SOIL MAPS OF CADMIUM IN NEW ZEALAND

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Contents

Summary

Project and Client
The Ministry of Agriculture & Forestry engaged Landcare Research Ltd to establish a GIS-based system providing national coverage of a cadmium baseline, current levels with the option of establishing future levels.

Objectives

1. In a pilot study in Waikato, Wellington and Canterbury, assess sample density, variability, and drivers of landscape-scale variation of topsoil total cadmium from existing data collated by Environment Waikato, Greater Wellington and Environment Canterbury. Produce three regional topsoil total-cadmium soil maps for soil types represented in these regions using Landcare Research data for verification. To be completed by 30 June 2006.
2. Extend the pilot study in Objective 1 to a national study for both background and current total cadmium by collating existing data from all further sources of data identified in the Statement of Interest "Establishing Cadmium levels in New Zealand". Use the new data to refine the understanding of drivers of landscape scale variation. Identify where data are lacking and the relative need to reduce uncertainty in different landscapes. To be completed by 30 June 2007.
3. Design a nationally consistent sampling and analysis scheme. To be completed by 30 June 2007.

Methods
Current data sources of cadmium data were identified with the help of MAF. Samples were topsoils of varying depth to a maximum of 20 cm. Most samples were 0 to 10 or 0 to 7.5 cm depth. The average sample depths for background, pastoral, cropping and horticultural soil samples were 10.0, 9.4, 14 and 13 cm respectively. Cropping and horticultural soils are regularly mixed due to cultivation, while pastoral and background soils often are not cultivated. They were mainly collected at two time periods 1989–1995 and 2000 to the present, and the results presented here may underestimate the real situation. Sampling strategy and protocol varied with the purpose of sample collection. Same samples were for specific experiments while others were for regional or national survey. Testing for cadmium was either by strong acid extraction of the soil followed by spectrophotographic analysis or by x-ray fluorescence spectrophotometry of the whole soil. Some samples had associated grid references suitable for plotting on maps while others only had regional location data. Other samples included landuse data but were not georeferenced. Samples from sites of known cadmium contamination were not included in the database analysis. Where possible, the largest set of samples was used for analysis.

Data and metadata additional to that used in the pilot study of Objective 1 were collated and entered in the database (developed in Objective 1). Relationships between possible drivers of variation such as soil group, land use, vegetation, climate, regional fertiliser use, etc., were investigated. Cadmium spatial data layers were generated by developing the relationships explored in Objective 1 and applying them to the enlarged cadmium dataset and the soil polygons in the Fundamental Soils Layer.

The Fertiliser Manufacturers Research Association (FMRA) CadBal model for predicting cadmium concentrations in soils was used to forward project total cadmium levels.

A nationally consistent sampling and analysis scheme is detailed.

Results

Data from a total of 1794 dried topsoil samples were collated. Of these, 1649 were georeferenced and used to derive the maps. Samples were mainly collected at two time periods 1989–1995 and 2000 to the present, and the results presented here may underestimate the real situation. A selection of 372 of these samples from sites with land-uses reserve, tussock, bush, indigenous forest and plantation forestry were used to derive background levels of cadmium in New Zealand topsoils. These data show a national average baseline value of 0.16 μg g^{-1}, similar to that found for non-farmed soils (0.20 μg g^{-1}, Roberts et al. 1994), and baseline cadmium was consistent across all regions and soil types. No national map was produced for background topsoil cadmium concentrations as it would be monochromatic.

A national map of current topsoil cadmium concentrations was produced. The national average concentration for cadmium was 0.35 with a range of 0-2.52 μg g^{-1}. An attempt to estimate the historic accumulation rate was thwarted by lack of data on fertiliser history.

Land-use was a key driver of topsoil cadmium concentrations. Cropping, pasture and horticulture land-uses all had higher concentrations of cadmium in soil than background land-use. Dairying has the highest national average for cadmium concentration (0.73 μg g^{-1}) and had showed the largest number of data points outside the 95 and 5 percentiles for the pasture landuse, reflecting the wide range of cadmium values measured. Kiwifruit (0.71 μg g^{-1}), berries (0.68 μg g^{-1}), orchards (0.66 μg g^{-1}), market gardening (0.46 μg g^{-1}), drystock pasture (0.40 μg g^{-1}) were also above the national average. Cropped soils appear to be mostly below the national average of 0.35 μg g^{-1} for cadmium; however, these soils are tilled to a greater depth (200 mm) than other land-uses, and dilution decreases the cadmium concentration. Soils where tobacco was grown were more elevated in cadmium (0.34 μg g^{-1}) than other cropping soils. These soils will now have other land-uses as tobacco is no longer grown in New Zealand. Sites receiving little or no fertiliser had the lowest cadmium concentrations (unfertilised 0.19 μg g^{-1}, plantation forestry 0.14 μg g^{-1}, native forest 0.10 μg g^{-1}).

The data in the database was tested for representativeness by comparing topsoil total-cadmium concentrations and associated metadata with LCDB2 vegetation class and the number of sites per 100 square km calculated. Depleted tussock grassland, tall tussock grassland and sub-alpine shrubland are relatively poorly represented with the number of sites per 100 square km less than 0.04.

Data on topsoil total-cadmium levels and associated metadata were tabulated according to region and the number of sites per region calculated. The region with the highest average cadmium concentration was Taranaki (0.69 μg g^{-1}). Other regions with similar cadmium concentrations include Waikato (0.55 μg g^{-1}) and Bay of Plenty (0.53 μg g^{-1}). Dairy farming with high fertiliser use is traditional in these areas and the soils of these regions have a high propensity to accumulate cadmium according to the FMRA cadmium model (see below). The regions with the lowest cadmium average concentrations were Canterbury (0.17 μg g^{-1}), Gisborne (0.20 μg g^{-1}), Manawatu-Wanganui (0.17 μg g^{-1}), Nelson-Marlborough (0.11 μg g^{-1}), Otago (0.20 μg g^{-1}) and Southland (0.20), all historic sheep farming areas. Soils from these regions have a low propensity to accumulate cadmium according to the FMRA cadmium model (see below).

An initial estimation of future topsoil cadmium concentrations was carried out using the FMRA CadBal model. This model only produces results based on the New Zealand Soil Generic Classification. Results from running the data from the database through the model showed BGCL, YBL and YBP soils accumulated more cadmium than the other soil types while alluvial, YBE and YGE accumulated the least cadmium. Differences in soil type cadmium accumulation appear due to differences in leaching losses and soil bulk densities input to the model.

Increasing the sampling depth from 0–7.5 to 0–10 to 0–20 cm was shown to dilute the cadmium concentration effectively from 0.43 µg g^{-1} to 0.37 µg g^{-1} to 0.26 µg g^{-1} for a YBE under dairy (30 kg P $ha^{-1}y^{-1}$).

The model also showed pastoral farming resulted in increased soil cadmium content in all regions and nationally. The peat soils of the Waikato region showed the highest potential for cadmium accumulation. The regions with the highest present-day soil cadmium content also have the highest potential to accumulate cadmium in the future. Sheep/beef farming led to more accumulation of cadmium than dairy when both are under the same fertiliser regime although, dairy farming requires more fertiliser for optimal production than beef and sheep farming in practice. The difference in accumulation was due to the difference in sedimentation losses (900 kg ha^{-1} y^{-1} for dairy farming and 500 kg ha^{-1} y^{-1} for sheep and beef). However, sedimentation losses are due to a range of factors including topography, soil type, leaching class and climate, not just farm type, and this result is questionable. Cadmium levels in soils under dairy farms were shown to decrease in cadmium with time once soil cadmium exceeded about 1.3 mg kg^{-1} due to removal in sediment, erosion products and leaching. This result has important implications for farm sustainability and its accuracy should be further investigated.

Without consideration of bulk density, very light organic soil appears to contain extremely high amounts of cadmium compared with mineral soil. However, when converted onto a volumetric basis, both organic soil and mineral soil can have similar amounts of cadmium.

Conclusions

1. Sites with land-uses such as reserve, tussock, bush, indigenous forest and plantation forestry or described as unfertilised may be considered background and are suitable for assessing soil cadmium baseline concentrations
2. The national average soil cadmium concentration measured in the database was 0.35 µg g^{-1} and the national average baseline soil cadmium value was 0.16 µg g^{-1}
3. Cropping, pasture and horticulture land-uses all had higher concentrations of cadmium in soil than background landuse indicating accumulation of cadmium in these soils
4. Horticulture land-uses had the highest average soil cadmium concentration (0.50 µg g^{-1}) indicative of high fertiliser use or some other localised contamination source. Samples classified as berries (0.68 µg g^{-1}), kiwifruit (0.71 µg g^{-1}) and orchards (0.66 µg g^{-1}) contained soils double or nearly double the national average of 0.35 µg g^{-1} reflecting high inputs of fertiliser or some other source of cadmium contamination. Although market gardening had an average soil cadmium concentration of 0.46 µg g^{-1}, it had the greatest range of values and had more data points outside the 95 and 5 percentiles than the other farm types
5. Pastoral land-uses had the highest individual soil cadmium value (2.70 µg g^{-1}). Dairying showed the highest average soil cadmium concentrations (0.73 µg g^{-1}), averaging double the national average of 0.35 µg g^{-1}. Dairying also showed the largest number of data points outside the 95 and 5 percentiles for the pasture landuse, reflecting the wide range of cadmium values measured. Average values for beef farming and all drystock were slightly above (0.42 µg $g^{-1}$and 0.40 µg g^{-1} respectively) and sheep farming slightly below (0.33 µg g^{-1}) the national average
6. Soils where tobacco was grown were more elevated in cadmium (0.34 µg g^{-1}) than other cropping soils. These soils will now have other land-uses as tobacco is no longer grown in New Zealand. Cropped soils appear to be mostly below the national average of 0.35 µg g^{-1} for cadmium, however, these soils are tilled to a greater depth (200 cm) than other land-uses and dilution decreases the cadmium concentration

7. The data in the database were tested for representativeness by comparing topsoil total-cadmium concentrations and associated metadata with LCDB2 vegetation class and the number of sites per 100 square km calculated. Depleted tussock grassland, tall tussock grassland and sub-alpine shrubland are relatively poorly represented with number of sites per 100 square km less than 0.04. However, further sampling based on vegetation class is not required as the main farming vegetation classes are adequately covered
8. The region with the highest average cadmium concentration was Taranaki (0.66 $\mu g\ g^{-1}$). Other regions with cadmium concentrations above the national average include Waikato (0.60 $\mu g\ g^{-1}$) and Bay of Plenty (0.52 $\mu g\ g^{-1}$). Dairy farming with high fertiliser use is traditional in these areas and likely to be the cause for the elevated levels. The regions with the lowest cadmium average concentrations were Canterbury (0.18 $\mu g\ g^{-1}$), Gisborne (0.20 $\mu g\ g^{-1}$), Manawatu-Wanganui (0.17 $\mu g\ g^{-1}$), Nelson-Marlborough (0.23 $\mu g\ g^{-1}$), Otago (0.20 $\mu g\ g^{-1}$), Southland (0.20 $\mu g\ g^{-1}$) and Wellington (0.20), all historic sheep farming areas
9. Results from running the data from the database through the FMRA CadBal model showed:
    a. Pastoral farming resulted in increased soil cadmium content in all regions
    b. Regions with the highest present day soil cadmium content also have the highest potential to accumulate cadmium in the future
    c. Peat soil apparently has the greatest potential to accumulate cadmium from fertiliser
    d. BGCL, YBL and YBP soils accumulated higher amounts of cadmium than alluvial, YBE and YGE soils, which accumulated the least cadmium. Gley soils were intermediate. Differences in soil type cadmium accumulation appear due to differences in the assumed leaching losses and soil bulk densities input to the model
    e. Increasing the sampling depth effectively diluted the cadmium concentration
    f. Sheep/beef farming lead to more accumulation of cadmium than dairy when both are under the same fertiliser regime. Accumulation under dairy is higher when both are under their respective optimal fertiliser schemes
    g. Cadmium levels in soils under dairy farms receiving 30 kg P $ha^{-1}y^{-1}$ or less appear to decrease with time once soil cadmium exceeded about 1.3 mg kg^{-1}
10. Weaknesses identified in the CadBal model include:
    a. The model is based on the New Zealand Genetic Soil Classification, which has been superseded
    b. The model was not calibrated for many recent soils, podzols, rendzinas or intergrades between soil types
    c. The sedimentation loss figures used in this analysis by the model are oversimplified as sedimentation losses are due to a range of factors including topography, soil type, leaching class and climate, not just farm type
    d. Cadmium leaching figures for different soil groups are assumed to be independent of location and climate
    e. A default "zero" leaching figure was used for alluvial soils
    f. No consideration is given in the model to accumulation of erosion debris
    g. The model assumes atmospheric deposition of cadmium is constant across the whole country
    h. No consideration is given to animal relocation of cadmium through faeces or land application of dairyshed effluent
11. When soil bulk density is not considered, organic soil can appear to have extremely high cadmium levels compared with mineral soil.

Recommendation Specific to this Project

1. There were few samples with associated land-use data for soils utilised for cropping by crop type. Other specific land-uses with few samples include horse and deer farming and vineyards. Further samples should be obtained from these land-uses from across the country

and analysed for cadmium following the sampling and analysis scheme included in this report to improve the representativeness of the dataset. Details regarding current and historical crop type should be collected simultaneously where possible

2. To increase confidence in the regional ranges and averages, further sampling following the sampling and analysis scheme included in this report, to 50 samples per region is recommended in regions with low numbers of samples. These regions include Gisborne, Nelson-Marlborough, Northland and Westland

3. Cadmium concentration data on peat, organic and other light soils should be assessed after conversion to a volumetric basis to account for bulk density

4. The results from the CadBal model could be improved to portray sediment, erosion and leaching losses more accurately and to include deposition of erosion debris. The sedimentation losses used by the model appear overestimated. The apparent decrease in soil cadmium predicted by the model for dairy farms receiving 30 kg P $ha^{-1}y^{-1}$ should be tested in a field study

5. The CadBal model should also be calibrated using the current New Zealand soil classification (Hewitt 1998) and include all soil orders

6. A national soil inventory including site and soil information at 8-kilometre intervals across New Zealand should be carried out. Sampling priority would be given to sites with intensive land use. The information should be collected by way of a grid survey, each sample point should be georeferenced and accessory data collected on the landform, slope, current land use, soil classification, profile characteristics, and a range of contaminants including cadmium and other potential contaminants should be analysed. The Carbon Monitoring System (MfE and Landcare Research) provides a mechanism by which some of this sampling regime could be carried out. Soil samples should be extracted using a strong acid digestion procedure and analysed using graphite furnace atomic absorption spectrometry or inductively coupled emission mass spectroscopy by a New Zealand accredited laboratory.

General Recommendations

1. Soil bulk density should be considered when assessing soil contamination, especially when setting maximum permitted levels and other guidelines as soils of low bulk density can appear to have extremely high contaminant concentrations compared with soil of high bulk density

2. Future soil samples should also be analysed for other potential contaminants such as fluorine.

1. Introduction

Cadmium accumulation in soils is largely irreversible and ultimately unsustainable, yet is tied to phosphate use, which underpins New Zealand's agricultural production. It also appears likely that cadmium uptake in some crops and animals could cause non-compliances with food standards. Assessment of New Zealand's cadmium status requires an objective assessment of a baseline, current and projected future levels of cadmium accumulation in soils, plants, animals and humans. First, it is important to establish what the baseline levels of cadmium in soil may have been, what the current levels are and what projected future levels may be within established timeframes. Landcare Research was engaged to establish a GIS-based system providing national coverage of baseline and current cadmium levels in soil, with the option of establishing future levels.

2. METHODS

NATIONAL AND REGIONAL CADMIUM LEVELS IN TOPSOIL

Identification of Data Sources
Current data sources of cadmium data were identified with the help of MAF. Samples were topsoils of varying depth to a maximum of 20 cm. Most samples were 0 to 10 or 0 to 7.5 cm depth. The average sample depths for background, pastoral, cropping and horticultural soil samples were 10.0, 9.4, 14 and 13 cm respectively. Cropping and horticultural soils are regularly mixed due to cultivation while pastoral and background soils often are not cultivated. Samples were mainly collected at two time periods; 1989–1995 and 2000 to the present, and the results presented here may underestimate the real situation. Some samples had associated grid references suitable for plotting on maps while others only had regional location data. Other samples included land-use data but were not georeferenced. Samples from sites of known cadmium contamination, such as fertiliser storage facilities or irrigated with effluent, were not included in the database analysis. Where possible, the largest set of samples was used for analysis. The following data sources were identified:

AgResearch
AgResearch provided 4 sets of data:

- The nation wide survey of pastoral soils
- A survey of south Auckland market gardens
- A survey of mid-Canterbury wheat farms
- A small study in the Waikato

The nation wide survey of pastoral soils is the best internally consistent national survey that specifically targeted cadmium (and some other contaminants). Both unfertilised and fertilised sites were sampled. Extraction was by refluxing with a mixture of concentrated perchloric and nitric acid. Analysis was by Flame Atomic Absorption Spectroscopy or Graphite Furnace Atomic Absorption Spectroscopy. The other surveys provide valuable data for specific land-uses in a particular location.

Landcare Research
Landcare Research provided data from a comparison of archived and present-day soil samples, samples from a transect away from a fertiliser bin, a comparison of paired unfertilised and fertilised soils, and a survey of Waikato wetlands. These surveys also included land-use and soil-

type data. Extraction was by refluxing with nitric acid. Analysis was by Flame Atomic Absorption Spectroscopy or Graphite Furnace Atomic Absorption Spectroscopy.

Regional Councils
Environment Canterbury and Taranaki Regional Council provided cadmium data and Environment Waikato, Greater Wellington and Environment Bay of Plenty included multi-element analysis data in their '500 soils' regional soil surveys. These surveys also included land-use and soil-type data. In addition, Environment Waikato provided multi-element analysis, land-use and soil-type data for a transect of soil sites across the region, and Greater Wellington provided cadmium data for parks and reserves. Methods reported included: Extraction by refluxing with a mixture of concentrated perchloric and nitric acid and analysis by Flame Atomic Absorption Spectroscopy or Graphite Furnace Atomic Absorption Spectroscopy; or extraction by nitric and hydrochloric acid followed by analysis by Inductively Coupled Plasma Mass Spectroscopy; or analysis of whole sample by X-Ray Fluorescence spectroscopy.

Tertiary Institutes
Cadmium and soil type data was extracted from 6 publications from Massey University and 1 publication from The University of Waikato and discussions with the authors (Gaw et al. 2005; Loganathan et al. 1995, 1997, 1999; Loganathan & Hedley 1997; Zanders et al. 1999; Andrewes et al. 1996). These publications also provided records of historic fertiliser use.

Dr David Hawke, Christchurch Polytechnic, provided cadmium, landuse and soil type data from his research into soil indicators of pre-European seabird breeding in New Zealand (Harrow et al. 2006; Hawke 2003; Hawke et al. 1999).

Some data were supplied with regional location data but under the condition that they were not to be plotted on a map or the exact sample locations indicated beyond which region they were from. Some other data had only regional location data but lacked exact grid references. These data were used with the data with full location data to assess national and regional cadmium concentrations and associations with landuse. They have not been plotted on any of the maps produced in this report.

Database
Data on topsoil total-cadmium levels and associated metadata from existing Environment Waikato, Greater Wellington and Environment Canterbury soil surveys was collated into a relational geospatial database for total cadmium. This database was extended to a national study by collating existing data from all further sources of data identified in the Statement of Interest "Establishing Cadmium levels in New Zealand" and from other sources found by Landcare Research. Data were categorised under the following headings:

Sample Name – Identification given by data source

Date – Date or year of sampling

Depth (cm) – depth of soil sample

Grouping – Is sample part of a pair, set, profile or transect

Unique Number – Unique number given each sample pair, set, profile and transect

New Zealand Soil Classification – Some soil sample data were already classified under the New Zealand Soil Classification (NZSC) while others were classified as soil series, soil set, soil type or soil group. These other classes were converted to NZSC soil order using lookup tables.

Easting – 7 digit NZMS 260 grid reference. Data not supplied with NZMS 260 grid references were converted e.g. from NZMS1 or degrees, minutes, seconds.

Northing – 7 digit NZMS 260 grid reference. Data not supplied with NZMS 260 grid references were converted e.g. from NZMS1 or degrees, minutes, seconds.

Landuse – A description of the landuse at the time of sampling

Cd μg g^{-1} – Gravimetric concentration of cadmium in parts per million.

Variation and drivers of variation were identified by relating collated samples to soils in the Fundamental Soils Layer and National Soils Database (from Land Resource Information System). Areas where data is lacking and the relative need to reduce uncertainty in different landscapes were identified.

Maps were created using MXDs, JPEGs, Data and Shapefiles.

<u>MXDs</u>
Maps were generated in ArcMap 9.1 build 722. The *.MXD files are on this directory.

<u>JPEGs</u>
These are the *.jpg files used in the report

<u>DATA</u>
Base data

Mcoastnz	is a coverage of the outline of the coast
Nzregcoast.shp	is a shapefile of the regional boundaries
Regionmaps.dbf	is a dbase file of cadmium data used for the regional and NZ maps

<u>SHAPEFILES</u>
The cadmium data files were converted into shapefiles
Cdregions.shp = regionmaps.dbf

2.2 DATABASE ANALYSIS

The average and range of data from all sites where landuse was recorded (1794 samples) was calculated and compared with the average and range of data from all sites that were georeferenced (1649 samples) to test robustness of the data set. To evaluate what type of land cover is represented by the cadmium data, the data were tested for representativeness by overlaying sample landuse onto the Land Cover Database 2 (LCDB2) vegetation class. The numbers of sites per 100 square km for each vegetation class were calculated. Vegetation classes that had greater than 1 site per 100 square km were considered to be relatively well represented in the database. Data on topsoil total-cadmium concentration and associated data were tabulated according to region and landuse, and graphed as boxplots.

2.3 PREDICTING FUTURE CADMIUM LEVELS

Future levels of cadmium in New Zealand were calculated using the New Zealand Fertiliser Manufacturers Research Association (FMRA) CadBal model. Data from the database was supplied to the FMRA for input into the model. This model is based on the New Zealand Genetic Soil Classification which has been superseded by the New Zealand Soil Classification (Hewitt 1998). The model has been calibrated against data from Winchmore AgResearch Station (Roberts & Longhurst 1997). 8 soil groups are considered by the model. They are Yellow Grey Earth (YGE), Yellow Brown Earth (YBE), Yellow Brown Loam (YBL), Yellow Brown Pumice (YBP), Gley (G), Peat (P), Brown Granular Loams & Clay (BGLC) and Alluvial (ALL). Alluvial soils are a subset of the recent soils group in the New Zealand Genetic Soil Classification. The model was not calibrated for other recent soils, podzols, rendzinas or intergrades between soil types. Parameters used for entry into the CadBal model include initial soil cadmium concentration, region, farm type, soil group and the output files given a classification name e.g. WKD3L for Waikato Dairy on YBL with low initial cadmium. Cadmium leaching figures for different soil groups are those described by Grey et al. (2003a) which range between 270 and 850 mg ha^{-1} y^{-1} (Table 1). The location of the soil did not affect the leaching figure used, e.g., Northern YGE were considered to have the same leaching figure as Central and Southern YGE despite these locations having different climatic conditions. The model's default "zero" leaching figure was used for alluvial soils. The soil bulk density figures used in the model are also detailed in Table 1. The atmospheric accession figure for cadmium used throughout New Zealand was 200 mg ha^{-1} y^{-1} (Grey et al. 2003b).

