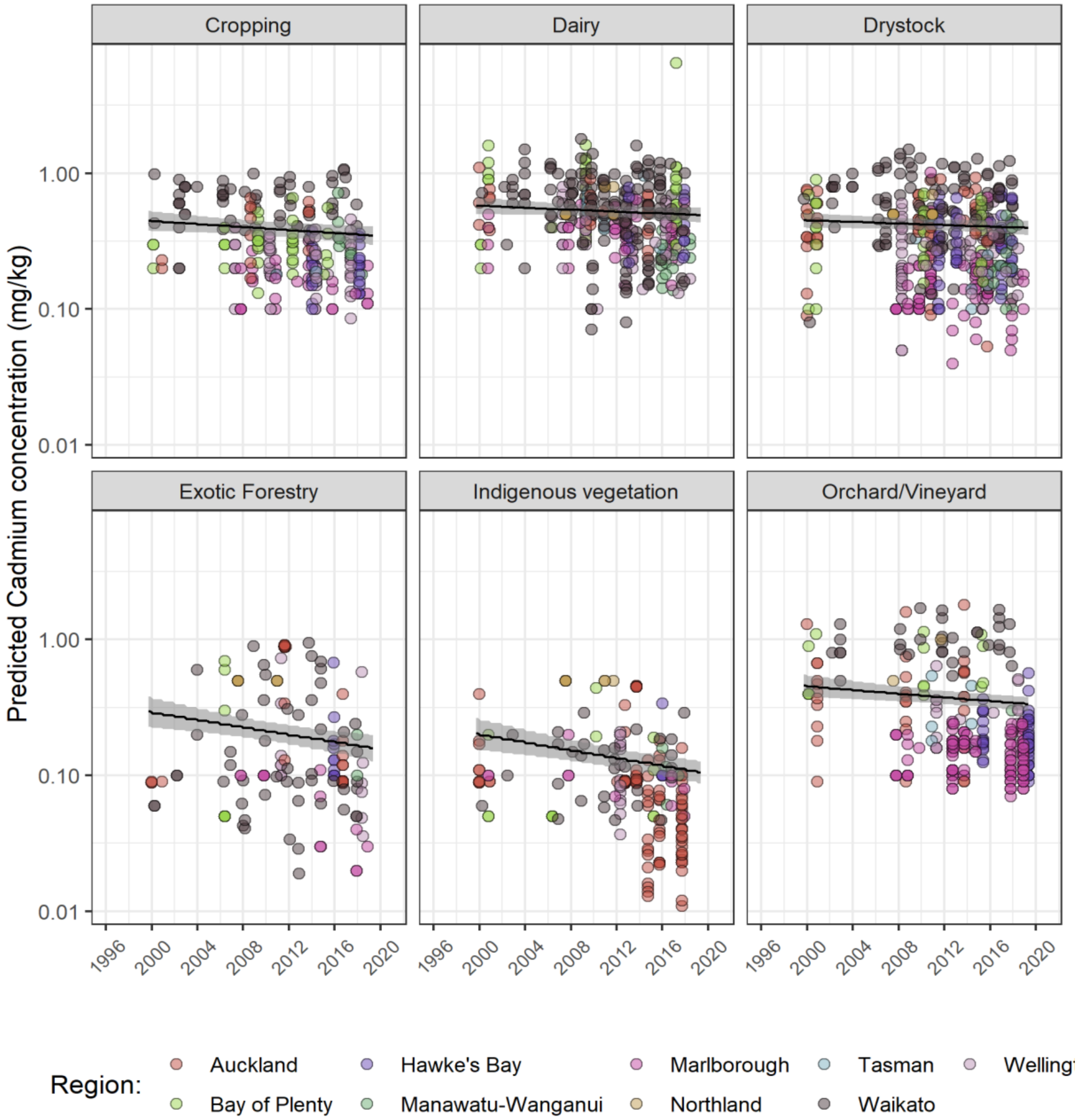

Figure 11: Plot of measured Cadmium concentration over time, by land use class. The points are coloured by the administrative region. The solid line represents the estimate of the trend in Cadmium concentration for each land use class over time. Note that the Cadmium concentration values are shown on a log-scaled axis.