The model was run using the following default values and assumptions:

- Sedimentation losses from each site are 900 kg ha^{-1} y^{-1} for dairy farming and 500 kg ha^{-1} y^{-1} for cropping and sheep and beef farming
- Sedimentation losses are not influenced by soil group or landscape topography
- There is no accumulation of erosion debris
- Atmospheric deposition of cadmium is constant across the whole country
- Leaching losses are identical in all regions for a particular soil group
- Alluvial soils had no losses from leaching
- Animal relocation of cadmium through faeces or land application of dairyshed effluent is insignificant
- Diammonium phosphate (DAP) is used in cropping while single superphosphate (SSP) is used in animal production
- DAP contains 175 mg Cd kg P^{-1} while SSP contains 230 mg Cd kg P^{-1}

Table 1: Cadmium leaching figures (from Grey et al. 2003a) and soil bulk density figures used by the CalBal model for different soil groups

Soil types	Leaching figure used (mg ha^{-1} y^{-1})	Soil Bulk Density figure used (kg m^{-3})
Yellow Brown Loam and Brown Granular Clays and Loams	425	750
Yellow Brown Earths	540	910
Yellow Grey Earths	270	1070
Yellow Brown Pumice	280	680
Gley	280	870
Alluvial[1]	0[2]	750

[1] Not a defined soil group in the New Zealand Genetic Soil Classification
[2] CalBal model default value

Based on measured data from the cadmium database, 287 scenarios were run using average data for New Zealand as a whole and for regions. PDF files of the scenario outputs are on the accompanying CD under the CalBal scenarios directory. Soil bulk density emerged as an influential factor and this influence is discussed in a separate section.

2.4 A NATIONALLY CONSISTENT SAMPLING AND ANALYSIS SCHEME

Assessment of an overseas national sampling and analysis scheme and options for New Zealand are presented and discussed.

3. RESULTS AND DISCUSSION

3.1 NATIONAL AND REGIONAL TOPSOIL TOTAL-CADMIUM SOIL LEVELS

Data on topsoil total-cadmium concentration and associated metadata were tabulated according to region and the number of sites per region calculated (Table 2). Data from a total of 1649 samples with regional location data were used and the national average concentration for cadmium calculated to be 0.35 µg g^{-1}. Data from 1443 of these samples also had grid references suitable for plotting on a national map (Figure 1). These data were plotted as boxplots (Figure 2). All regions with greater than 8 data points showed data skewed towards 0 and points outside the 90 percentile whiskers. Individual regions were plotted (Figures 3–16) Cadmium concentrations above 1 µg g^{-1} were found in the Taranaki, Waikato and Bay of Plenty Regions.

The region with the highest average cadmium concentration was Taranaki (0.66 µg g^{-1}) (Table 1). Other regions with similar cadmium concentrations include Waikato (0.60 µg g^{-1}) and Bay of Plenty (0.52 µg g^{-1}). Dairy farming with high fertiliser use is traditional in these areas and likely to be the cause of the elevated levels. The regions with the lowest cadmium average concentrations were Canterbury (0.18 µg g^{-1}), Gisborne (0.20 µg g^{-1}), Manawatu-Wanganui (0.17 µg g^{-1}), Nelson-Marlborough (0.23 µg g^{-1}), Otago (0.20 µg g^{-1}) and Southland (0.20 µg g^{-1}), all historic sheep farming areas. Soils in higher cadmium areas are dominated by Allophanic, Pumice and Granular soils while regions with lower cadmium are dominated by Recent, Pallic and Brown Soils. However, soil order was often not described for the sample sites, making it difficult to identify if there is a soil component to the cadmium concentrations or if differences in cadmium are due to land-use only.

Table 2: Number of topsoil samples, average and range of cadmium concentration per region

Region	Number of samples	Average (µg g^{-1})	Range (µg g^{-1})
Auckland	195	0.32	0.03–1.10
Bay of Plenty	130	0.52	0.05–1.60
Canterbury	425	0.18	0.01–0.89
Gisborne	8	0.20	0.05–0.27
Hawke's Bay	36	0.31	0.05–0.63
Manawatu-Wanganui	78	0.17	0.04–0.9
Nelson-Marlborough	50	0.23	0.03–1.00
Northland	24	0.33	0–0.67
Otago	42	0.20	0.03–0.91
Southland	46	0.20	0.04–0.62
Taranaki	83	0.66	0.04–1.7
Waikato	362	0.60	0.03–2.52
Wellington	169	0.20	0.05–0.90
Westland	1	0.40	–
National	**1649**	**0.35**	**0–2.52**

The regions of Canterbury and Waikato had the highest number of samples (425 and 362 respectively). The regions of Bay of Plenty (130), Taranaki (83) and Wellington (169) are also relatively well represented. Regions with low numbers of samples, where further sampling may be beneficial to increase confidence, include Gisborne (8), Hawke's Bay (36), Northland (24) and Westland (1).

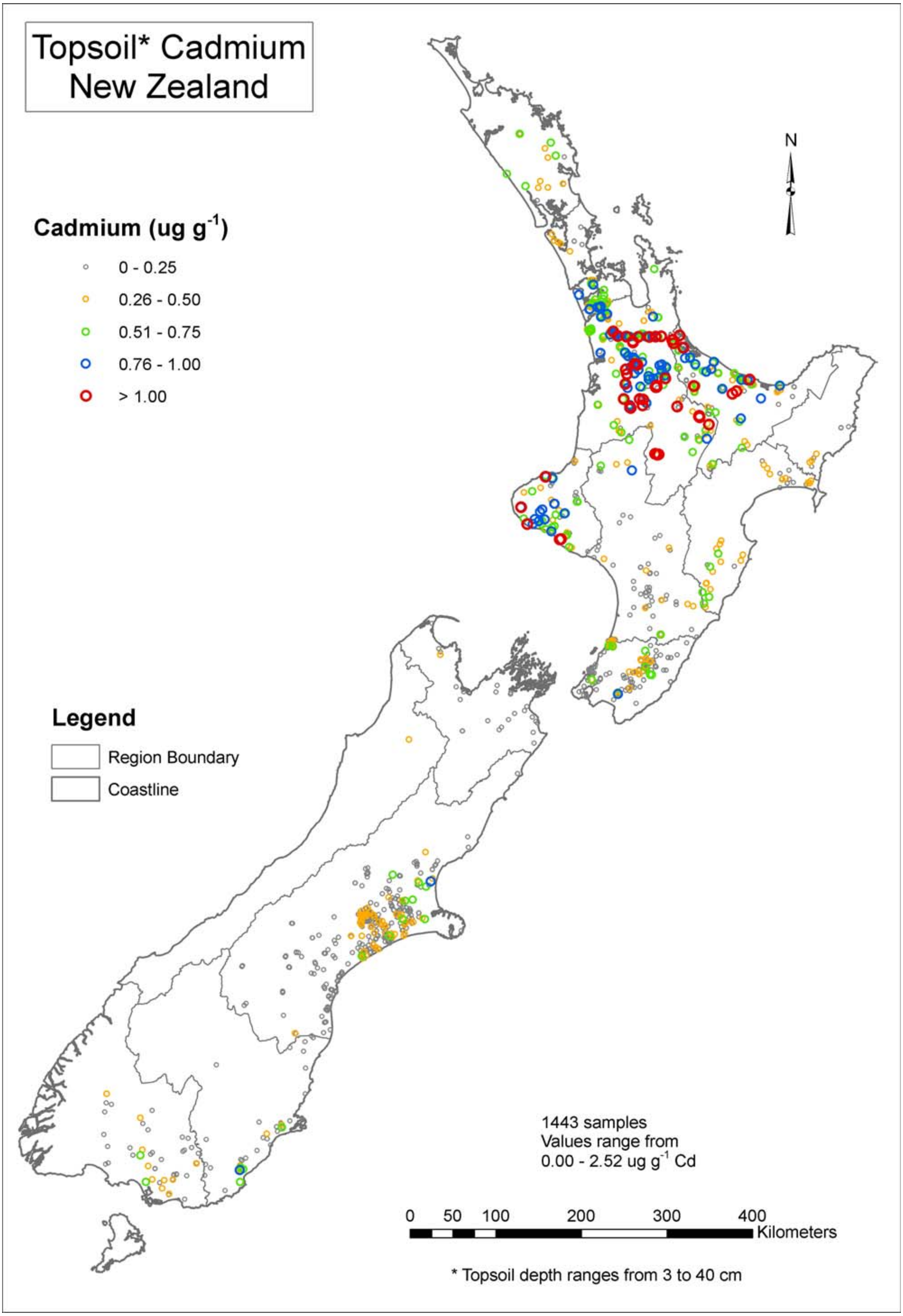

Figure 1: Regional map of topsoil cadmium levels

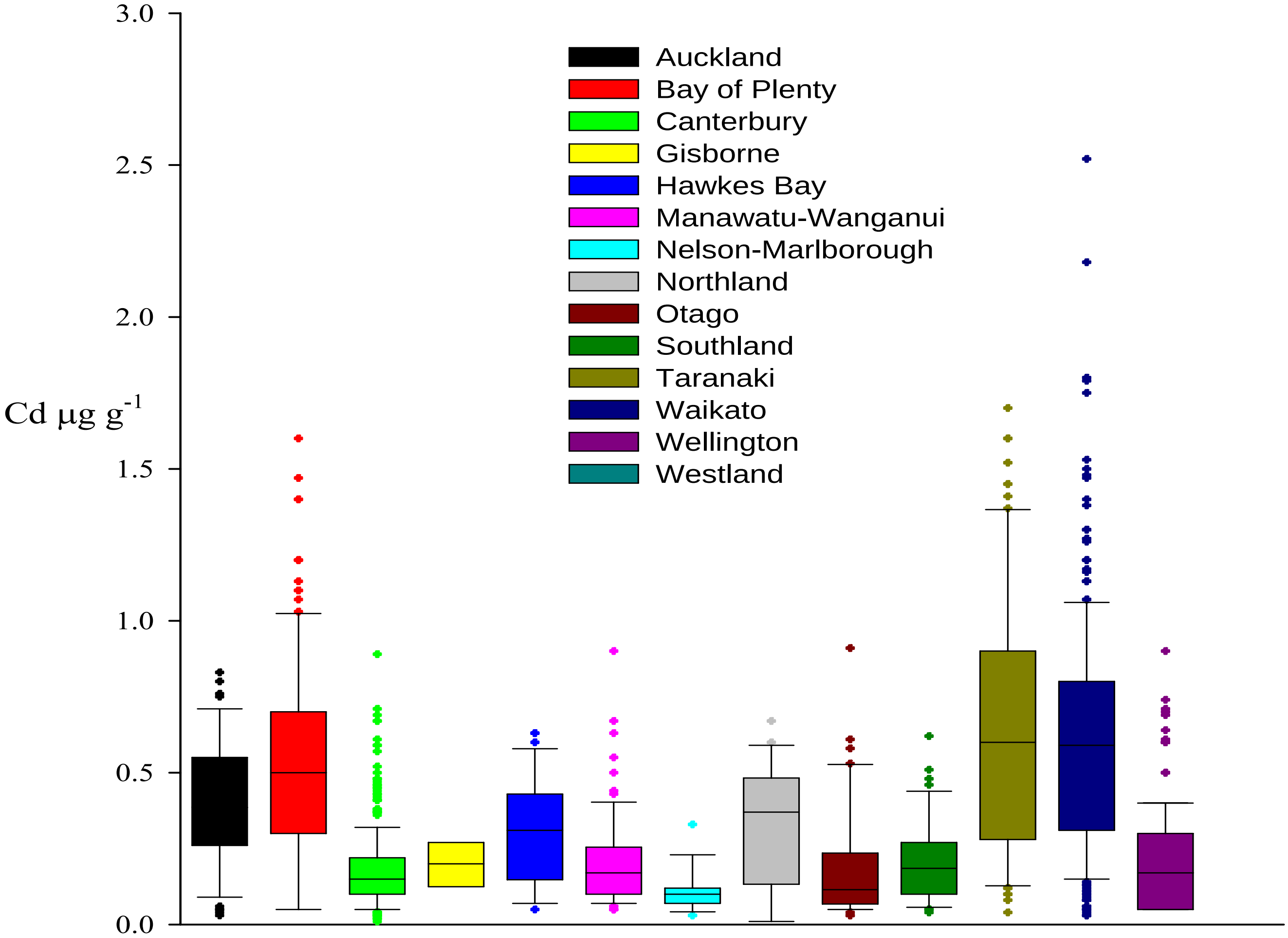

Figure 2: Boxplots of cadmium in soil according to region showing mean and 90% confidence levels

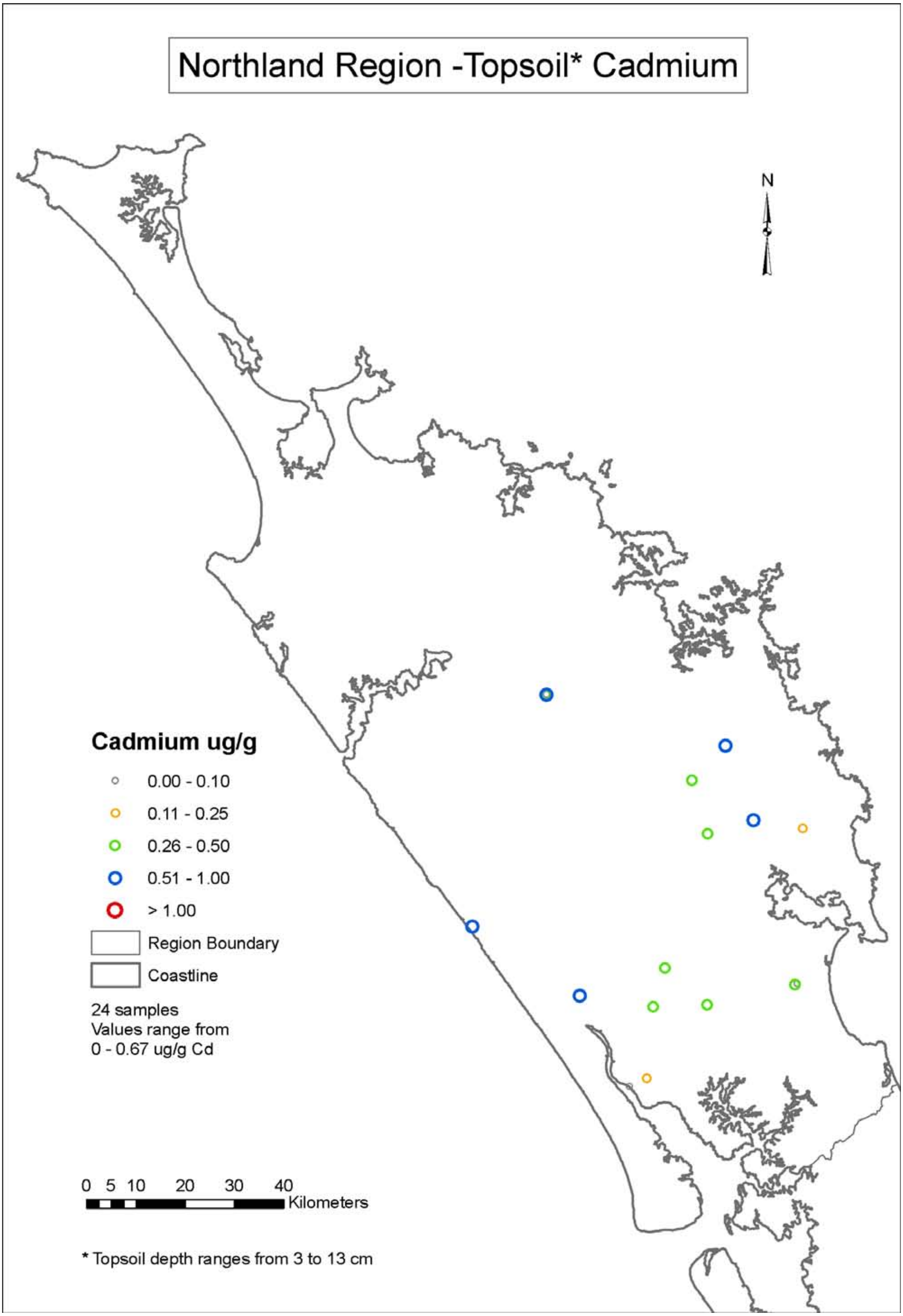

Figure 3. Regional map of Northland topsoil cadmium levels

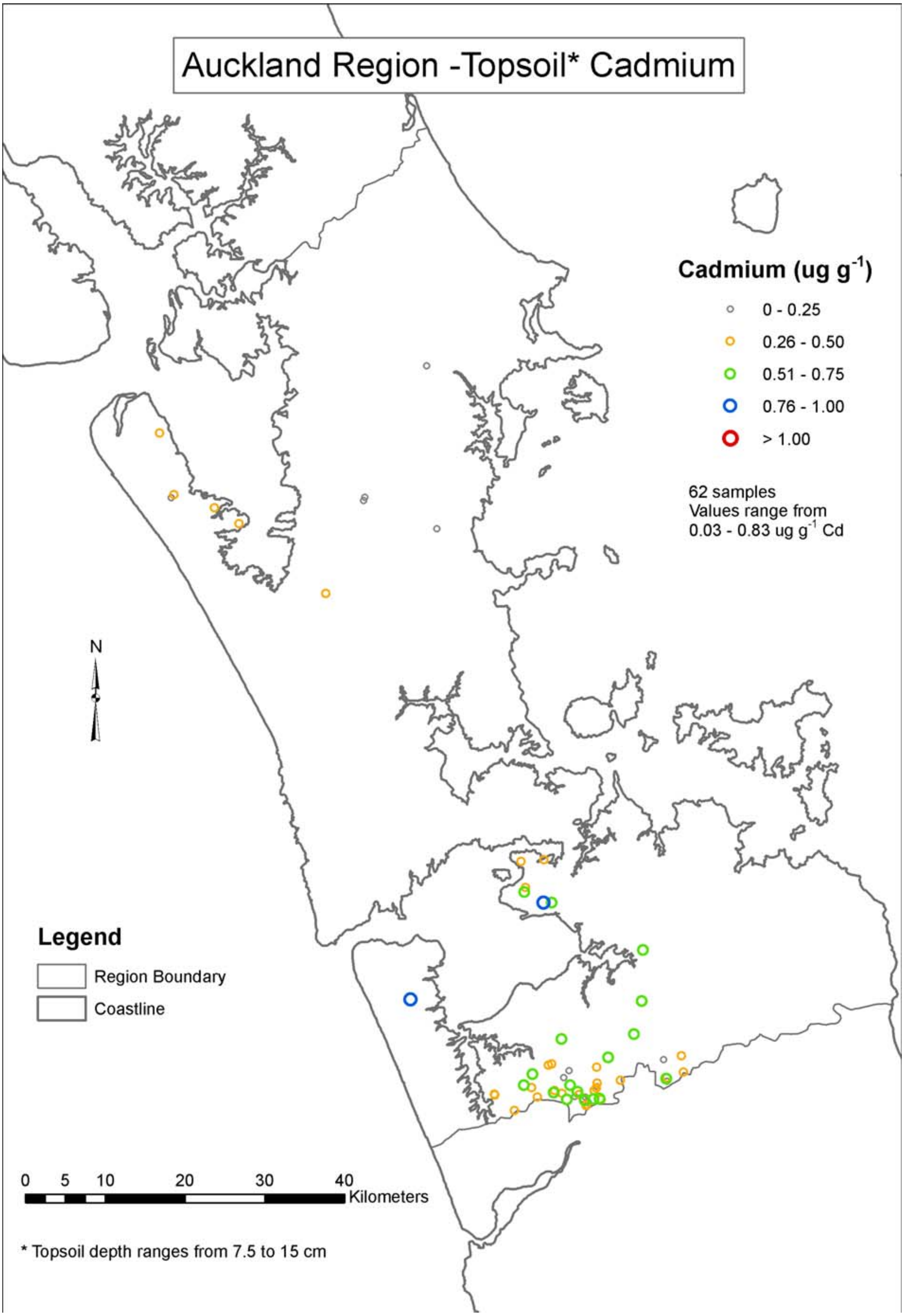

Figure 4: Regional map of Auckland topsoil cadmium levels

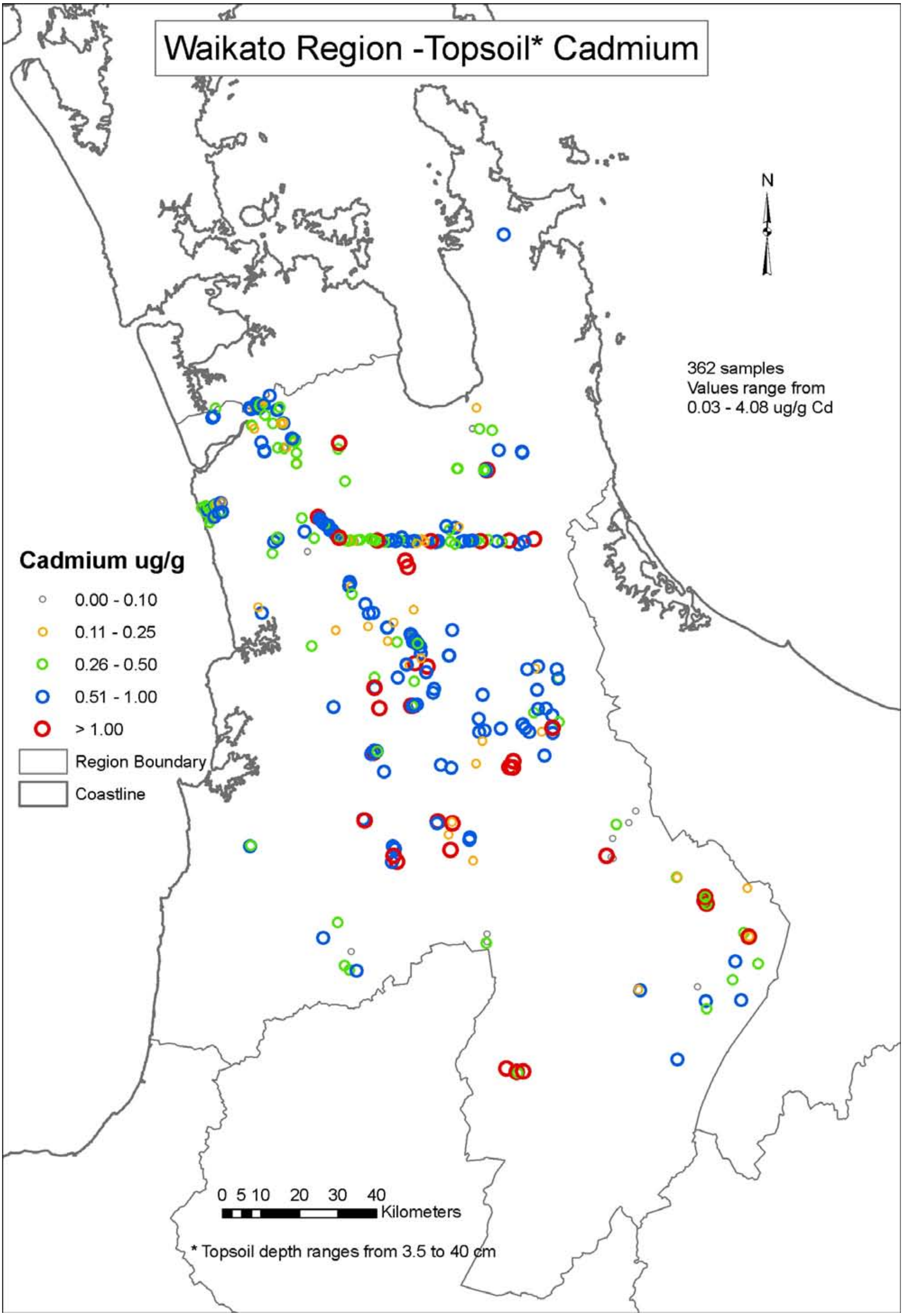

Figure 5: Regional map of Waikato topsoil cadmium levels

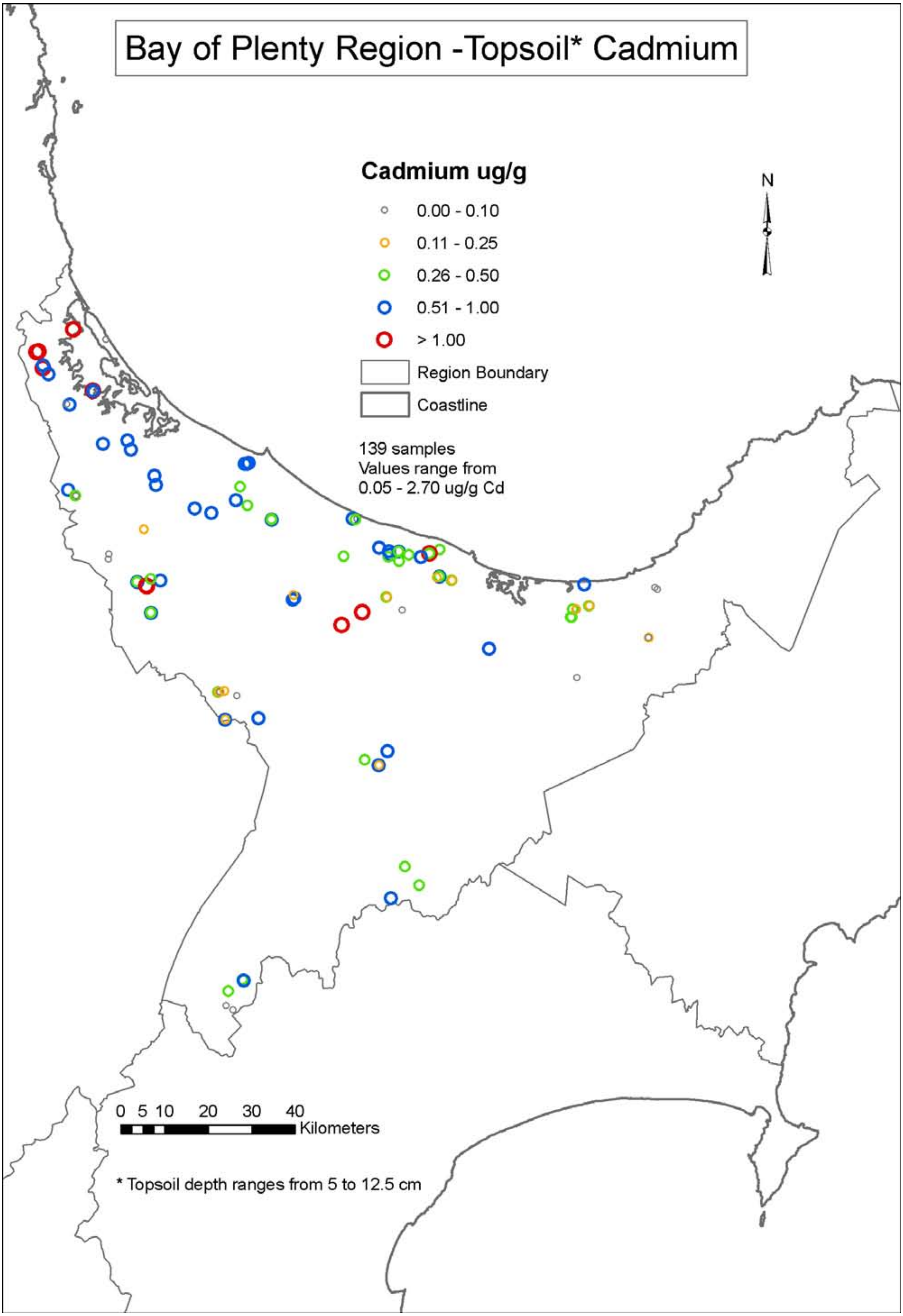

Figure 6: Regional map of Bay of Plenty topsoil cadmium levels

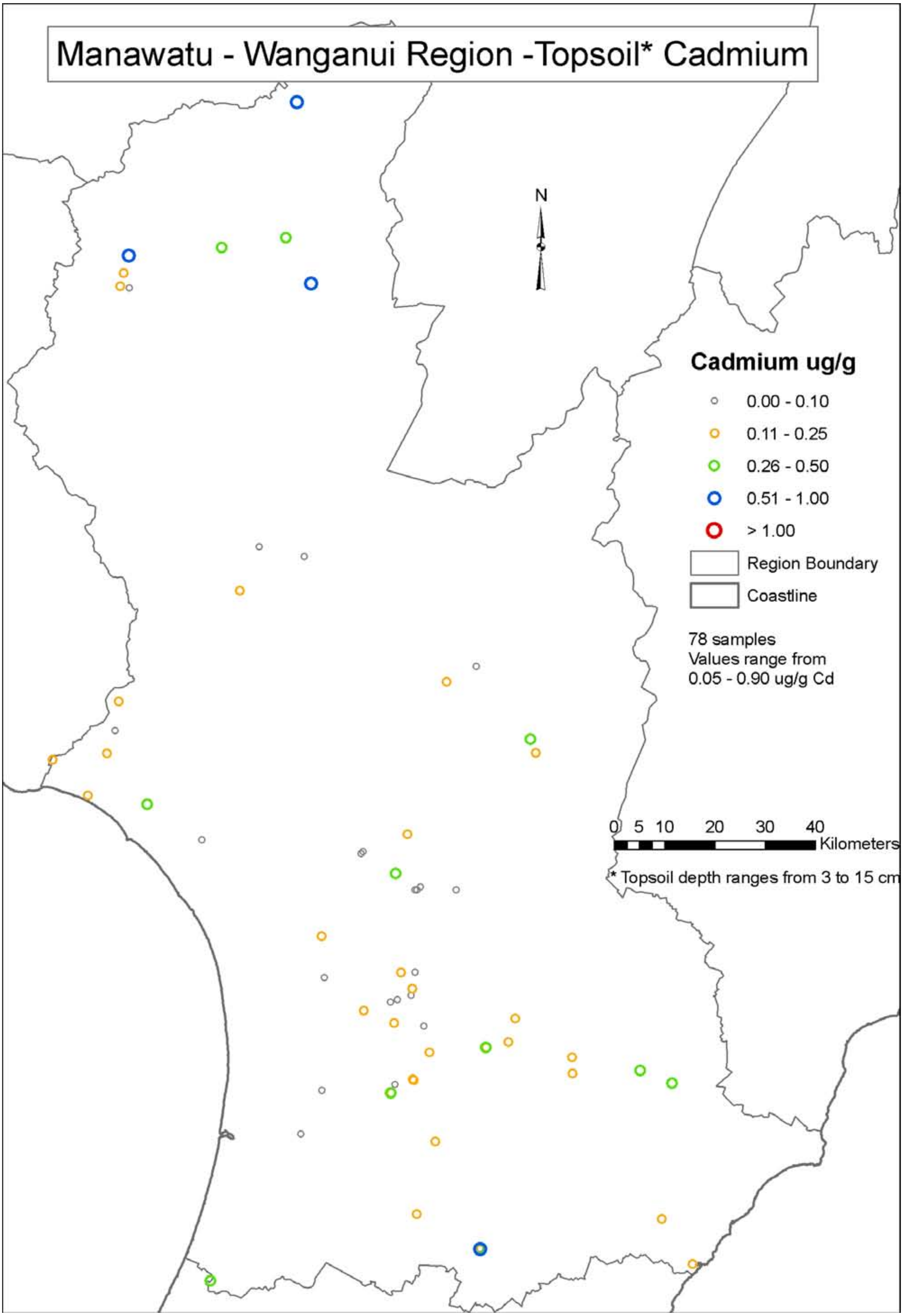

Figure 7: Regional map of Manawatu-Wanganui topsoil cadmium levels

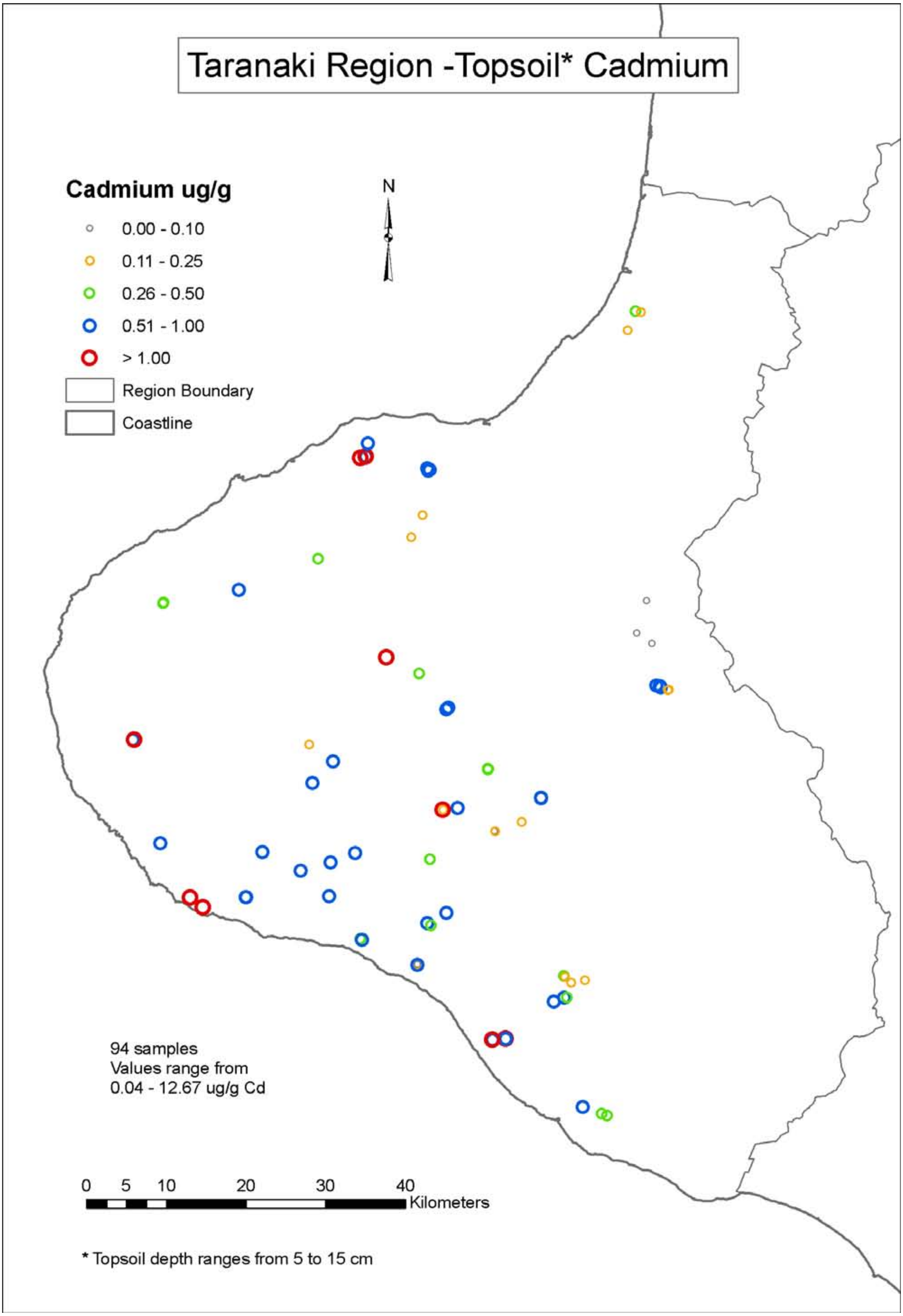

Figure 8: Regional map of Taranaki topsoil cadmium levels

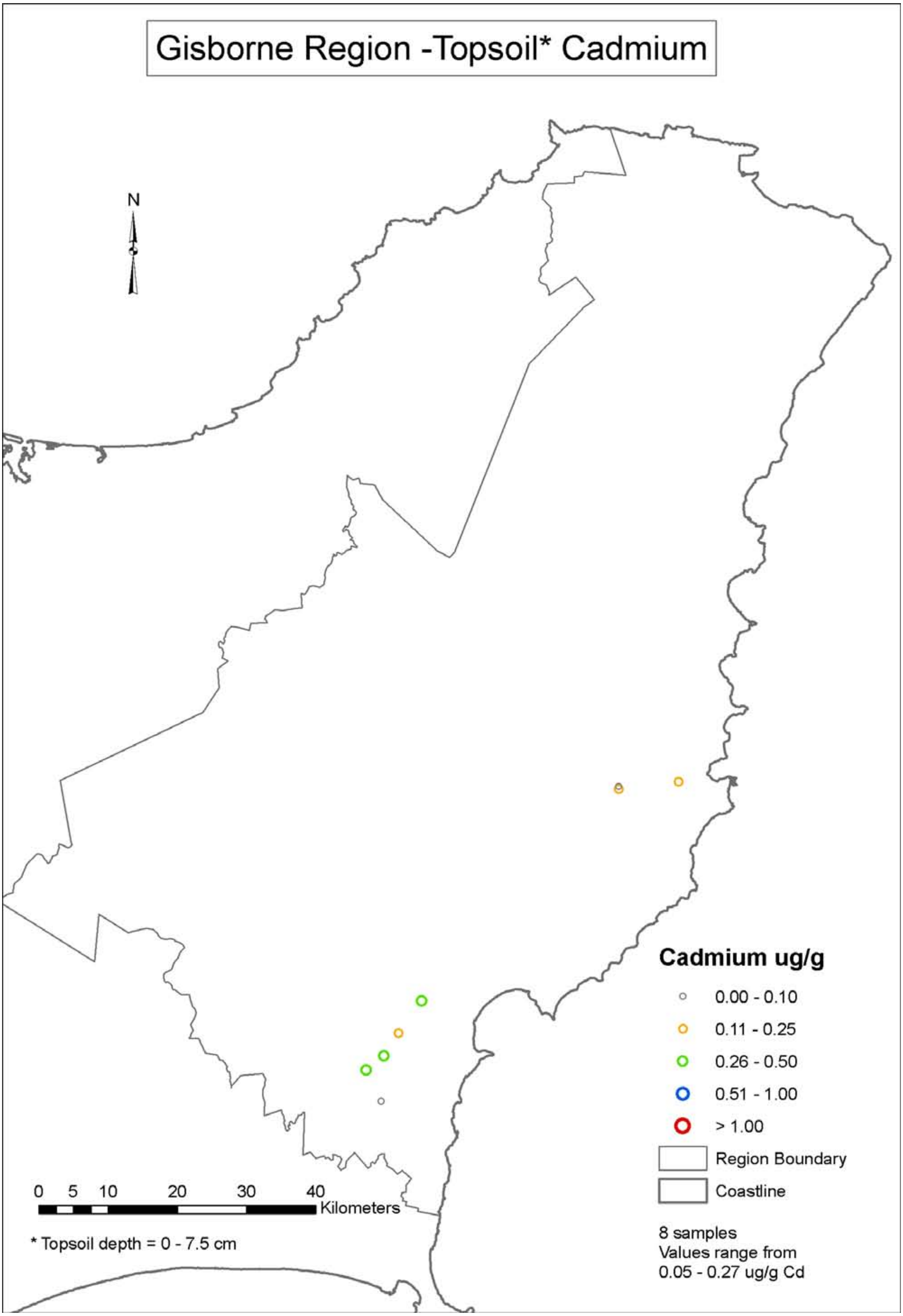

Figure 9: Regional map of Gisborne topsoil cadmium levels

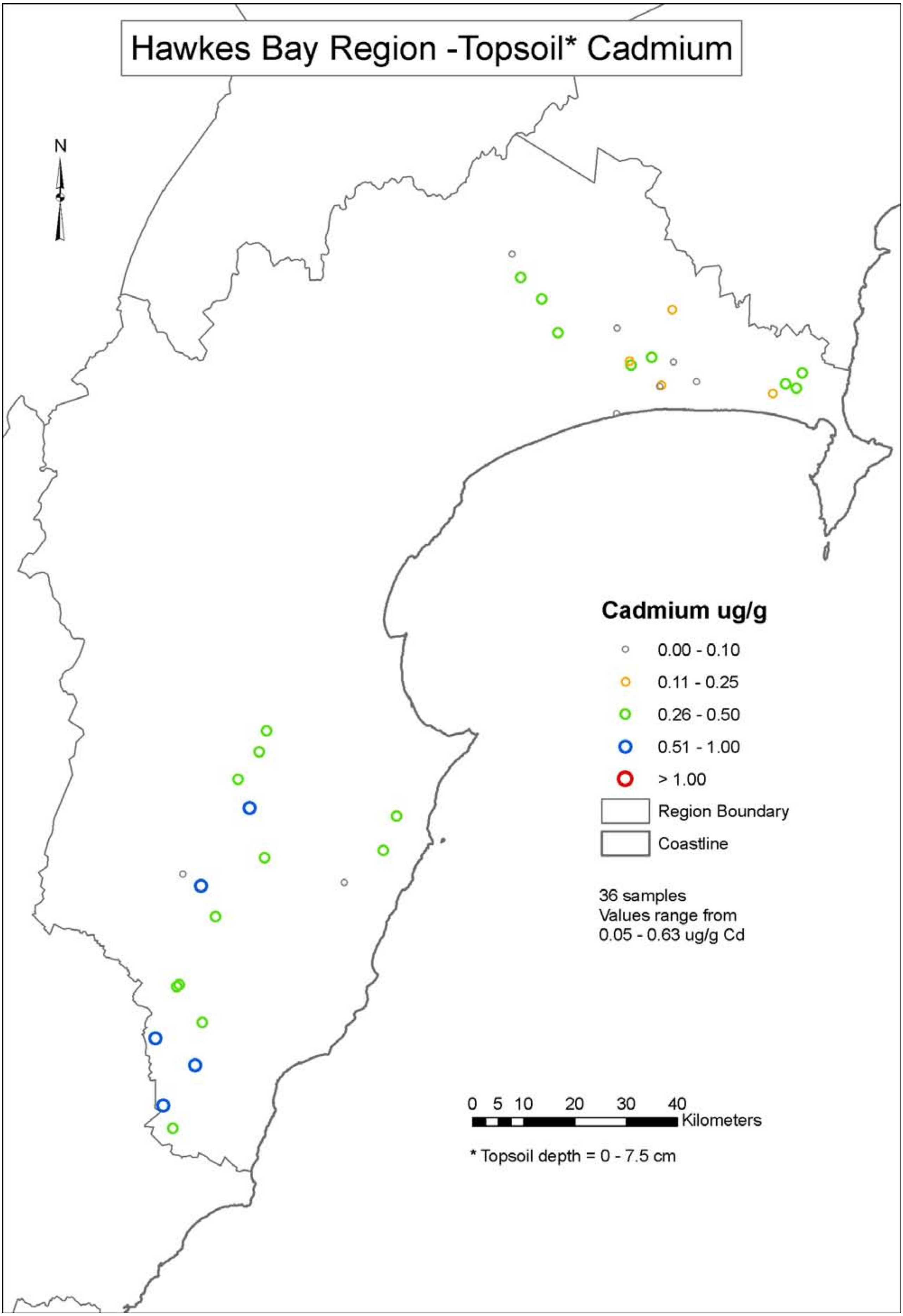

Figure 10: Regional map of Hawke's Bay topsoil cadmium levels

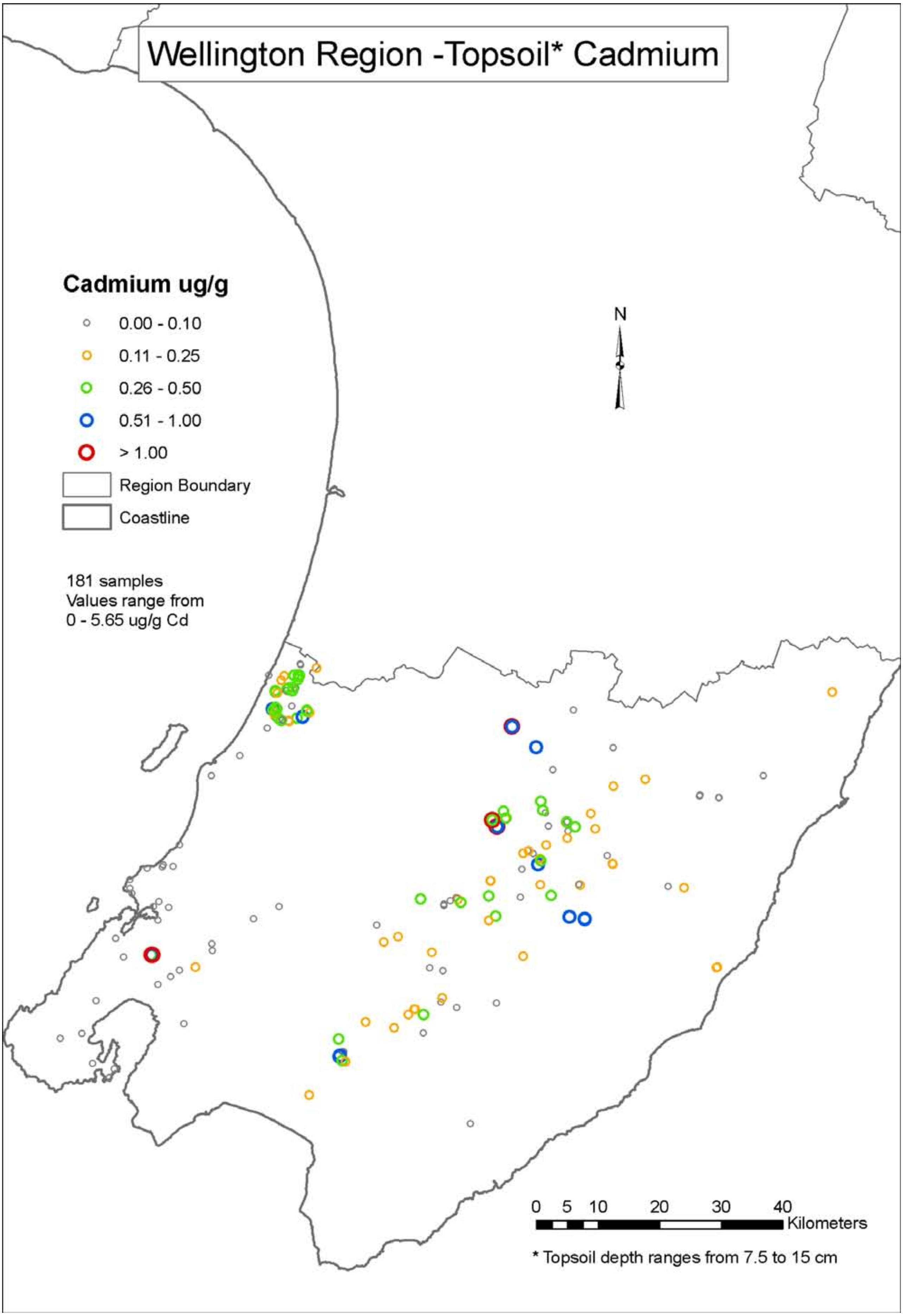

Figure 11: Regional map of Wellington topsoil cadmium levels

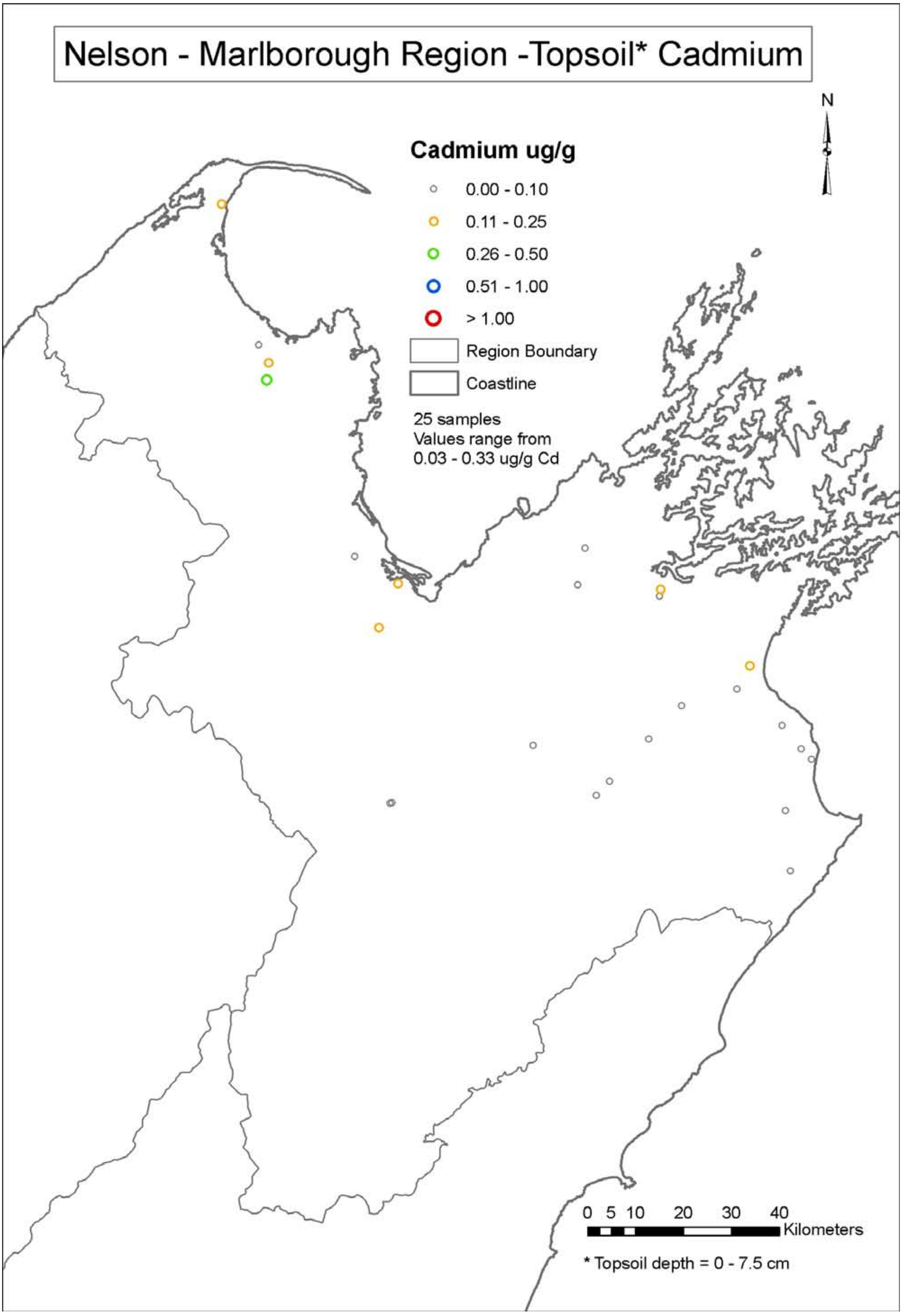

Figure 12: Regional map of Nelson-Marlborough topsoil cadmium levels

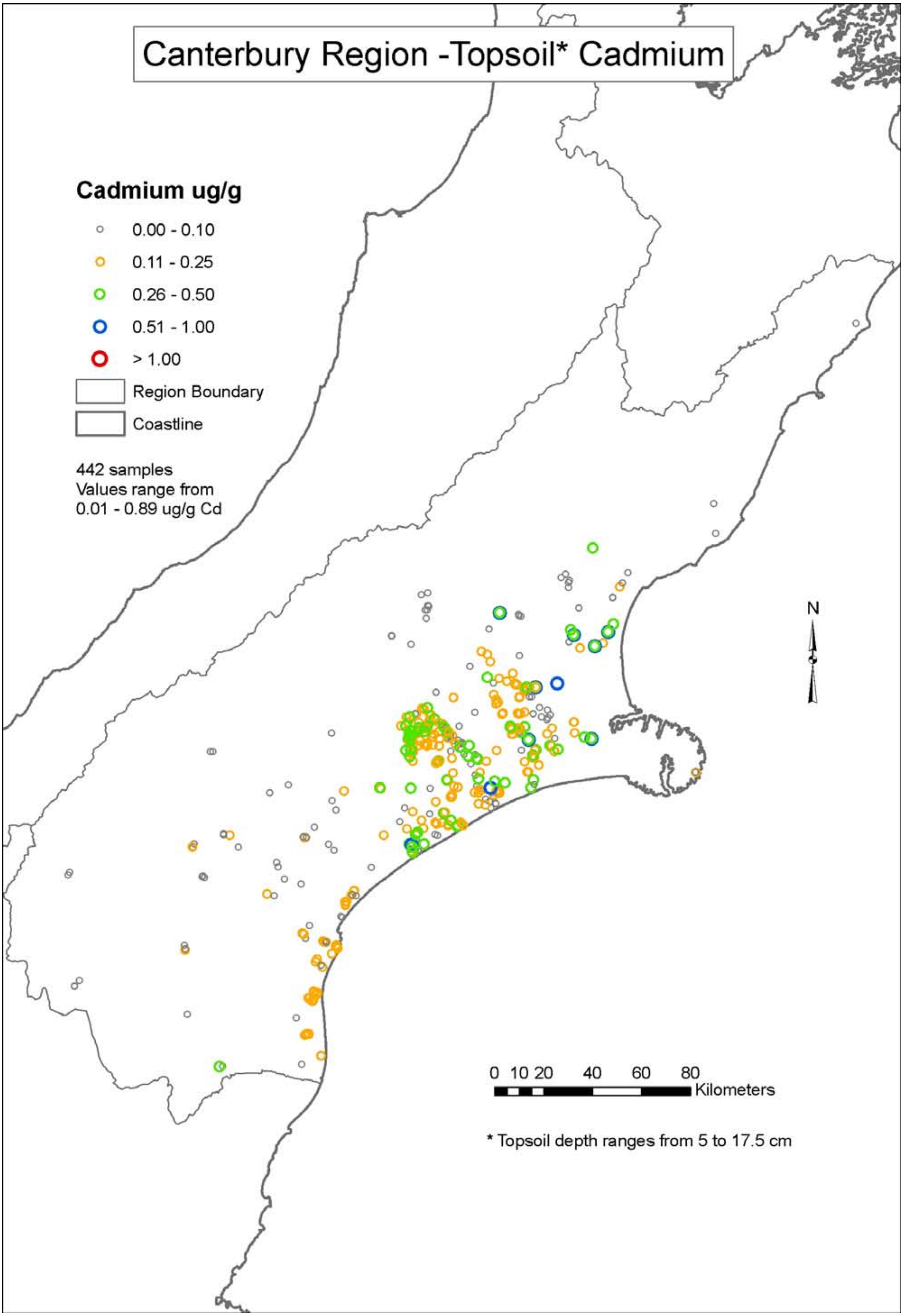

Figure 13: Regional map of Canterbury topsoil cadmium levels

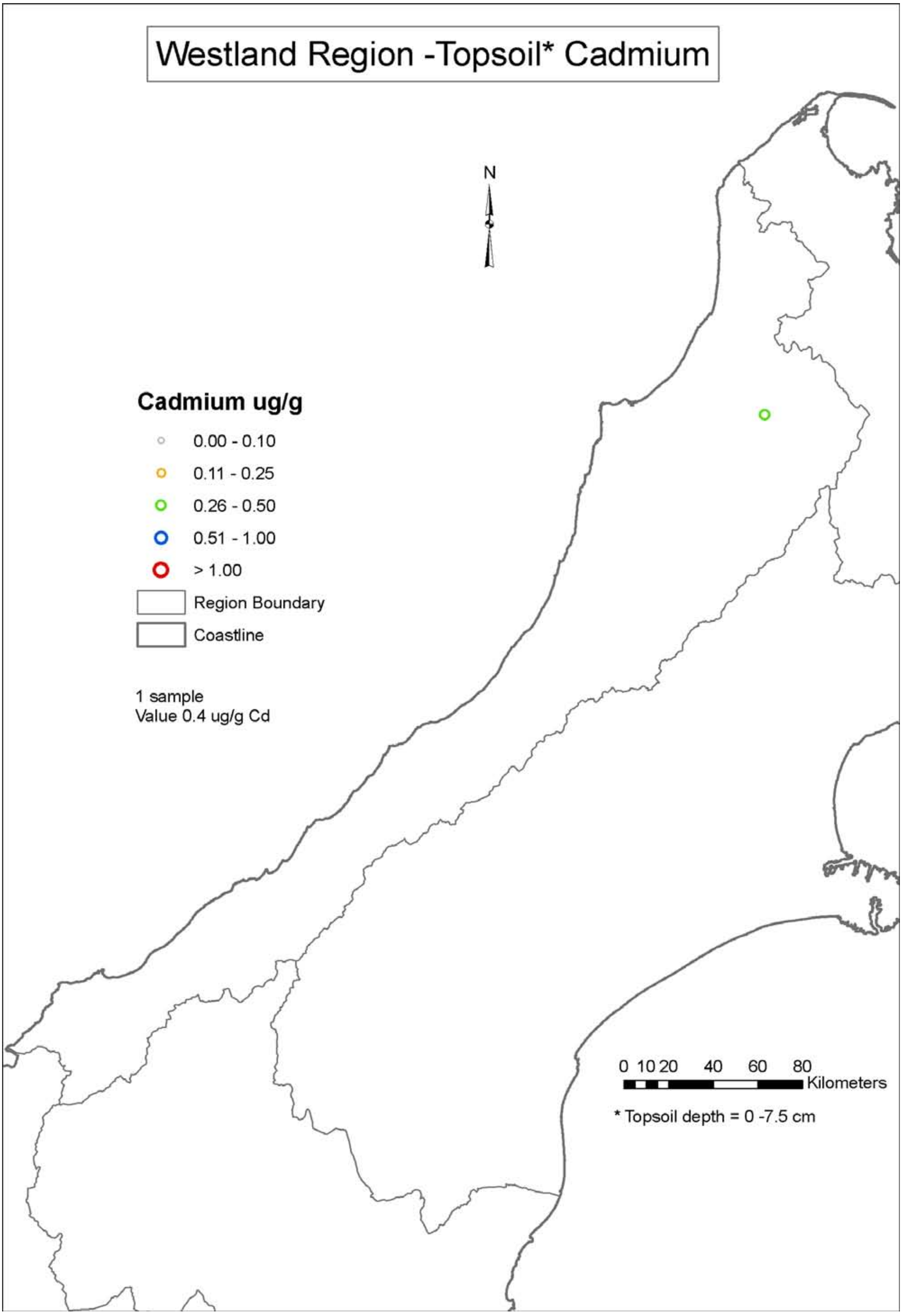

Figure 14: Regional map of Westland topsoil cadmium levels

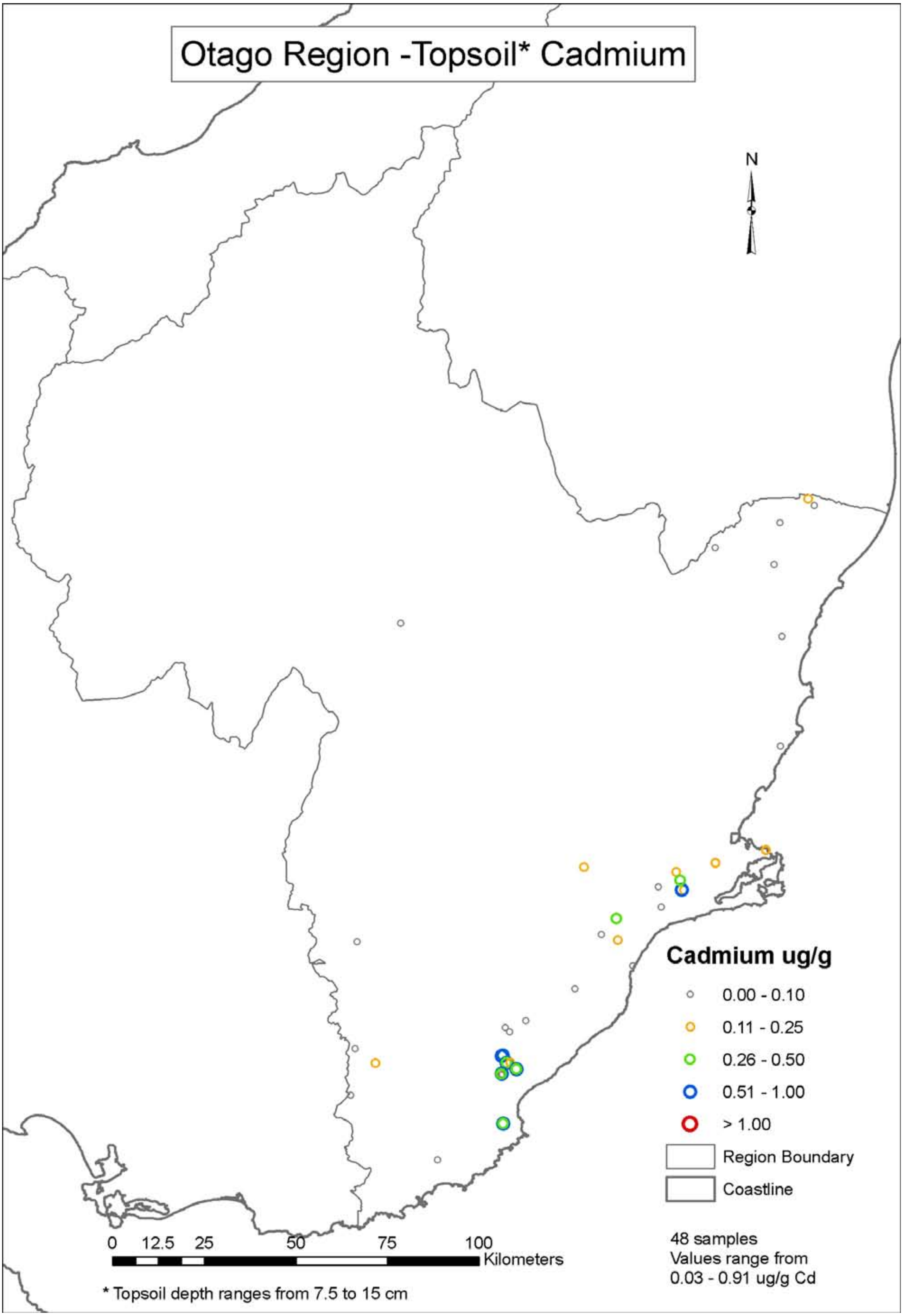

Figure 15: Regional map of Otago topsoil cadmium levels

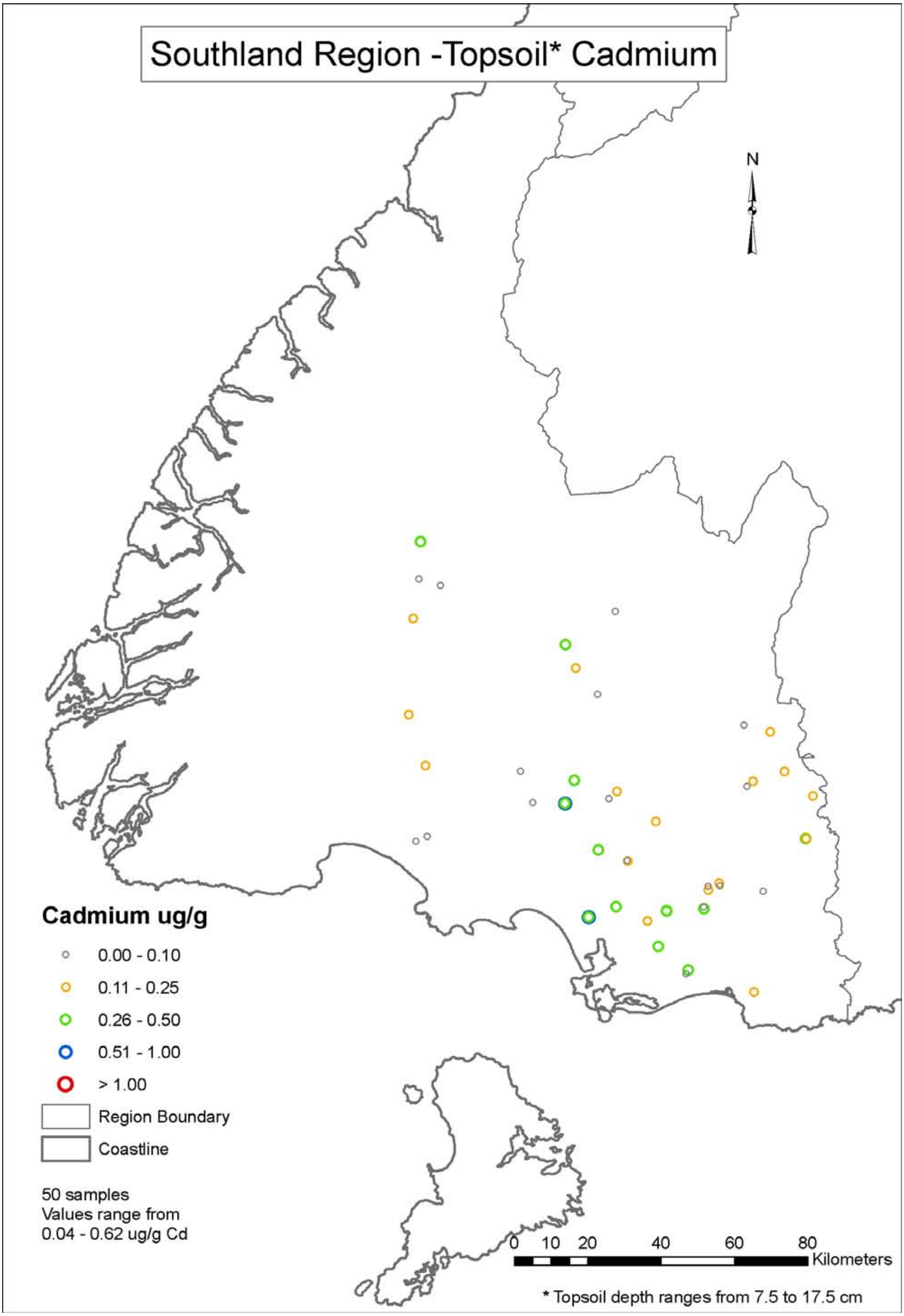

Figure 16: Regional map of Southland topsoil cadmium levels

3.2 BACKGROUND LEVELS OF CADMIUM IN NEW ZEALAND

Sites with land-uses such as native, tussock, plantation forestry and parks or described as "unfertilised" may be considered suitable for assessing soil cadmium background concentrations (Table 3). Because it had the largest number of samples, the landuse "unfertilised" has the largest influence on the result. It also has the highest cadmium concentrations of the background soils, possibly as a result of contamination, e.g., fertiliser drift or animal transfer. As we were unable to identify conclusively if these samples were contaminated or not we report both a total background average and a background without unfertilised average.

There were no statistically significant or visual differences between soil type or regions for this background data, and the national average was calculated using data from all soil types and regions. Most background soil samples were 10 cm deep with a few soil samples of other soil depths (average 10.0 cm). The average was 0.16 µg g^{-1}, similar to the 0.20 µg g^{-1} found by Roberts et al. (1994) for non-farmed soils. The background average without "unfertilised" samples was lower – 0.11 µg g^{-1}. Boxplots of the data by landuse showed skewedness towards 0 and points outside the 90 percentile whiskers (Figure 17). This skewedness could be caused by natural variation, perhaps related to soil bulk density (as discussed later in section 3.8) or to a localised source of contamination for some samples. However, further investigation would be required to identify the cause definitively.