4 Summary and Conclusions

We are now confident that the statistical models adequately fit the data; however, we would still advise a degree of caution in assessment of indicator temporal trends for the Land 2021 report as these trends could be associated with a variety of factors. Because each site within a land use class is managed differently, the degree of variation in trends of individual sites is high and the slopes (where significant) are often only slightly different from 0. Nevertheless, the current trend analysis does represent a significant step forward in progressing analysis of the soil quality dataset for national reporting.

Individual indicator trends should be considered within the context of the other statistics associated with that indicator (e.g., what is the median value for that indicator, where does the median value lie within the target range and whether the trend is moving toward or away from midpoint of the target range). Temporal trends for each indicator are summarised below.

pH

The only significant temporal trend for pH was an increase in pH in the cropping land use. This is consistent with the intensive management associated with the cropping land use.

Total C

Total C exhibited a decreasing temporal trend in both cropping and indigenous land uses. The loss of C in the cropping land use is consistent with the high soil disturbance and generally lower C inputs into the soil. The trend in the indigenous land use appears to be driven primarily by the relatively large number of samples from the Auckland region, which have only been sampled twice. Since soil characteristics are generally more variable under indigenous vegetation (Giltrap & Hewitt 2004), this trend may be due to a variety of factors such as slight differences in sampling location or a greater number of disturbed sites in the second sampling. With the lack of repeat samplings for this land use and the dominance of Auckland sites, we suggest the trend for indigenous sites be interpreted with caution. The apparent decline in C in the indigenous land use also has flow on effects to other indicators associated with soil C (total N, C:N ratio and mineralizable N).

Total N and C:N ratio

Both cropping and indigenous land uses exhibited a declining temporal trend in total N. This is consistent with the loss of C as C and N are associated components of organic matter. There was also a decreasing temporal trend in the C:N ratio in cropping, dairy, indigenous and orchard/vineyard land uses. Depending on mean C:N values for the particular land uses, this may be a concern. As the C:N ratio decreases and approaches a theoretical value of 10, the soil is thought to be reaching N saturation capacity and greater N leaching is likely to occur (Schipper et al. 2004).

Olsen P

Olsen P displayed an increasing temporal trend in cropping, drystock, and exotic forestry. The increase in forestry could potentially be due to a shift to younger-aged stands as some P fertilisation often occurs when seedlings are planted (the decrease in macroporosity in exotic forests would also tend to support this conclusion as there is often significant disturbance during harvest of the previous stand and planting of the new stand).

The increasing trend in Olsen P for drystock is not necessarily a negative trend, but will depend on what the median Olsen P value for drystock is and where it lies within the target value range (i.e., is the median Olsen P value for drystock in the lower part of the target range and the increasing moving it more towards the mid-point of the target range or is it moving it towards the upper limit of the target range).

The increasing temporal trend in Olsen P values in cropping may be a concern as Olsen P values in cropping are sometimes very high (>100).

Mineralisable N (AMN)

AMN exhibited a decreasing temporal trend in the indigenous land use. This trend is consistent with the decline in carbon.

Bulk Density

No significant temporal trends for bulk density were detected.

Macroporosity

Macroporosity displayed a decreasing temporal trend in exotic forestry. As mentioned above, this may potentially be due to a shift to younger forest stands sampled (after harvest or after planting, when compaction and disturbance are greater than in mature stands).

Though there was not a significant decreasing temporal trend for macroporosity in drystock and dairy, both of these land uses (dairy in particular) generally have a significant number of sites that are below the established target range. While there is no evidence to suggest compaction is getting worse, there is little evidence to suggest it is improving either.

Trace Elements

There were some significant trends for trace elements (e.g., an apparent increase in arsenic under orchard/vineyards and generally decreasing trends in copper on cropping, drystock, exotic forestry and indigenous land uses and decreases in cadmium for cropping, exotic forestry, indigenous and orchard/vineyard). There was an overall increasing trend in chromium over time, but a GLMM with land use*date interaction could not be fitted so the slope and confidence intervals are the same across all land uses.

5 Acknowledgements

We thank Jo Cavanagh, Alistair Ritchie, Shirley Vickers, Robbie Price, and Brendon Whitehead for the tireless efforts in provisioning of the dataset from the NSDR, and council authorities for the original provision of the data.

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