Table 3: Background Cd concentration by landuse

Landuse	Number of samples	Average Cd (µg g^{-1})	Range (µg g^{-1})
Native	69	0.10	0.00–0.39
Forestry	42	0.14	0.02–0.65
Parks	36	0.11	0.06–0.20
Tussock	4	0.08	0.07–0.09
"Unfertilised"	221	0.19	0.02–0.77
Background (No unfertilised)	151	0.11	0.00–0.65
Total Background	**372**	**0.16**	**0.00–0.77**

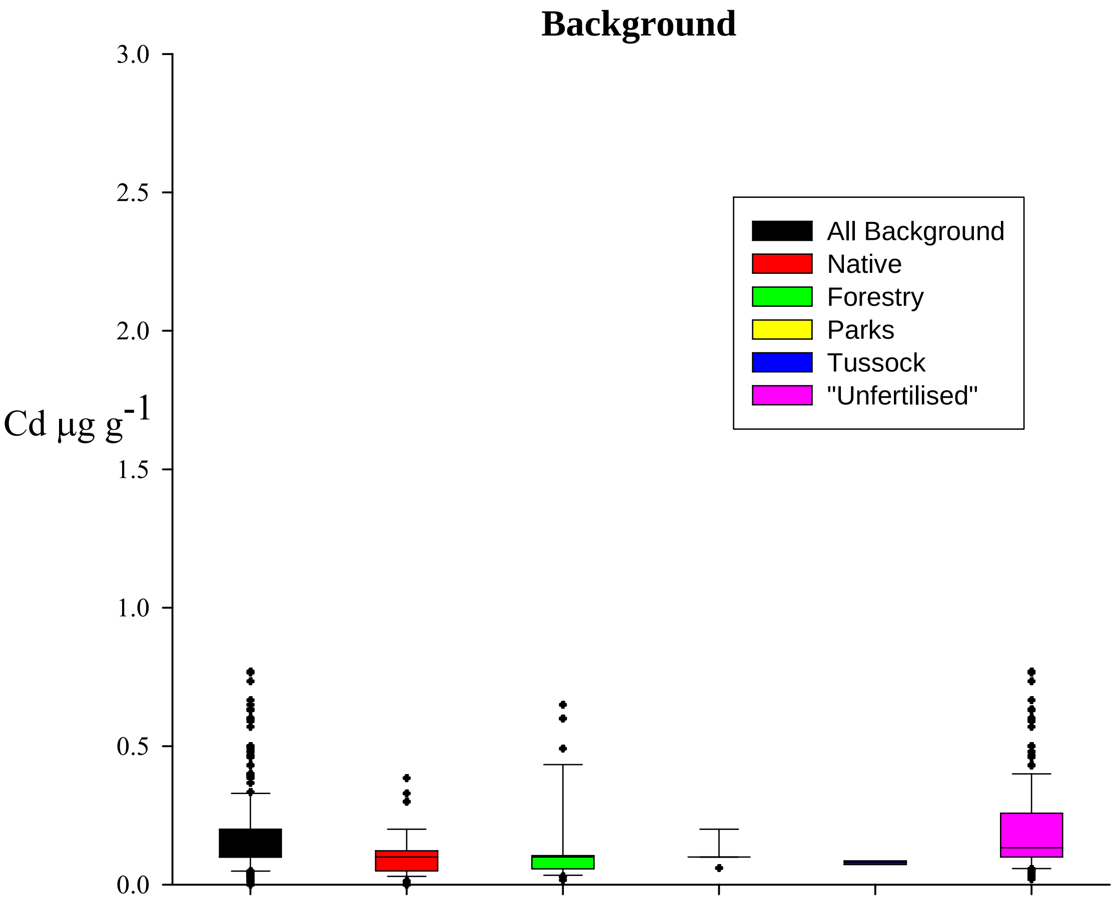

Figure 17: Boxplots of background cadmium in soil by land-use

3.3 CURRENT LEVELS OF CADMIUM IN NEW ZEALAND

Data on topsoil total-cadmium concentrations and associated metadata were tabulated according to 4 major landuse classes (Table 4). The average and range were the same as those calculated using the georeferenced subset, confirming the robustness of the data set. Sites with land-uses such as native, tussock, plantation forestry and parks or described as "unfertilised" are considered to represent background soil cadmium concentrations (Table 3, Figure 17). Land that had been used for agriculture (cropping, pasture and horticulture) had elevated concentrations of cadmium in soil compared with background values indicating accumulation of cadmium in these soils. Horticulture had the highest average (0.50 µg g^{-1}), while pasture had the highest individual value (2.52 µg g^{-1}), indicative of high fertiliser use or some other localised contamination source. Again, boxplots showed data skewed towards 0 and points outside the 90 percentile whiskers (Figure 18). This skewedness could be caused by natural variation, perhaps related to soil bulk density (as discussed later in section 3.5), localised sources of contamination for some soils or a history of high inputs of cadmium from fertiliser.

Table 4: Cd concentration in 4 major landuse classes

Landuse	Number of samples	Average sampling depth (cm)	Average Cd (µg g^{-1})	Range (µg g^{-1})
Cropping	301	14.3, Mostly 0–15	0.24	0.00–0.99
Pasture	825	9.39, Mostly 0– 7.5, 0–10 or 10–5	0.43	0.00–2.52
Horticulture	296	13.1, Mostly 0–10	0.50	0.00–2.00
Background	372	10.0, Mostly 0–10	0.16	0.00–0.77
All Landuses	**1794**		**0.35**	**0.00–2.52**

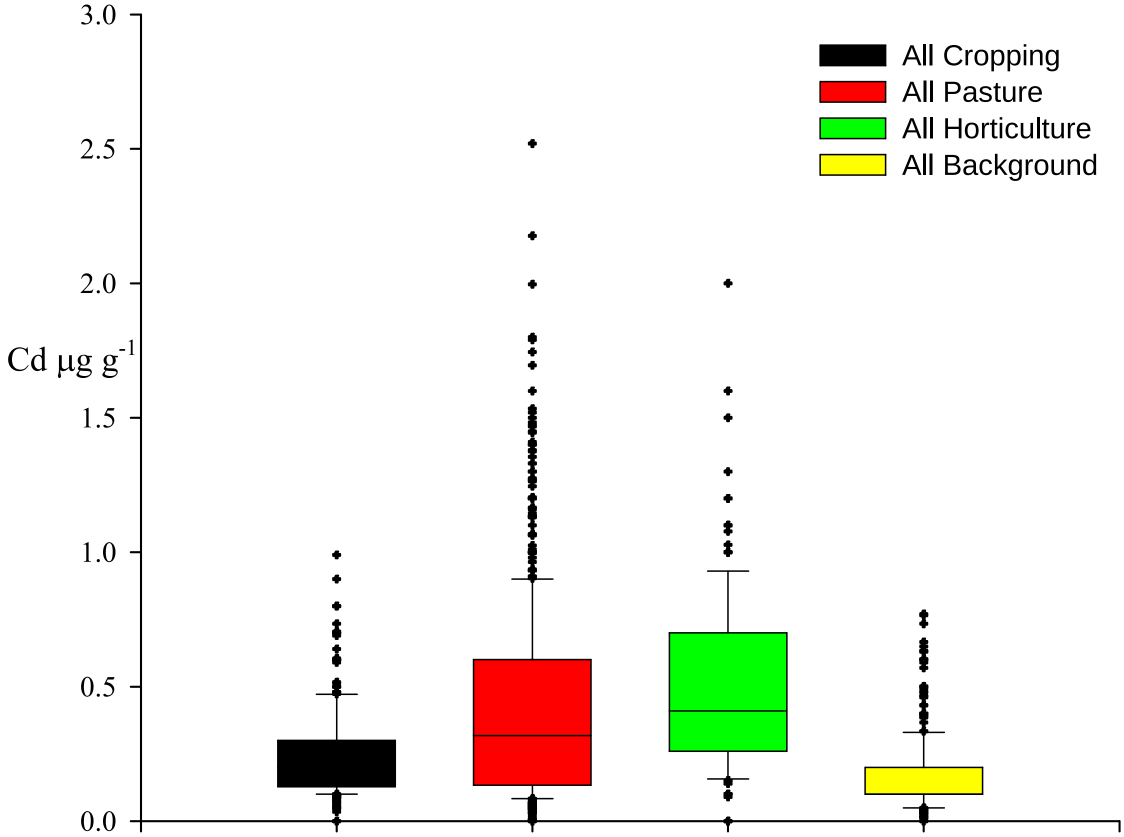

Figure 18: Boxplots of cadmium in soil in 4 major landuse classes

Each of the 3 major agricultural land-uses was further investigated. Most soil samples from cropping land were 15 cm deep, with a few soil samples of 10 cm depth (average 14.3 cm). Relatively few (33 out of 301) of the cropping land-use data included detailed information on crop type (Table 5, Figure 19). One reason for this may be several crops being grown in rotation at one location; so it would therefore be incorrect to assign one crop type to such a site. Where there were crop type data, they were mostly from two regions – Canterbury and Nelson-Marlborough. Soils where tobacco was grown were more elevated in cadmium (0.34 µg g^{-1}) than other cropping soils. These soils will now have other land-uses as tobacco is no longer grown in New Zealand. Cropped soils appear to be mostly below the national average of 0.35 µg g^{-1} for cadmium.

Table 5: Cd concentration in cropland by crop type

Landuse	Number of samples	Average Cd (µg g^{-1})	Range (µg g^{-1})
Barley	6	0.15	0.10–0.25
Maize	11	0.25	0.10–0.40
Peas	3	0.15	0.11–0.17
Tobacco	5	0.34	0.20–0.70
Wheat	8	0.11	0.09–0.16
All Cropping	**301**	**0.24**	**0.00–0.99**

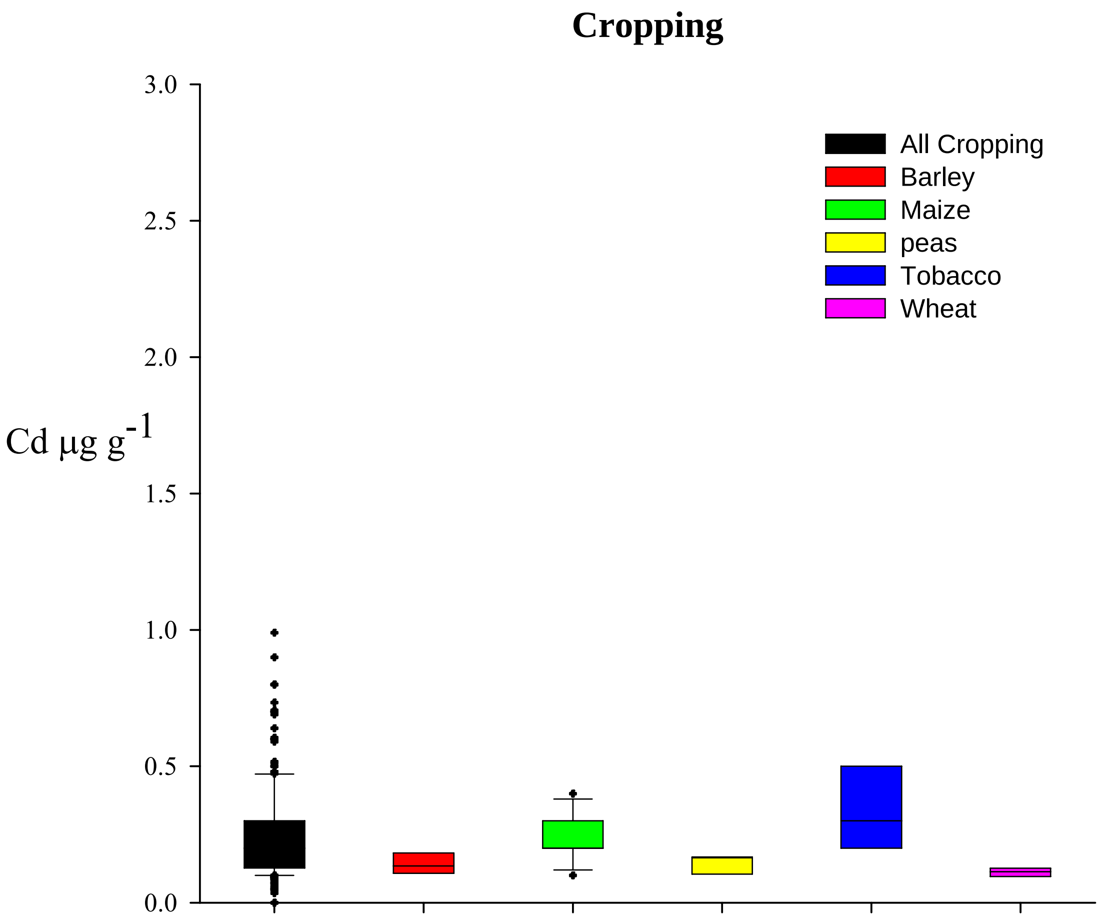

Figure 19: Boxplots of cadmium in cropland soil by crop type

Pasture land-use includes dairy and drystock farming. Soil samples from pastoral land were generally 7.5, 10 or 15 cm deep, with a few soil samples of other depths (average 9.39 cm). Drystock can be further broken down into beef, deer, horses and sheep. Dairying showed the highest soil cadmium concentrations (0.73 µg g^{-1}), averaging double the national average of 0.35 µg g^{-1} (Table 6). Dairying also showed the largest number of data points outside the 95 and 5 percentiles for the pasture landuse (Figure 20), reflecting the wide range of cadmium values measured. Deer and horse farming were also associated with higher average concentrations of soil cadmium (0.68 µg g^{-1} and 0.53 µg g^{-1} respectively). However, there were few samples, and these farms were from 1 region – the Waikato, and may have previously been used for dairying. They may not reflect national trends. Average values for beef farming and all drystock were slightly above (0.42 µg $g^{-1}$and 0.40 µg g^{-1} respectively) and sheep farming slightly below (0.33 µg g^{-1}) the national average.

Table 6: Cd concentration in pasture soils by farm type

Landuse	Number of samples	Average Cd (µg g^{-1})	Range (µg g^{-1})
Dairy	144	0.73	0.00–2.52
Deer	12	0.68	0.40–1.20
Beef	48	0.42	0.04–1.40
Horses	4	0.53	0.40–0.60
Sheep	34	0.33	0.03–1.20
All Drystock	**111**	**0.40**	**0.00–1.40**
All Pasture	**825**	**0.43**	**0.00–2.52**

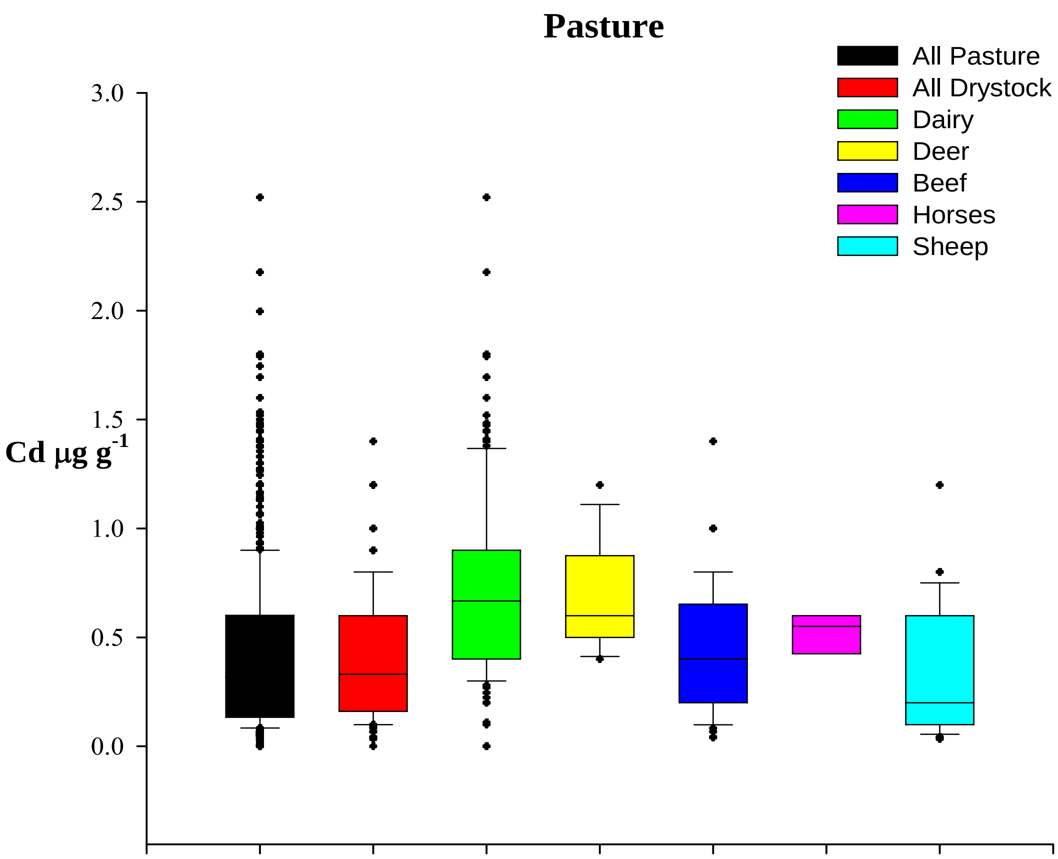

Figure 20: Boxplots of cadmium in pasture soils by farm type

There was more information on the type of farming within the horticultural land-use then the other land-use classes. Most soil samples from horticultural land were 10 or 15 cm deep with a few soil samples of other soil depths (average 13.1 cm). Samples classified as berries (0.68 µg g^{-1}), kiwifruit (0.71 µg g^{-1}) and orchards (0.66 µg g^{-1}) contained soils double or nearly double the national average of 0.35 µg g^{-1} reflecting high inputs of fertiliser or some other source of cadmium contamination (Table 7). Although market gardening had an average soil cadmium concentration of 0.46 µg g^{-1}, it had the greatest range of values and had more data points outside the 95 and 5 percentiles than the other farm types in the horticultural landuse class (Figure 21).

Table 7: Cd concentration in horticultural soils by farm type

Landuse	Number of samples	Average Cd (µg g^{-1})	Range (µg g^{-1})
Berries	50	0.68	0.20–1.20
Kiwifruit	37	0.71	0.30–1.20
Vineyard	12	0.38	0.20–0.70
Market Gardening	142	0.46	0.00–2.00
Orchard	49	0.66	0.10–1.50
All Horticulture	**296**	**0.50**	**0.00–2.00**

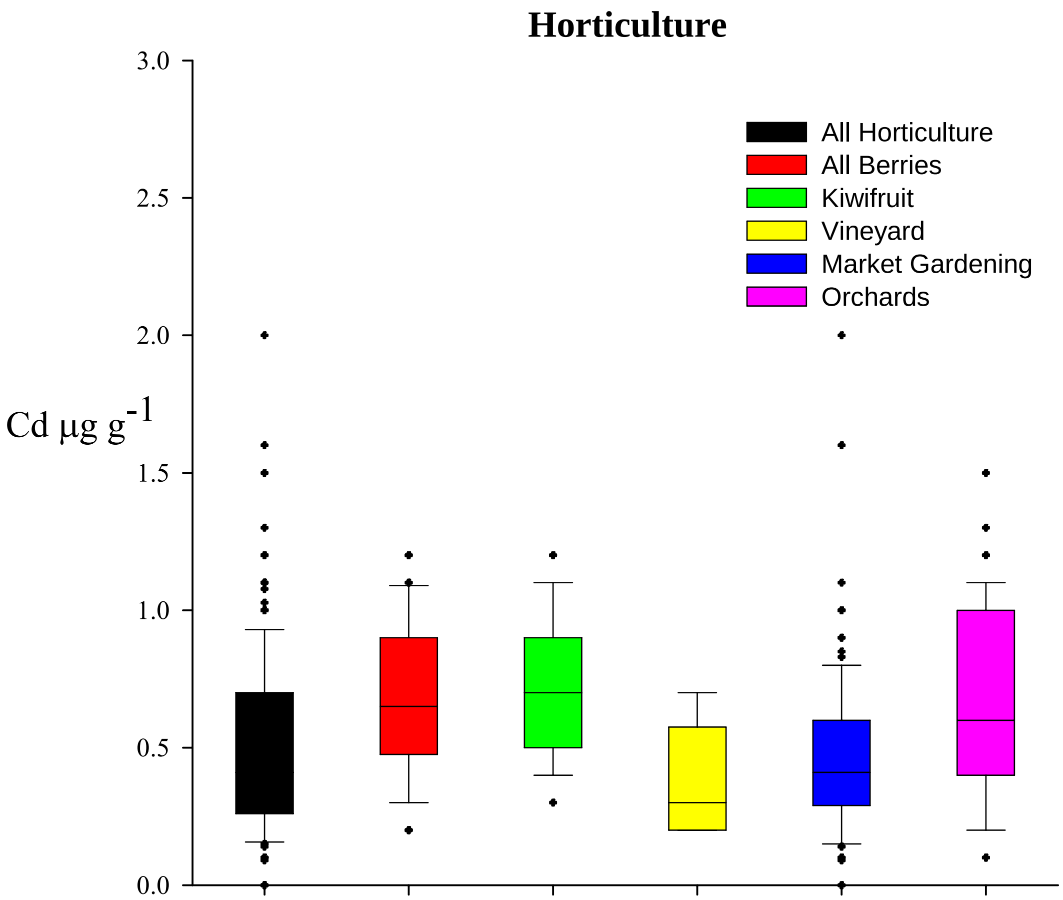

Figure 21: Boxplots of cadmium in horticultural soils by farm type

3.4 REPRESENTIVENESS OF THE DATA

The data in the database was tested for representativeness by comparing topsoil total-cadmium concentrations and associated metadata with LCDB2 vegetation class and the number of sites per 100 square km calculated (Table 8, Figure 22).

High-producing introduced grassland had the highest number of samples (930). Short-rotation cropland was next (345) but had the highest number of sites per 100 square km (10.34). Afforestation, orchard and other perennial crops, surface mine, urban parkland/ open space and vineyard are also relatively well represented with more than 1 site per 100 square km. Depleted tussock grassland, tall tussock grassland and sub alpine shrubland are relatively poorly represented with less than 0.04 sites per 100 square km. Further sampling based on vegetation class is not required as the main farming vegetation classes are adequately covered.

Table 8: Number of sites and number of sites per 100 square km according to LCDB2 vegetation class

LCDB2 vegetation class	Number of sites	Number of sites/100 km sq
Afforestation (imaged, post LCDB 1)	9	1.06
Broadleaved Indigenous Hardwoods	25	0.46
Built-up Area	16	0.98
Deciduous Hardwoods	4	0.48
Depleted Tussock Grassland	1	0.04
Estuarine Open Water	2	0.22
Forest Harvested	7	0.30
Gorse and Broom	4	0.20
Grey Scrub	1	0.14
Herbaceous Freshwater Vegetation	2	0.23
High-producing Exotic Grassland	930	1.05
Indigenous Forest	79	0.12
Low-producing Grassland	30	0.18
Mangroves	1	0.38
Manuka and or Kanuka	26	0.22
Matagouri	2	0.68
Orchard and Other Perennial Crops	38	6.52
Other Exotic Forest	13	0.98
Pine Forest – Closed Canopy	28	0.29
Pine Forest – Open Canopy	6	0.12
Short-rotation Cropland	345	10.34
Sub Alpine Shrubland	1	0.03
Surface Mine	2	2.05
Tall Tussock Grassland	4	0.02
Urban Parkland/Open Space	8	1.99
Vineyard	9	3.54

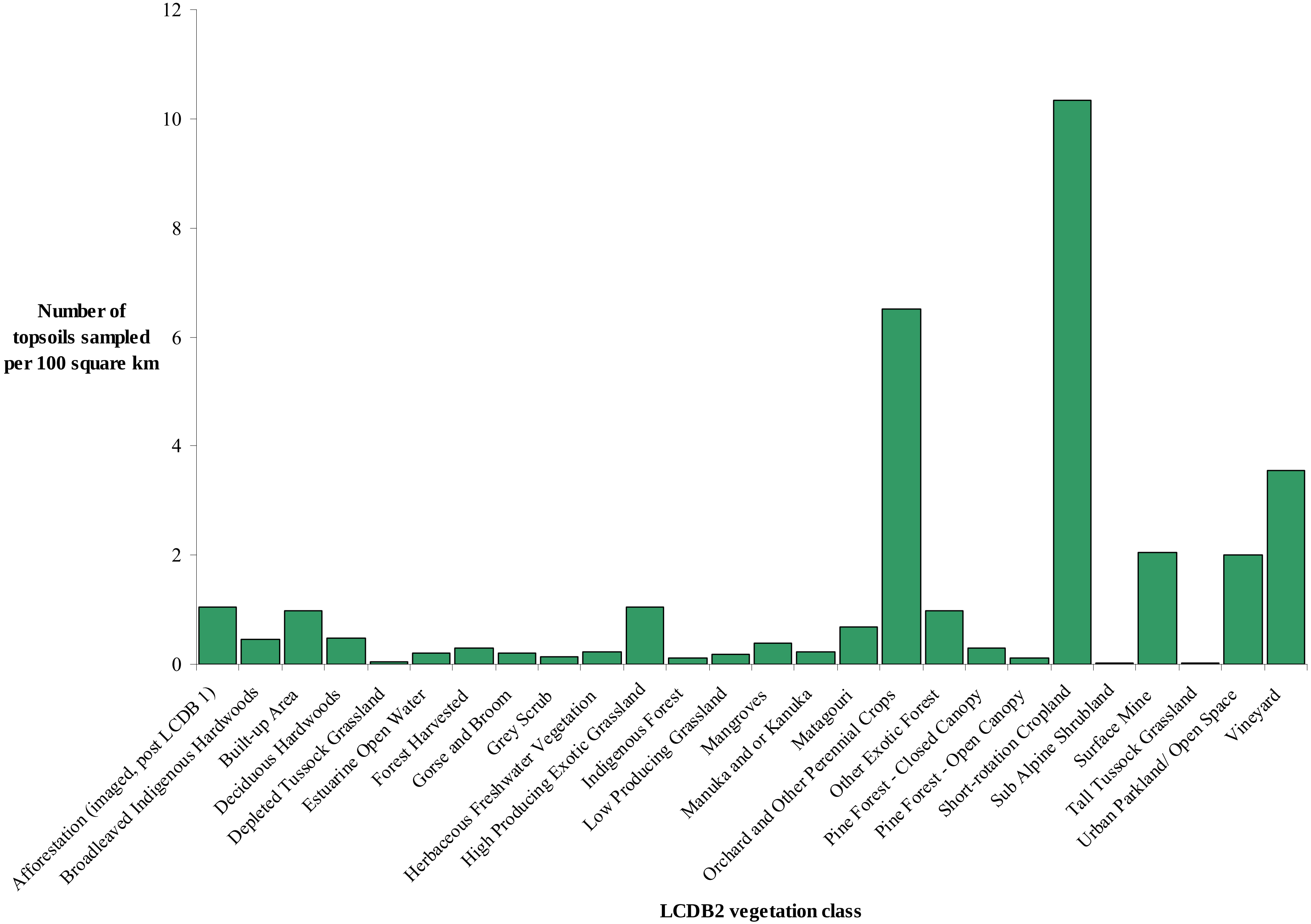

Figure 22: Number of site sampled per 100 square km according to LCDB2 vegetation

3.5 FUTURE LEVELS OF CADMIUM IN NEW ZEALAND

Future levels of cadmium in New Zealand were calculated using the New Zealand Fertiliser Manufacturers Research Association (FMRA) CadBal model. Based on measured data from the cadmium database, 287 scenarios were run and are summarised in Table 9. Full scenario data are found on pages 40 -44 of this report. Scenarios were run using average and range data for New Zealand as a whole and for regions.

The CalBal model indicated future soil cadmium concentrations would be higher under sheep/beef farming than under dairy farming after 100 years when both are under the same fertiliser regime (Figure 23) although, dairy farming requires more fertiliser for optimal production than beef and sheep farming. Dairy farming was shown to lead to more accumulation of cadmium in soil than sheep/beef farming when both are receiving more typical levels of fertiliser (50 kg ha^{-1} y^{-1} for dairy and 30 kg ha^{-1} y^{-1} for sheep/beef) (Figure 24). The sedimentation losses used by the model are oversimplified as sedimentation losses are due to a range of factors including topography, soil type, leaching class and climate, not just farm type. Table 10 shows the variation in total suspended sediment (TSS) measurements for different landuses, topography and soil type reported in 5 publications. It appears likely the sedimentation losses used by the model are overestimated for flat land and should be adjusted. In addition, the model gave no consideration to deposition of eroded sediment from steep land to flatter land, animal relocation of cadmium through faeces or land application of dairyshed effluent.

Table 10: Comparison of sediment yield for different landuses, topography and soil type

Site Name	Farm Type	Topography	Soil type	TSS (kg ha^{-1} y^{-1})
Whatawhata Research Centre[1]	Sheep & beef	Mainly steep land	Brown and Ultic Soils, patches of Allophonic Soils	600–3212
Toenepi[1, 2]	Dairy	Rolling to flat	Recent and Granular Soils	142
Purukohukohu[1,3]	Sheep & beef	Moderately steep	Pumice Soils	22
Moutere[4]	Pasture	Moderately steep	Brown Soils, some Recent, Podzols, Ultic, Melanic and Gley Soils	210, 320, 670, and 790
Moutere[4]	Forestry	Moderately steep	Brown Soils, some Recent, Podzols, Ultic, Melanic and Gley Soils	40
Big Bush[4]	Native Bush	Moderately steep	Brown Soils, some Recent, Podzols, Ultic, Melanic and Gley Soils	60–110
Pukekohe[5]	Cropping	Rolling	Granular Soils	490–56800
Whatawhata Research Centre[6]	Sheep & beef	steep land (tread damaged soil)	Brown Soils	1666
Whatawhata Research Centre[6]	Sheep & beef	Easy contoured land (tread damaged soil)	Allophonic Soils	714

[1] Quinn & Stroud (2002)
[2] Wilcock et al. (1999)
[3] Cooper & Thomsen (1988)
[4] Basher (2003)
[5] Basher et al. (1997)
[6] Nguyen et al. (1998)

Table 9: Scenarios based on measured data from the cadmium database

	Farm type	Fertiliser Rate kg P /ha/y	Fertiliser Cd mg/kg P	Soil Group	sample depth m	initial Cd mg/kg	Cd at +100 years	Years to reach 1 mg/kg (Blank space = level not reached)	Years to reach 3 mg/kg
National	Dairy	30	230	Alluvial	0.075	0	0.4199	724	
National	Dairy	30	230	Gley	0.075	0	0.4604	602	
National	Dairy	30	230	YBE	0.075	0	0.4278		
National	Dairy	30	230	YBL	0.075	0	0.5022	587	
National	Dairy	30	230	YBP	0.075	0	0.5162	470	
National	Dairy	30	230	YGE	0.075	0	0.418	730	
National	Dairy	30	230	YGE	0.075	0.31	0.5129	675	
National	Dairy	30	230	YBL	0.075	0.5	0.6698	488	
National	Dairy	30	230	YBE	0.075	0.64	0.7205	782	
National	Dairy	30	230	Gley	0.075	1	1.0591	0	
National	Dairy	30	230	Alluvial	0.075	1.09	1.1301	0	
National	Dairy	30	230	YBL	0.075	1.35	1.3394	0	
National	Dairy	30	230	YBP	0.075	1.51	1.4995	0	
National	Dairy	30	230	YBL	0.075	2.36	2.1833	0	
National	Dairy	38	230	YBL	0.075	0.5	0.9839	104	
National	Dairy	38	230	YBL	0.075	2.36	2.5188	0	604
National	Dairy	50	230	YGE	0.075	0	0.8412	125	522
National	Dairy	50	230	YBE	0.075	0	0.9215	112	474
National	Dairy	50	230	YBL	0.075	0	1.1897	81	339
National	Dairy	50	230	YBP	0.075	0	1.1997	80	332
National	Dairy	50	230	Gley	0.075	0	0.9874	102	425
National	Dairy	50	230	Peat	0.075	0	1.6206	55	225
National	Dairy	50	230	Alluvial	0.075	0	0.8755	119	487
National	Dairy	50	230	BGCL	0.075	0	1.0884	90	379
National	Dairy	50	230	YGE	0.075	2.52	2.9495	0	113
National	Dairy	50	230	YBE	0.075	2.52	2.9832	0	104
National	Dairy	50	230	YBL	0.075	2.52	3.1559	0	74
National	Dairy	50	230	YBP	0.075	2.52	3.1734	0	72
National	Dairy	50	230	Gley	0.075	2.52	3.0403	0	92
National	Dairy	50	230	Peat	0.075	2.52	3.4652	0	48
National	Dairy	50	230	Alluvial	0.075	2.52	2.9855	0	104
National	Dairy	50	230	BGCL	0.075	2.52	3.0933	0	83
National	Dairy	30	230	Gley	0.1	0.01	0.4027	802	
National	Dairy	30	230	Gley	0.1	1.33	1.3414	0	
National	Dairy	30	230	YBE	0.1	0	0.3751		
National	Dairy	30	230	YBE	0.1	0.89	0.918	484	
National	Dairy	30	230	YBL	0.1	0.14	0.4657	771	
National	Dairy	30	230	YBL	0.1	1.31	1.3069	0	
National	Dairy	30	230	YBP	0.1	0	0.4516	627	
National	Dairy	30	230	YBP	0.1	1.55	1.537	0	
National	Dairy	38	230	YBL	0.1	0.14	0.6635	199	
National	Dairy	38	230	YBL	0.1	1.31	1.5639	0	
National	Dairy	30	230	YBE	0.2	0	0.2643		
National	Dairy	30	230	YBE	0.2	1.03	1.0367	0	
National	Dairy	30	230	YBL	0.2	0.18	0.3697		
National	Dairy	30	230	YBL	0.2	1.43	1.4205	0	
National	Dairy	38	230	YBL	0.2	0.18	0.4746	389	
National	Dairy	38	230	YBL	0.2	1.43	1.5534	0	
National	Lettuce	80	175	BGLC	0.15	0.62	1.5892	39	255
National	Potato	45	175	BGLC	0.15	0	0.5957	171	556
National	Potato	45	175	BGLC	0.15	0.89	1.445	20	405
National	Potato	45	175	BGLC	0.15	0.89	1.447	20	405
National	sheep/beef	30	230	Alluvial	0.075	0	0.5474	228	981
National	sheep/beef	30	230	Gley	0.075	0	0.6293	188	809
National	sheep/beef	30	230	YBE	0.075	0	0.5798	214	957
National	sheep/beef	30	230	YBL	0.075	0	0.7384	151	666
National	sheep/beef	30	230	YBP	0.075	0	0.7532	147	632
National	sheep/beef	30	230	YGE	0.075	0	0.5438	230	990
National	sheep/beef	30	230	YGE	0.075	0.31	0.7084	185	945

National	sheep/beef	30	230 YBE	0.075	0.64	1.0074	98	842
National	sheep/beef	30	230 Gley	0.075	1	1.3902	0	621
National	sheep/beef	30	230 Alluvial	0.075	1.09	1.408	0	726
National	sheep/beef	30	230 YBL	0.075	1.35	1.7897	0	442
National	sheep/beef	30	230 YBP	0.075	1.51	1.9557	0	382
National	sheep/beef	30	230 YBE	0.1	0	0.475	285	
National	sheep/beef	30	230 YBE	0.1	0	0.475	285	
National	sheep/beef	30	230 YBE	0.1	0.5	0.7936	177	
National	sheep/beef	30	230 YBE	0.1	0.73	1.002	100	
National	sheep/beef	30	230 YBL	0.1	0	0.6006	202	888
National	sheep/beef	30	230 YBL	0.1	0.04	0.6131	199	885
National	sheep/beef	30	230 YBL	0.1	1.1	1.4521	0	659
National	sheep/beef	30	230 YBL	0.1	1.25	1.5911	0	618
National	sheep/beef	30	230 YGE	0.1	0	0.4441	307	
National	sheep/beef	30	230 YGE	0.1	0.33	0.6329	242	
National	sheep/beef	30	230 Alluvial	0.15	0.07	0.3669	443	
National	sheep/beef	30	230 Alluvial	0.15	0.27	0.4935	383	
National	sheep/beef	30	230 YBE	0.15	0	0.3598	427	
National	sheep/beef	30	230 YBE	0.15	0.67	0.8567	181	
National	sheep/beef	30	230 YGE	0.15	0	0.334	460	
National	sheep/beef	30	230 YGE	0.15	0.66	0.8364	197	
National	sheep/beef	30	230 YBE	0.2	0	0.295	570	
National	sheep/beef	30	230 YBE	0.2	0.85	0.9841	113	
National	sheep/beef	50	230 BGCL	0.075	0	0.6805	169	745
National	sheep/beef	50	230 Peat	0.075	0	1.048		
Auckland	Dairy	50	230 YBE	0.075	0.03	0.931	110	472
Auckland	Dairy	50	230 YBE	0.075	1.1	1.739	0	348
Auckland	Dairy	50	230 BGCL	0.075	0.03	1.0977	89	378
Auckland	Dairy	50	230 BGCL	0.075	1.1	1.8836	0	278
Bay of Plen	Dairy	50	230 YBE	0.075	0.05	0.9381	109	471
Bay of Plen	Dairy	50	230 YBE	0.075	1.6	2.1769	0	271
Bay of Plen	Dairy	50	230 Gley	0.075	0.05	1.0042	100	423
Bay of Plen	Dairy	50	230 Gley	0.075	1.6	2.2389	0	241
Bay of Plen	Dairy	50	230 YBL	0.075	0.05	1.2053	79	337
Bay of Plen	Dairy	50	230 YBL	0.075	1.6	2.3869	0	193
Bay of Plen	Dairy	50	230 YBP	0.075	0.05	1.2157	78	331
Bay of Plen	Dairy	50	230 YBP	0.075	1.6	2.4024	0	188
Bay of Plen	Dairy	50	230 Alluvial	0.075	0.05	0.8935	116	484
Bay of Plen	Dairy	50	230 Alluvial	0.075	1.6	2.164	0	273
Canterbury	Dairy	50	230 YGE	0.075	0.01	0.8444	125	522
Canterbury	Dairy	50	230 YGE	0.075	0.89	1.4935	18	414
Canterbury	Dairy	50	230 Alluvial	0.075	0.01	0.8935	116	484
Canterbury	Dairy	50	230 Alluvial	0.075	0.089	1.5309	17	385
Gisborne	Dairy	50	230 YBE	0.075	0.05	0.9381	109	471
Gisborne	Dairy	50	230 YBE	0.075	0.27	1.0517	93	455
Gisborne	Dairy	50	230 Alluvial	0.075	0.05	0.8935	116	484
Gisborne	Dairy	50	230 Alluvial	0.075	0.27	1.014	98	466
Hawkes Ba	Dairy	50	230 YGE	0.075	0.05	0.8587	123	519
Hawkes Ba	Dairy	50	230 YGE	0.075	0.63	1.2647	57	454
Hawkes Ba	Dairy	50	230 Alluvial	0.075	0.05	0.8965	116	484
Hawkes Ba	Dairy	50	230 Alluvial	0.075	0.63	1.3023	54	422
Hawkes Ba	Dairy	50	230 YBE	0.075	0.05	0.9381	109	471
Hawkes Ba	Dairy	50	230 YBE	0.075	0.63	1.3316	51	413
Hawkes Ba	Dairy	50	230 YBP	0.075	0.05	1.2157	78	331
Hawkes Ba	Dairy	50	230 YBP	0.075	0.63	1.5938	37	289
Manawatu	Dairy	50	230 YGE	0.075	0.04	0.855	123	520
Manawatu	Dairy	50	230 YGE	0.075	0.9	1.5023	16	413
Manawatu	Dairy	50	230 Alluvial	0.075	0.04	0.8896	117	485
Manawatu	Dairy	50	230 Alluvial	0.075	0.9	1.5398	15	383
Manawatu	Dairy	50	230 YBE	0.075	0.04	0.9345	110	472

Manawatu	Dairy	50	230	YBE	0.075	0.9	1.5643	15	377
Nelson-Mai	Dairy	50	230	YGE	0.075	0.03	0.8513	124	521
Nelson-Mai	Dairy	50	230	YGE	0.075	1	1.5913	0	397
Nelson-Mai	Dairy	50	230	Alluvial	0.075	0.03	0.8859	117	485
Nelson-Mai	Dairy	50	230	Alluvial	0.075	1	1.6287	0	368
Nelson-Mai	Dairy	50	230	YBE	0.075	0.03	0.931	110	472
Nelson-Mai	Dairy	50	230	YBE	0.075	1	1.6515	0	362
Northland	Dairy	50	230	YGE	0.075	0	0.8412	125	522
Northland	Dairy	50	230	YGE	0.075	0.67	1.2995	51	448
Northland	Dairy	50	230	YBE	0.075	0	0.9215	12	474
Northland	Dairy	50	230	YBE	0.075	0.67	1.3656	46	408
Northland	Dairy	50	230	Alluvial	0.075	0	0.8755	119	487
Northland	Dairy	50	230	Alluvial	0.075	0.67	1.337	48	416
Northland	Dairy	50	230	BGCL	0.075	0	1.0884	90	379
Northland	Dairy	50	230	BGCL	0.075	0.67	1.5206	37	326
Otago	Dairy	50	230	YGE	0.075	0.03	0.8513	124	521
Otago	Dairy	50	230	YGE	0.075	0.91	1.5112	15	411
Otago	Dairy	50	230	YBE	0.075	0.03	0.931	110	472
Otago	Dairy	50	230	YBE	0.075	0.91	1.573	13	375
Otago	Dairy	50	230	Alluvial	0.075	0.03	0.8859	117	485
Otago	Dairy	50	230	Alluvial	0.075	0.91	1.5487	14	382
Southland	Dairy	50	230	YGE	0.075	0.04	0.855	123	520
Southland	Dairy	50	230	YGE	0.075	0.62	1.2561	59	455
Southland	Dairy	50	230	YBE	0.075	0.04	0.9345	110	472
Southland	Dairy	50	230	YBE	0.075	0.62	1.3231	53	414
Southland	Dairy	50	230	Alluvial	0.075	0.04	0.8896	117	485
Southland	Dairy	50	230	Alluvial	0.075	0.62	1.2936	55	423
Taranaki	Dairy	50	230	YBL	0.075	0.04	1.2019	79	338
Taranaki	Dairy	50	230	YBL	0.075	1.7	2.4704	0	181
Taranaki	Dairy	50	230	Peat	0.075	0.04	1.6322	54	224
Taranaki	Dairy	50	230	Peat	0.075	1.7	2.8235	0	119
Waikato	Dairy	50	230	YBL	0.075	0.03	1.1987	80	338
Waikato	Dairy	50	230	YBL	0.075	2.52	3.1559	0	74
Waikato	Dairy	50	230	Peat	0.075	0.03	1.6291	54	224
Waikato	Dairy	50	230	Peat	0.075	2.52	3.4652	0	48
Waikato	Dairy	50	230	BGCL	0.075	0.03	1.0977	89	378
Waikato	Dairy	50	230	BGCL	0.075	2.52	3.0933	0	83
Waikato	Dairy	50	230	YBP	0.075	0.03	1.2089	79	331
Waikato	Dairy	50	230	YBP	0.075	2.52	3.1734	0	72
Waikato	Dairy	50	230	Alluvial	0.075	0.03	0.8859	117	485
Waikato	Dairy	50	230	Alluvial	0.075	2.52	2.9855	0	104
Wellington	Dairy	50	230	YGE	0.075	0.05	0.8587	123	519
Wellington	Dairy	50	230	YGE	0.075	0.9	1.5023	16	413
Wellington	Dairy	50	230	Alluvial	0.075	0.05	0.8935	116	484
Wellington	Dairy	50	230	Alluvial	0.075	0.9	1.5398	15	383
Wellington	Dairy	50	230	YBE	0.075	0.05	0.9381	109	461
Wellington	Dairy	50	230	YBE	0.075	0.9	1.5643	15	377
Westland	Dairy	50	230	YBE	0.075	0.04	0.9345	110	472
Auckland	sheep/beef	30	230	YBE	0.075	0.03	0.5888	211	955
Auckland	sheep/beef	30	230	YBE	0.075	1.1	1.4296	0	715
Auckland	sheep/beef	30	230	BGCL	0.075	0.03	0.6893	168	743
Auckland	sheep/beef	30	230	BGCL	0.075	1.1	1.5164	0	554
Bay of Plen	sheep/beef	30	230	YBE	0.075	0.05	0.5955	210	953
Bay of Plen	sheep/beef	30	230	YBE	0.075	1.6	1.894	0	560
Bay of Plen	sheep/beef	30	230	Gley	0.075	0.05	0.6456	184	805
Bay of Plen	sheep/beef	30	230	Gley	0.075	1.6			
Bay of Plen	sheep/beef	30	230	YBL	0.075	0.05	0.7534	148	663
Bay of Plen	sheep/beef	30	230	YBL	0.075	1.6	2.016	0	386
Bay of Plen	sheep/beef	30	230	YBP	0.075	0.05	0.7687	144	629
Bay of Plen	sheep/beef	30	230	YBP	0.075	1.6	2.0373	0	363
Bay of Plen	sheep/beef	30	230	Alluvial	0.075	0.05	0.5917	206	872

Bay of Plen	sheep/beef	30	230	Alluvial	0.075	1.6	1.9195	0	495
Canterbury	sheep/beef	30	230	YGE	0.075	0.01	0.5469	229	989
Canterbury	sheep/beef	30	230	YGE	0.075	0.89	1.2179	33	793
Canterbury	sheep/beef	30	230	Alluvial	0.075	0.01	0.5771	210	876
Canterbury	sheep/beef	30	230	Alluvial	0.075	0.089	1.2538	30	696
Gisborne	sheep/beef	30	230	YBE	0.075	0.05	0.5955	210	953
Gisborne	sheep/beef	30	230	YBE	0.075	0.27	0.7077	181	924
Gisborne	sheep/beef	30	230	Alluvial	0.075	0.05	0.5917	206	872
Gisborne	sheep/beef	30	230	Alluvial	0.075	0.27	0.7136	176	842
Hawkes Ba	sheep/beef	30	230	YGE	0.075	0.05	0.5609	226	986
Hawkes Ba	sheep/beef	30	230	YGE	0.075	0.63	0.9779	107	867
Hawkes Ba	sheep/beef	30	230	Alluvial	0.075	0.05	0.5917	206	872
Hawkes Ba	sheep/beef	30	230	Alluvial	0.075	0.63	1.0137	97	763
Hawkes Ba	sheep/beef	30	230	YBE	0.075	0.05	0.5955	210	953
Hawkes Ba	sheep/beef	30	230	YBE	0.075	0.63	0.9985	101	844
Hawkes Ba	sheep/beef	30	230	YBP	0.075	0.05	0.7687	144	629
Hawkes Ba	sheep/beef	30	230	YBP	0.075	0.63	1.1636	68	554
Manawatu	sheep/beef	30	230	YGE	0.075	0.04	0.5572	227	987
Manawatu	sheep/beef	30	230	YGE	0.075	0.9	1.2273	30	790
Manawatu	sheep/beef	30	230	Alluvial	0.075	0.04	0.5878	207	873
Manawatu	sheep/beef	30	230	Alluvial	0.075	0.9	1.2631	27	694
Manawatu	sheep/beef	30	230	YBE	0.075	0.04	0.5921	211	954
Manawatu	sheep/beef	30	230	YBE	0.075	0.9	1.2445	29	772
Nelson-Mai	sheep/beef	30	230	YGE	0.075	0.03	0.5536	228	988
Nelson-Mai	sheep/beef	30	230	YGE	0.075	1	1.3208	0	760
Nelson-Mai	sheep/beef	30	230	Alluvial	0.075	0.03	0.5841	208	874
Nelson-Mai	sheep/beef	30	230	Alluvial	0.075	1	1.3566	0	667
Nelson-Mai	sheep/beef	30	230	YBE	0.075	0.03	0.5888	211	955
Nelson-Mai	sheep/beef	30	230	YBE	0.075	1	1.337	0	744
Northland	sheep/beef	30	230	YGE	0.075	0	0.5438	230	990
Northland	sheep/beef	30	230	YGE	0.075	0.67	1.0144	96	856
Northland	sheep/beef	30	230	YBE	0.075	0	0.5798	214	957
Northland	sheep/beef	30	230	YBE	0.075	0.67	1.0343	91	834
Northland	sheep/beef	30	230	Alluvial	0.075	0	0.5138	210	877
Northland	sheep/beef	30	230	Alluvial	0.075	0.67	1.0501	87	753
Northland	sheep/beef	30	230	BGCL	0.075	0	0.6805	169	745
Northland	sheep/beef	30	230	BGCL	0.075	0.67	1.1273	72	647
Otago	sheep/beef	30	230	YGE	0.075	0.03	0.5536	228	988
Otago	sheep/beef	30	230	YGE	0.075	0.91	1.2366	27	787
Otago	sheep/beef	30	230	YBE	0.075	0.03	0.5888	211	955
Otago	sheep/beef	30	230	YBE	0.075	0.91	1.2538	26	769
Otago	sheep/beef	30	230	Alluvial	0.075	0.03	0.5841	208	874
Otago	sheep/beef	30	230	Alluvial	0.075	0.91	1.2724	25	691
Southland	sheep/beef	30	230	YGE	0.075	0.04	0.5572	227	987
Southland	sheep/beef	30	230	YGE	0.075	0.62	0.9689	110	870
Southland	sheep/beef	30	230	YBE	0.075	0.04	0.5921	211	954
Southland	sheep/beef	30	230	YBE	0.075	0.62	0.9896	103	847
Southland	sheep/beef	30	230	Alluvial	0.075	0.04	0.5878	207	873
Southland	sheep/beef	30	230	Alluvial	0.075	0.62	1.0046	99	766
Taranaki	sheep/beef	30	230	YBL	0.075	0.04	0.7502	149	663
Taranaki	sheep/beef	30	230	YBL	0.075	1.7	2.1065	0	363
Taranaki	sheep/beef	30	230	Peat	0.075	0.04	1.038	96	404
Taranaki	sheep/beef	30	230	Peat	0.075	1.7	2.3543	0	215
Waikato	sheep/beef	30	230	YBL	0.075	0.03	0.747	150	664
Waikato	sheep/beef	30	230	YBL	0.075	2.52	2.8488	0	150
Waikato	sheep/beef	30	230	Peat	0.075	0.03	1.0348	96	404
Waikato	sheep/beef	30	230	Peat	0.075	2.52	3.0699	0	87
Waikato	sheep/beef	30	230	BGCL	0.075	0.03	0.6893	168	743
Waikato	sheep/beef	30	230	BGCL	0.075	2.52	2.8153	0	168
Waikato	sheep/beef	30	230	YBP	0.075	0.03	0.7621	145	630
Waikato	sheep/beef	30	230	YBP	0.075	2.52	2.8713	0	140
Waikato	sheep/beef	30	230	Alluvial	0.075	0.03	0.5841	208	874
Waikato	sheep/beef	30	230	Alluvial	0.075	2.52	2.7834	0	188
Wellington	sheep/beef	30	230	YGE	0.075	0.05	0.2609	226	986
Wellington	sheep/beef	30	230	YGE	0.075	0.9	1.2273	30	790
Wellington	sheep/beef	30	230	Alluvial	0.075	0.05	0.5917	206	872
Wellington	sheep/beef	30	230	Alluvial	0.075	0.9	1.2631	27	694
Wellington	sheep/beef	30	230	YBE	0.075	0.05	0.5955	210	953
Wellington	sheep/beef	30	230	YBE	0.075	0.9	1.2445	29	772
Westland	sheep/beef	30	230	YBE	0.075	0.04	0.5921	211	954

Wellingtor	sheep/beef	18	230	YBE	0.1	0.19	0.3228			
Wellingtor	sheep/beef	18	230	YBE	0.075	0.14	0.3342	0.0002		
Waikato	sheep/beef	36	230	YBE	0.2	0.39	0.625	0.0002	276	
Waikato	sheep/beef	36	230	YBE	0.1	0.65	1.0744	0.0006	82	645
Waikato	sheep/beef	36	230	YBE	0.075	0.53	1.1024	0.0008	82	504
Waikato	sheep/beef	36	230	YBL	0.2	0.68	0.9783	0.0004	108	908
Waikato	sheep/beef	36	230	YBL	0.1	0.68	1.2635	0.0009	54	454
Waikato	sheep/beef	36	230	YBL	0.075	0.8	1.5547	0.0015	26	326
Waikato	Potato	45	175	BGLC	0.15	0.41	0.9879	0.0004	103	488
Waikato	Dairy	34	230	YBE	0.2	0.49	0.588	0.0003	675	
Waikato	Dairy	34	230	YBE	0.1	0.55	0.721	0.0007	308	
Waikato	Dairy	30	230	YBE	0.2	0.49	0.5411	0.0003		
Waikato	Dairy	30	230	YBE	0.1	0.55	0.63	0.0006		
Waikato	Dairy	34	230	YBL	0.2	0.72	0.8279	0.0006	281	
Waikato	Dairy	34	230	YBL	0.1	0.81	1.0023	0.0013	99	
Waikato	Dairy	38	230	YBL	0.2	0.72	0.8935	0.0006	166	
Waikato	Dairy	38	230	YBL	0.1	0.81	1.1297	0.0015	58	
Wellingtor	Dairy	39	230	YBE	0.1	0.35	0.3839	0.0007	220	
Wellingtor	Dairy	30	230	YBE	0.1	0.35	0.4933	0.0005		
Taranaki	sheep/beef	36	230	YBL	0.1	0.37	0.9929	0.0007	102	501
Taranaki	sheep/beef	36	230	YBL	0.075	0.75	0.75	0.0015	32	332
Taranaki	Dairy	39	230	YBL	0.1	0.61	0.9935	0.0013	102	
Taranaki	Dairy	39	230	YBL	0.75	1.41	1.7668	0.0032	0	734
Taranaki	Dairy	38	230	YBL	0.1	0.61	0.962	0.0013	112	
Taranaki	Dairy	38	230	YBL	0.075	1.41	1.7248	0.0031	0	986
Southland	sheep/beef	21	230	YGE	0.075	0.18	0.4152	0.0003	685	
Southland	sheep/beef	21	230	YGE	0.1	0.31	0.4421	0.0002		
Southland	sheep/beef	21	230	YBE	0.075	0.18	4147	0.0003	875	
Otago	sheep/beef	21	230	YGE	0.1	0.23	0.3974	0.0002	894	
Otago	sheep/beef	21	230	YGE	0.075	0.1	0.3853	0.0002	702	
Otago	sheep/beef	21	230	YBE	0.075	0.11	0.3917	0.0003	890	
Northland	sheep/beef	20	230	YBE	0.075	0.31	0.4494	0.0003		
Manawatu	sheep/beef	18	230	YGE	0.2	0.15	0.2479	0.0001		
Manawatu	sheep/beef	18	230	YGE	0.12	0.2	0.3159	0.0001		
Manawatu	sheep/beef	18	230	YGE	0.075	0.16	0.3461	0.0002		
Manawatu	sheep/beef	18	230	YBE	0.15	0.12	0.2591	0.0001		
Manawatu	sheep/beef	18	230	YBE	0.075	0.27	0.3793	0.0003		
Manawatu	sheep/beef	18	230	YBL	0.075	0.18	0.3905	0.0004		
Hawks Ba	sheep/beef	20	230	YBP	0.075	0.31	0.5219	0.0005	586	
Hawks Ba	sheep/beef	20	230	YBE	0.075	0.31	0.4494	0.0003		

The CalBal model indicated future soil cadmium concentrations would be higher under sheep/beef farming than under dairy farming after 100 years when both are under the same fertiliser regime (Figure 23), although dairy farming requires more fertiliser for optimal production than beef and sheep farming. Dairy farming was shown to lead to more accumulation of cadmium in soil than sheep/beef farming when both are receiving more typical levels of fertiliser (50 kg ha^{-1} y^{-1} for dairy and 30 kg ha^{-1} y^{-1} for sheep/beef) (Figure 24). The sedimentation losses used by the model are oversimplified as sedimentation losses are due to a range of factors including topography, soil type, leaching class and climate, not just farm type. Table 10 shows the variation in total suspended sediment (TSS) measurements for different land-uses, topography and soil type reported in 5 publications. It appears likely the sedimentation losses used by the model are overestimated for flat land and should be adjusted. In addition, the model gave no consideration to deposition of eroded sediment from steep land to flatter land, animal relocation of cadmium through faeces or land application of dairyshed effluent.

Table 10: Comparison of sediment yield for different landuses, topography and soil type

Site Name	Farm Type	Topography	Soil type	TSS (kg ha^{-1} y^{-1})
Whatawhata Research Centre[1]	Sheep & beef	Mainly steep land	Brown and Ultic Soils, patches of Allophonic Soils	600–3212
Toenepi[1, 2]	Dairy	Rolling to flat	Recent and Granular Soils	142
Purukohukohu[1,3]	Sheep & beef	Moderately steep	Pumice Soils	22
Moutere[4]	Pasture	Moderately steep	Brown Soils, some Recent, Podzols, Ultic, Melanic and Gley Soils	210, 320, 670, and 790
Moutere[4]	Forestry	Moderately steep	Brown Soils, some Recent, Podzols, Ultic, Melanic and Gley Soils	40
Big Bush[4]	Native Bush	Moderately steep	Brown Soils, some Recent, Podzols, Ultic, Melanic and Gley Soils	60–110
Pukekohe[5]	Cropping	Rolling	Granular Soils	490–56800
Whatawhata Research Centre[6]	Sheep & beef	steep land (tread damaged soil)	Brown Soils	1666
Whatawhata Research Centre[6]	Sheep & beef	Easy contoured land (tread damaged soil)	Allophonic Soils	714

[1] Quinn & Stroud (2002)
[2] Wilcock et al. (1999)
[3] Cooper & Thomsen (1988)
[4] Basher (2003)
[5] Basher et al. (1997)
[6] Nguyen et al. (1998)

Peat soils accumulated more cadmium than the other soil types, YBL, YBP and BGCL soils accumulated the next largest amount of cadmium while YBE, YGE and alluvial soils accumulated the least cadmium. Differences in cadmium accumulation were due to differences in the leaching losses and soil bulk densities used by the model. The importance of soil bulk density on soil cadmium concentrations is discussed in section 3.6. The model also showed cadmium levels in soils under dairy farms fertilised at 30 kg ha^{-1} y^{-1}, to decrease in cadmium with time once soil cadmium exceeded about 1.3 mg kg^{-1} due to high sedimentation losses (900 kg ha^{-1} y^{-1}). Figure 25 shows an example of this occurrence in a YBP soil under dairy farming with a fertiliser regime of 30 kg P $ha^{-1}y^{-1}$. The decrease should be further investigated to evaluate the accuracy of this prediction as it has implications for the long term sustainability of dairy farming.

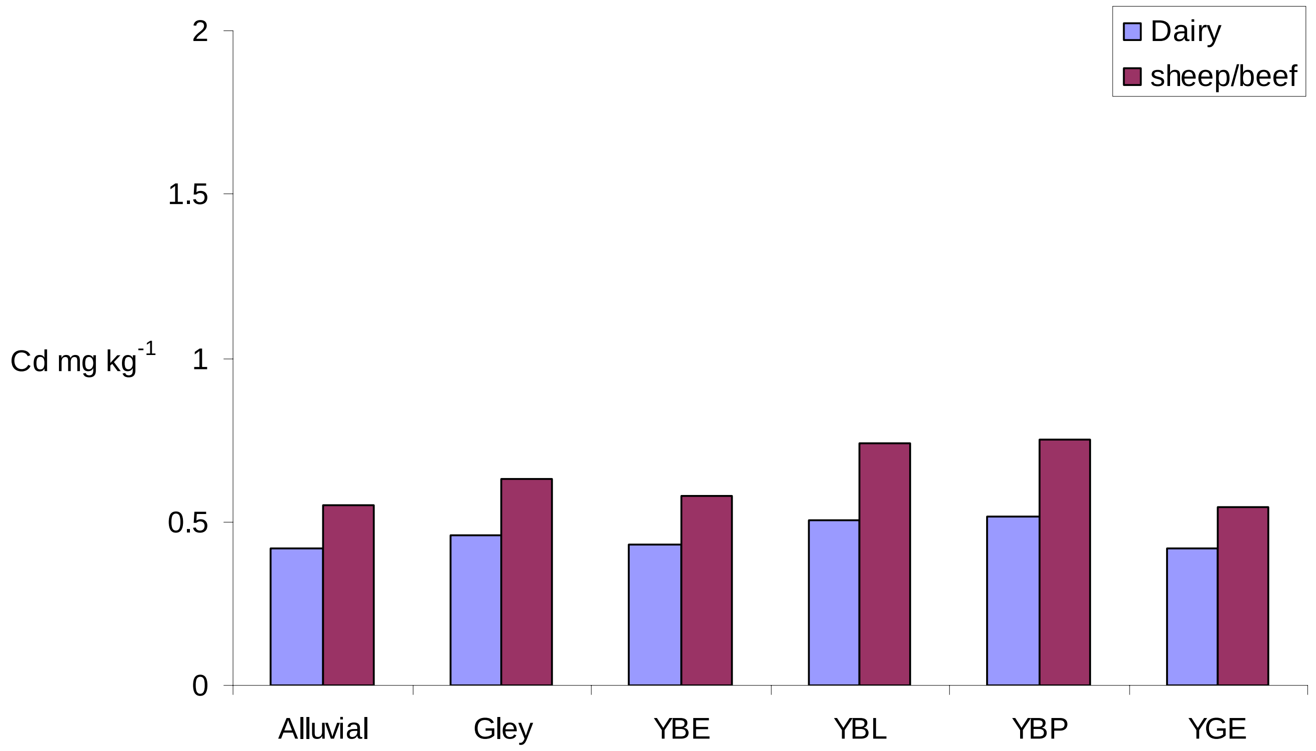

Figure 23: Comparison of 100 years accumulation of cadmium, starting at Cd = 0 mg kg^{-1}, by soil groups under dairy and sheep/beef farming (both 30 kg P $ha^{-1}y^{-1}$).

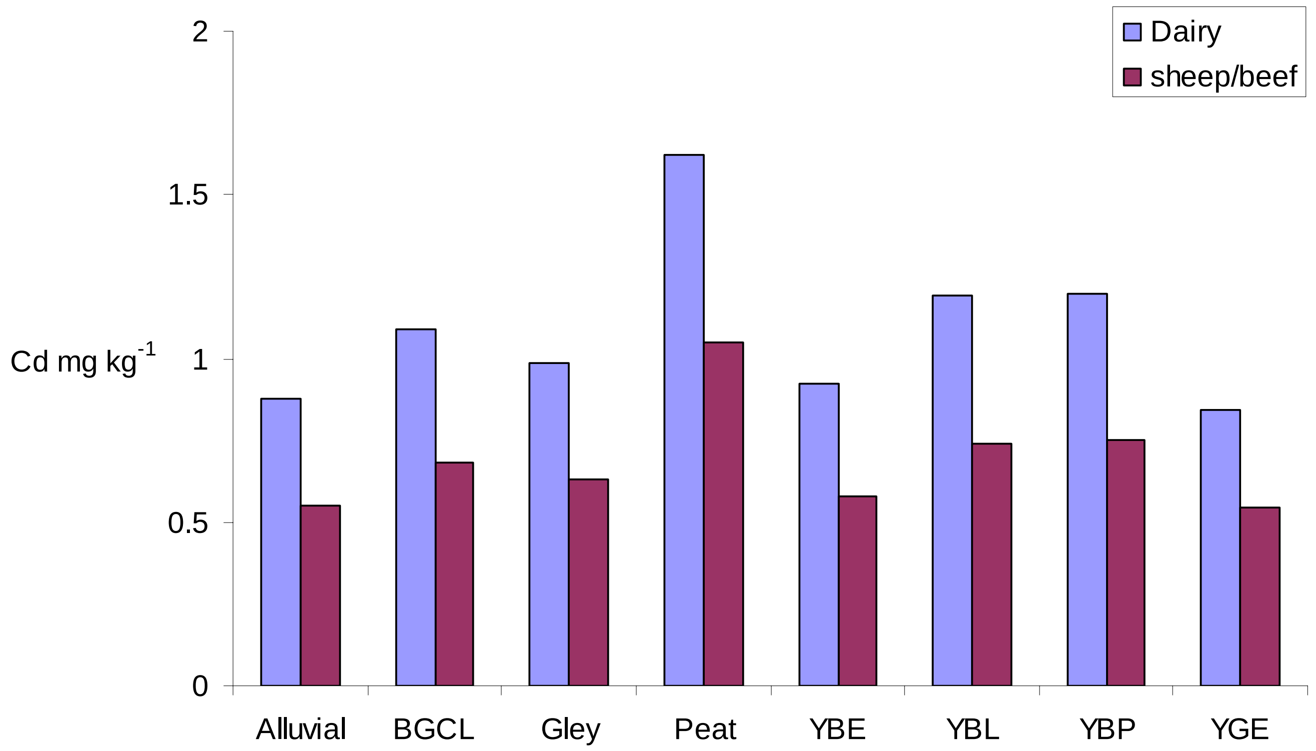

Figure 24: Comparison of 100 years accumulation of cadmium, starting at Cd = 0 mg kg^{-1}, by soil groups under dairy and sheep/beef farming (50 kg P ha^{-1} y^{-1} for dairy and 30 kg P ha^{-1} y^{-1} for sheep and beef).

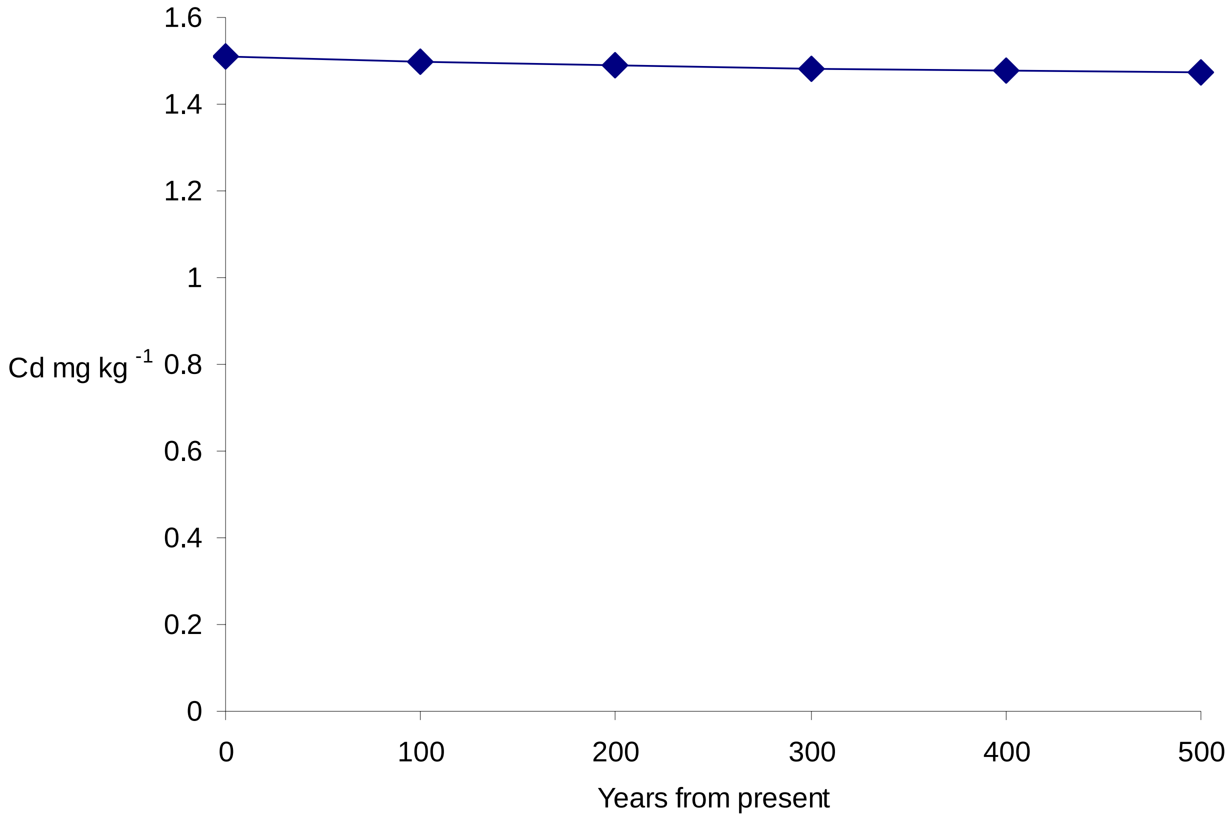

Figure 25: Soil cadmium concentrations decreasing with time in YBP soil under dairy (30 kg P ha^{-1}y^{-1}).

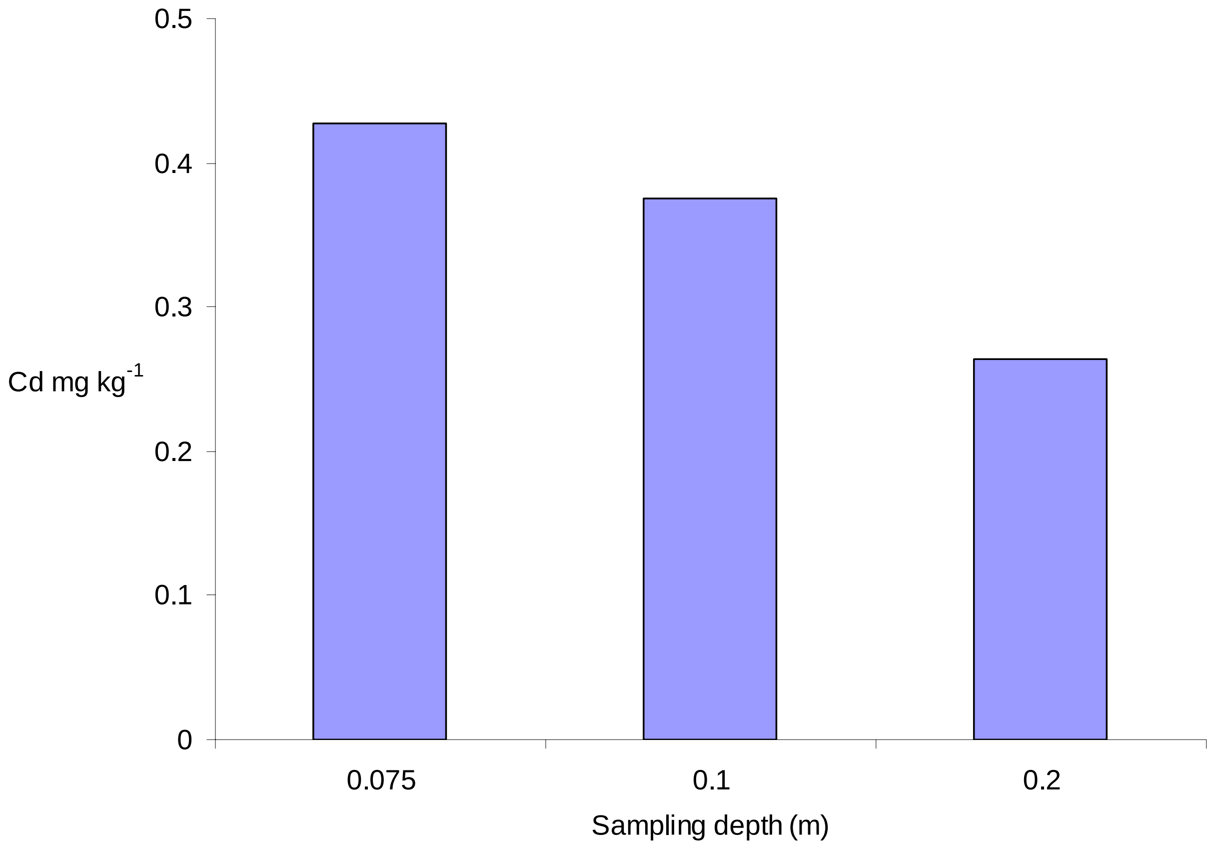

Figure 26: Soil cadmium concentrations decreasing with increased sample depth for a YBE under dairy (30 kg P ha^{-1}y^{-1}).

The CalBal model showed increasing the sampling depth effectively diluted the cadmium concentration due to mixing (Figure 26) indicating cadmium is held in the upper part of the topsoil. Cropping soils are usually regularly tilled to 20 cm allowing mixing, while pastoral soils may not be tilled after the initial seeding.

Pastoral farming resulted in increased soil cadmium content in all regions and nationally (Table 11). The peat soils of the Waikato region showed the highest potential for cadmium accumulation. The regions with the highest present day soil cadmium content also have the highest potential to accumulate cadmium in the future.

Table 11: Soil cadmium range in 100 years time after pastoral farming compared with present range

Region	Present Range ($\mu g\ g^{-1}$)	Range in 100 years assuming pastoral farming ($\mu g\ g^{-1}$)
Auckland	0.03–1.10	0.59–1.88
Bay of Plenty	0.05–1.60	0.59–2.40
Canterbury	0.01–0.89	0.55–1.53
Gisborne	0.05–0.27	0.59–1.05
Hawkes Bay	0.05–0.63	0.56–1.59
Manawatu-Wanganui	0.04–0.9	0.56–1.56
Nelson-Marlborough	0.03–1.00	0.58–1.65
Northland	0–0.67	0.51–1.52
Otago	0.03–0.91	0.55–1.57
Southland	0.04–0.62	0.56–1.32
Taranaki	0.04–1.7	0.75–2.82
Waikato	0.03–2.52	0.58–3.47
Wellington	0.05–0.90	0.56–1.56
Westland	–	0.59–0.93
National	**0–2.52**	**0.55–3.47**

3.6 DISCUSSION OF BULK DENSITY AFFECTS ON SOIL CADMIUM LEVELS

Soil bulk density should be considered when setting maximum permitted levels and other guidelines as, without consideration of bulk density, light, fluffy soil can appear to have extremely high concentrations of cadmium compared with heavier, denser soil. For example, cadmium in soil samples near storage facilities for phosphate fertiliser can be much higher than samples from the surrounding land (Taylor & Percival 2001) and this enhancement appears exacerbated when the soil has very low bulk density as demonstrated in the case study below.

Farmers have been observed bringing in several truckloads of phosphate fertiliser and storing it in a large pile on a convenient paddock (Taylor in press, Soil News). Soil samples were collected from 2 paddocks that had recently been used for temporary storage. One soil was an organic soil and the other an allophanic mineral soil. It is assumed that the amount of cadmium transferred to the soil was similar at both sites. Soil cores were collected over a 400-m^2 grid (Taylor 1997) and total acid soluble cadmium measured and plotted spatially (Figure 27). The areas where most spillage and accumulation occurred can be seen to the back right of the grids.

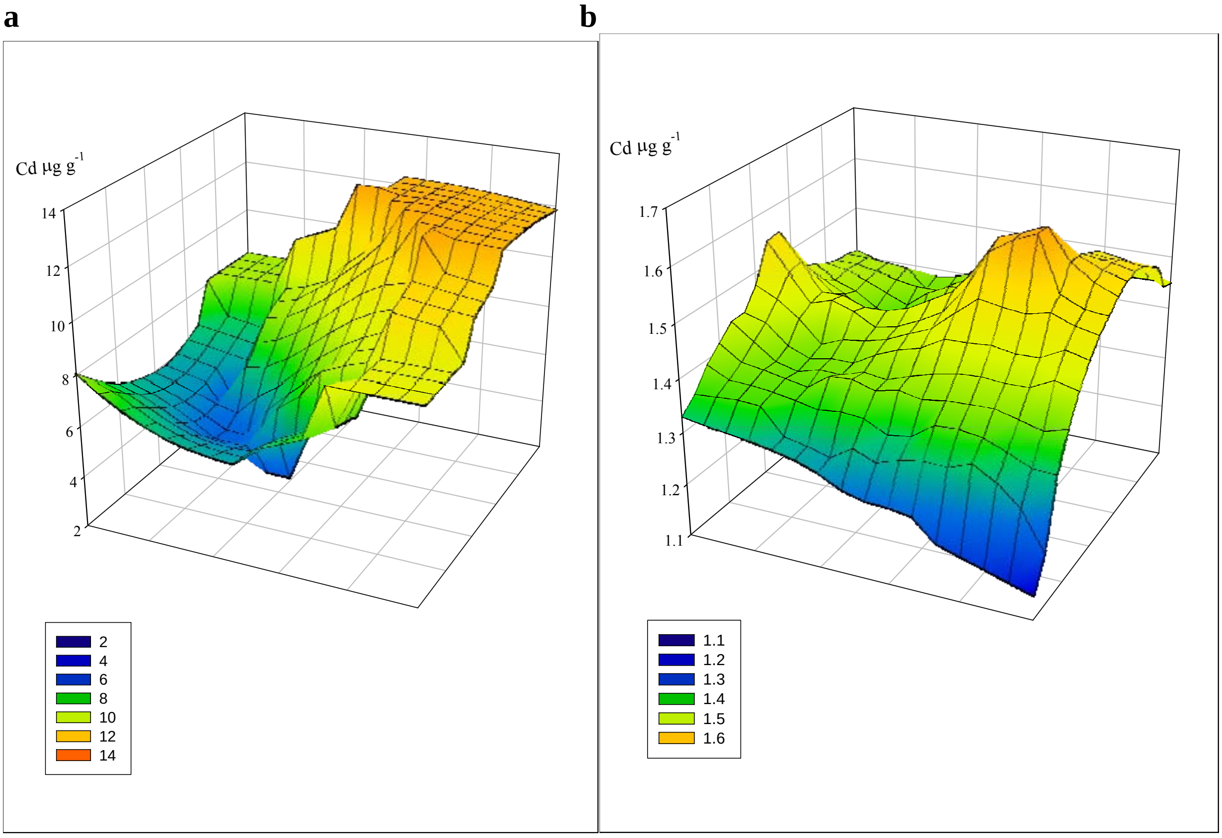

Figure 27a: Cadmium concentrations in an organic soil from a paddock previously used to store phosphate fertiliser.
Figure 27b: Cadmium concentrations in an allophanic Soil from a paddock previously used to store phosphate fertiliser.

Total acid extractable cadmium concentrations were higher in the organic soil than those in the allophanic soil and may be explained by difference in bulk density (Table 12). Without consideration of bulk density, the organic soil appeared to have much higher cadmium concentrations compared to the allophanic soil. However, when converted onto a volumetric basis, the organic soil appeared to have similar concentrations of cadmium to the allophanic one (Table 12).

Table 12: Cadmium in soil on a volumetric basis

	Present average Cd (mg dm $^{-3}$)	Present range of Cd (mg dm $^{-3}$)	Bulk Density (g cm $^{-3}$)
Organic Soil	1.0	0.5–1.4	0.11
Allophanic soil	1.0	0.8–1.3	0.74

Cadmium concentration data on peat, organic and other light soils should therefore be assessed after conversion to a volumetric basis to account for bulk density.

Soil bulk density should also be considered when setting maximum permitted levels and other guidelines so that standards and guidelines are practical, achievable and enforceable. One practical way of incorporating bulk density would be to normalise gravimetric measurements to the same soil density – say 1 g cm^{-3}.

3.7 A NATIONAL SAMPLING AND ANALYSIS SCHEME

Nationally consistent methodology for sampling, analysis and mechanisms to identify and record soil contamination by cadmium is needed as there is currently a mixture of different methodologies and guidelines used by practitioners in New Zealand leading to confusion for investigators and inconsistent interpretation of the resulting data.

The size of the sampling and analysis scheme will depend on the precision required. Fewer samples are needed to allow statements about means that the amount 90% of soil area is below than about means that the amount 95% of soil area is below. Claiming that all New Zealand soil cadmium concentrations were below a given value may be problematic if proved incorrect, e.g. claiming all New Zealand agricultural soil cadmium levels were below, say, 3 mg kg^{-1} would be incorrect due to "hotspots" caused by specific instances of contamination and may tarnish our international image as clean and green.

An overseas example is provided by the Nation Soil Inventory (NSI) of England and Wales. This study provided a comprehensive dataset including site and soil information at 5-kilometre intervals across England and Wales. The information was collected by way of a grid survey and for each grid intersect provides detailed information on the site, the soil profile and a range of inorganic topsoil analyses including cadmium and other potential contaminants. The strengths of the NSI are:

- Well-documented protocols for field and laboratory sampling. These are essential to maintain continuity and comparability between the sampling dates
- Baseline data from field observations on site and profile parameters, e.g., slope, land use and texture, horizon thickness, depth to water table and impermeable layer
- Baseline laboratory data on soil characteristics– particle size distribution
- Wide range of nutrient and heavy metal analyses
- The ability to produce robust statistics for different levels of aggregation, e.g., England and Wales (together and separately) and English regions.

These strengths were enhanced by a further re-sampling of the sites to give national and regional trends of soil health across the whole range of land use.

The overall cost of such a survey in New Zealand, and who is responsible for carrying it out and managing the resulting database in New Zealand needs careful consideration. A national government agency, such as MfE or Landcare Research, could be the lead agency due to the size and nature of the project. Existing databases and how these could be incorporated into a national database should be considered to minimise cost and maximise time efficiency. An example of an existing project that could be extended is the Carbon Monitoring System established by the Ministry for the Environment and Landcare Research. It provides a potential mechanism to obtain samples as a national 8-km sampling grid has been established. To date, about 400 soil samples have been collected from 20 by 20-m plots, mainly from indigenous forest and shrubland, analysed for carbon and archived in a soils database. Samples from a much wider range of land uses would need to be collected and analysed for cadmium.

To increase affordability, costs could be spread over a number of years, e.g. 20% of samples collected each year for 5 years, or a less intense survey on a larger scale grid may be more appropriate. Making use of independent knowledge of soil types, land-use, etc., allows a much more efficient sampling process. Sites should be based on a matrix of land-use type and soil order and modified by the area of the combination in each region. Most, but not all soil orders are directly influenced by climate so climate should also be considered for those orders where climate is not expressed. e.g., Gley and Recent Soils. Using these as strata in a stratified random sampling scheme would make the precision per sample higher (possibly much higher) than the British scheme. If cadmium is considered a measure of cumulative intensity of land use then such a survey will also be relevant to other lands use intensity effects, although a scheme optimal for cadmium may not be optimal for another soil property. However, all estimates would be unbiased and would have known precision. Soils should be classified to the soil order level, using the New Zealand soil classification (Hewitt 1998) to allow identification of soil-contaminant relationships. The quantity and pattern of soil contamination vary greatly and are affected by soil type, topography, fertilisation history, erosion/deposition, climate and other factors (Mallarino & Wittry 2001). While the Ministry for the Environment in New Zealand has produced guidelines for soil sampling (MFE 2004), these guidelines are more suitable for identifying hot spots than for obtaining a representative sample of an area and the following modifications should be made for a national cadmium study.

From each sampling area, take at least one composite soil sample made up of 25 cores, 0–10 cm depth, taken using a grid-point method (Schipper & Sparling 2000). This is a traditional approach used by Regional Councils to collect representative samples in soil quality studies. The 25 core samples are needed to cope with within-paddock variability, which can be considerable, especially in uncultivated land. The 0–10 cm soil sampling depth is more suitable for pastoral land than ploughed land as ploughing is generally conducted to 20-cm depth. If finance permits, the 10–20 cm depth should also be sampled. Cores should be bulked, mixed, air-dried and sieved <2 mm. The sampling area may be any shape as long as a representative sample for that area is obtained. Location should be accurately recorded using a global positioning system. Other site information recorded at each site should include the land owner or manager or local contact person, soil type and drainage class, farming practice, both current and historic, vegetation, topography, parent material, climate, and sources of contamination (fertiliser storage areas, roads, industrial facilities etc.) and their location to the prevailing wind.

To allow comparability between results from different laboratories, analysis for total cadmium should be carried out after a strong acid digestion. Cook et al. (1997) reported on an interlaboratory comparison of 20 different digestion methods. Excellent comparability was achieved for the results of strong acid digestion. The high degree of agreement between the metal concentrations in the digested samples indicates relatively low variability of extraction efficiency amongst the different strong acids. Kovacs et al. (1996, 2000) developed a method based on HNO_3-H_2O_2 digestion which is used by Landcare Research and Lincoln University. The advantages of this method include avoidance of dangerous acids (carcinogenic HF and explosive $HClO_4$) and avoidance of acids which reduce the lifetime of analytical equipment (HF and HCl). The parameters of the method are: 1 g dry weight of soil, 5mL HNO_3 as the digestion acid; predigest in a block digest apparatus at 60° C for 30 minutes or overnight at room temperature; addition of 5 mL 30% H_2O_2, digest at 120° C for 4.5 h; make to 50 ml with ultrapure water; filter.

For international credibility, measurement of contaminants should be carried out by a New Zealand accredited laboratory using flame or flameless atomic absorption spectrometry, graphite furnace atomic absorption spectrometry or inductively coupled emission mass spectroscopy.

4. Conclusions

1. Sites with land-uses such as reserve, tussock, bush, indigenous forest and plantation forestry or described as unfertilised may be considered background and are suitable for assessing soil cadmium baseline concentrations
2. The national average soil cadmium concentration measured in the database was 0.35 $\mu g\ g^{-1}$ and the national average baseline soil cadmium value was 0.16 $\mu g\ g^{-1}$
3. Cropping, pasture and horticulture land-uses all had higher concentrations of cadmium in soil than background landuse indicating accumulation of cadmium in these soils
4. Horticulture land-uses had the highest average soil cadmium concentration (0.50 $\mu g\ g^{-1}$) indicative of high fertiliser use or some other localised contamination source. Samples classified as berries (0.68 $\mu g\ g^{-1}$), kiwifruit (0.71 $\mu g\ g^{-1}$) and orchards (0.66 $\mu g\ g^{-1}$) contained soils double or nearly double the national average of 0.35 $\mu g\ g^{-1}$ reflecting high inputs of fertiliser or some other source of cadmium contamination. Although market gardening had an average soil

cadmium concentration of 0.46 μg g^{-1}, it had the greatest range of values and had more data points outside the 95 and 5 percentiles than the other farm types

5. Pastoral land-uses had the highest individual soil cadmium value (2.70 μg g^{-1}). Dairying showed the highest average soil cadmium concentrations (0.73 μg g^{-1}), averaging double the national average of 0.35 μg g^{-1}. Dairying also showed the largest number of data points outside the 95 and 5 percentiles for the pasture landuse, reflecting the wide range of cadmium values measured. Average values for beef farming and all drystock were slightly above (0.42 μg $g^{-1}$and 0.40 μg g^{-1} respectively) and sheep farming slightly below (0.33 μg g^{-1}) the national average
6. Soils where tobacco was grown were more elevated in cadmium (0.34 μg g^{-1}) than other cropping soils. These soils will now have other land-uses as tobacco is no longer grown in New Zealand. Cropped soils appear to be mostly below the national average of 0.35 μg g^{-1} for cadmium, however, these soils are tilled to a greater depth (200 cm) than other land-uses and dilution decreases the cadmium concentration
7. The data in the database was tested for representativeness by comparing topsoil total-cadmium concentrations and associated metadata with LCDB2 vegetation class and the number of sites per 100 square km calculated. Depleted tussock grassland, tall tussock grassland and sub-alpine shrubland are relatively poorly represented with number of sites per 100 square km less than 0.04. However, further sampling based on vegetation class is not required as the main farming vegetation classes are adequately covered
8. The region with the highest average cadmium concentration was Taranaki (0.66 μg g^{-1}). Other regions with cadmium concentrations above the national average include Waikato (0.60 μg g^{-1}) and Bay of Plenty (0.52 μg g^{-1}). Dairy farming with high fertiliser use is traditional in these areas and likely to be the cause for the elevated levels. The regions with the lowest cadmium average concentrations were Canterbury (0.18 μg g^{-1}), Gisborne (0.20 μg g^{-1}), Manawatu-Wanganui (0.17 μg g^{-1}), Nelson-Marlborough (0.23 μg g^{-1}), Otago (0.20 μg g^{-1}), Southland (0.20 μg g^{-1}) and Wellington (0.20), all historic sheep farming areas.
9. Results from running the data from the database through the FMRA CadBal model showed:
    a. Pastoral farming resulted in increased soil cadmium content in all regions
    b. Regions with the highest present day soil cadmium content also have the highest potential to accumulate cadmium in the future
    c. Peat soil apparently has the greatest potential to accumulate cadmium from fertiliser
    d. BGCL, YBL and YBP soils accumulated higher amounts of cadmium than alluvial, YBE and YGE soils, which accumulated the least cadmium. Gley soils were intermediate. Differences in soil type cadmium accumulation appear due to differences in the assumed leaching losses and soil bulk densities input to the model
    e. Increasing the sampling depth effectively diluted the cadmium concentration
    f. Sheep/beef farming lead to more accumulation of cadmium than dairy when both are under the same fertiliser regime. Accumulation under dairy is higher when both are under their respective optimal fertiliser schemes
    g. Cadmium levels in soils under dairy farms receiving 30 kg P $ha^{-1}y^{-1}$ or less appear to decrease with time once soil cadmium exceeded about 1.3 mg kg^{-1}
10. Weaknesses identified in the CadBal model include:
    a. The model is based on the New Zealand Genetic Soil Classification which has been superseded
    b. The model was not calibrated for many recent soils, podzols, rendzinas or intergrades between soil types
    c. The sedimentation loss figures used in this analysis by the model are oversimplified as sedimentation losses are due to a range of factors including topography, soil type, leaching class and climate, not just farm type

d. Cadmium leaching figures for different soil groups are assumed to be independent of location and climate
e. A default "zero" leaching figure was used for alluvial soils
f. No consideration is given in the model to accumulation of erosion debris
g. The model assumes atmospheric deposition of cadmium is constant across the whole country
h. No consideration is given to animal relocation of cadmium through faeces or land application of dairyshed effluent

11. When soil bulk density is not considered, organic soil can appear to have extremely high cadmium levels compared to mineral soil.

5. Specific Recommendations

1. There were few samples with associated landuse data for soils utilised for cropping by crop type. Other specific landuses with few samples include horse, deer and vineyards. Further samples should be obtained from these landuses from across the country and analysed for cadmium following the sampling and analysis scheme included in this report to improve the representativeness of the dataset. Details regarding current and historical crop type should be collected simultaneously where possible
2. To increase confidence in the regional ranges and averages, further sampling following the sampling and analysis scheme included in this report, to 50 samples per region is recommended in regions with low numbers of samples. These regions include Gisborne, Nelson-Marlborough, Northland and Westland
3. Cadmium concentration data on peat, organic and other light soils should be assessed after conversion to a volumetric basis to account for bulk density
4. The results from the CadBal model could be improved to more accurately portray sediment, erosion and leaching losses and include deposition of erosion debris. The sedimentation losses used by the model appear overestimated. The apparent decrease in soil cadmium predicted by the model for dairy farms receiving 30 kg P $ha^{-1}y^{-1}$ should be tested in a field study
5. The CadBal model should also be calibrated using the currently used New Zealand soil classification (Hewitt, 1993) and include all soil orders
6. A national soil inventory including site and soil information at 8-kilometre intervals across New Zealand should be carried out. Sampling priority would be given to sites with intensive land use. The information should be collected by way of a grid survey and each sample point should be georeferenced and accessory data collected on the landform, slope, current land use, soil classification, profile characteristics, and a range of contaminants including cadmium and other potential contaminants analysed. The Carbon Monitoring System (MfE and Landcare Research) provides a mechanism by which some of this sampling regime could be carried out. Soil samples should be extracted using a strong acid digestion procedure and analysed using graphite furnace atomic absorption spectrometry or inductively coupled emission mass spectroscopy by a New Zealand accredited laboratory.

6. General Recommendations

1. Soil bulk density should be considered when assessing soil contamination, especially when setting maximum permitted levels and other guidelines as soils of low bulk density can appear to have extremely high contaminant concentrations compared to soil of high bulk density

2. Future soil samples should also be analysed for other potential contaminants such as fluorine.

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