Annual soil quality monitoring report for the Wellington region, 2011/12

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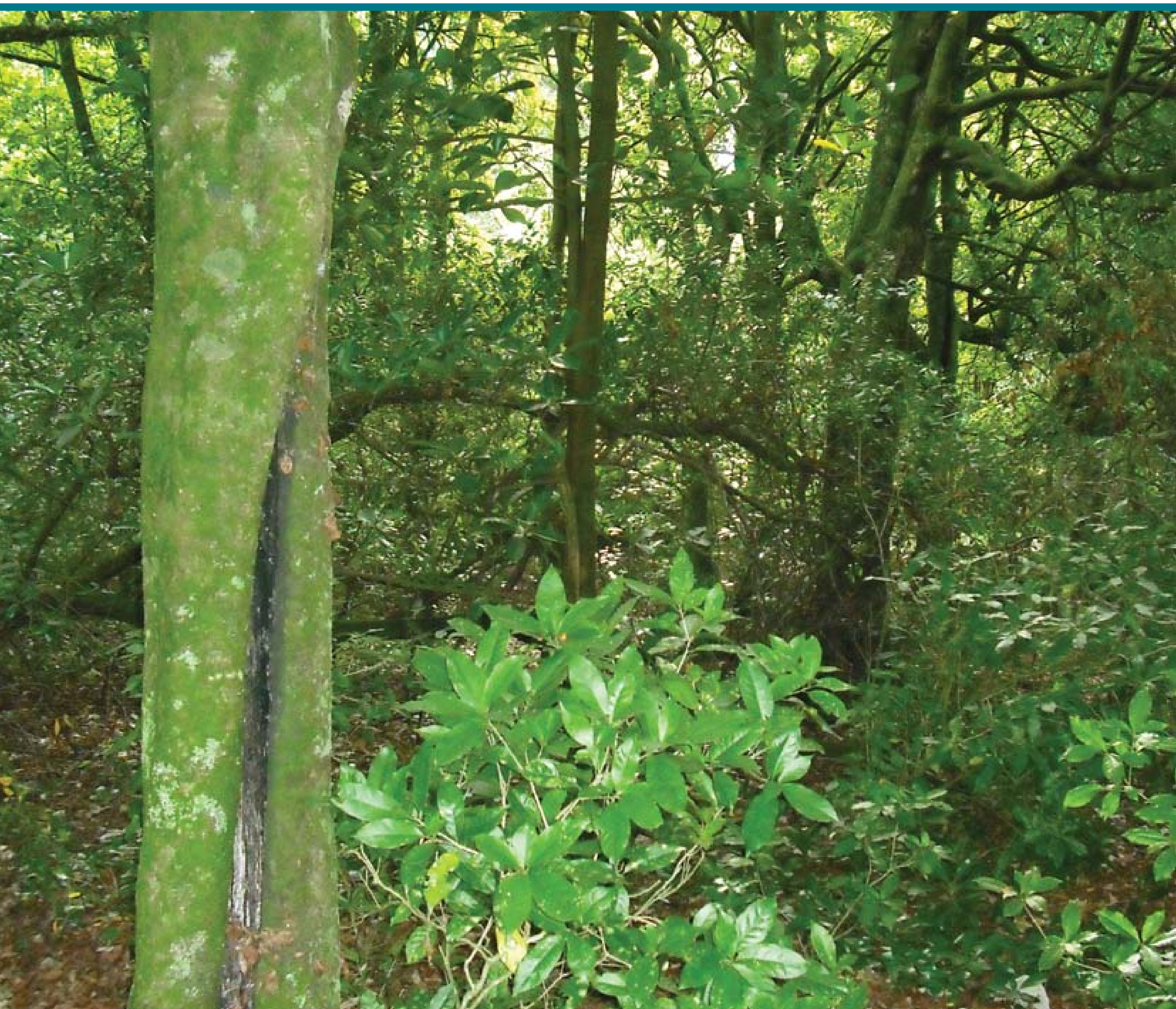

Annual soil quality monitoring report for the Wellington region, 2011/12

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Cover photo: An indigenous vegetation monitoring site

Contents

1. Introduction

Soils in the Wellington region support a wide range of land uses, including horticulture, viticulture, vegetable growing, cropping, dairy farming, drystock farming and forestry. Greater Wellington Regional Council (GWRC) monitors a variety of indicators to assess soil quality in the region. A reduction in soil quality can result in reduced agricultural yields, and less resilient soil and land ecosystems. Changes in soil quality can also be associated with changes in environmental risks, including potential effects on waterways, animal health and greenhouse gas emission. Monitoring soil quality is beneficial to improve knowledge of the soil resource, demonstrate changes in soil properties over time, and modify management practices if needed (Sparling & Schipper 2004; Houlbrooke et al. 2010).

This report summarises the results of the soil monitoring undertaken during the period 1 July 2011 to 30 June 2012 at 16 indigenous vegetation sites.

2. Overview of the soil monitoring programme

2.1 Background

GWRC became involved in a national soil quality programme known as "The 500 Soils Project" in 2000 (Sparling & Schipper 2004). The intention of that project was to measure and assess soil quality from 500 sites throughout New Zealand. After completion of the 500 soils project, GWRC implemented a soil quality monitoring programme to continue monitoring the quality of soils in the Wellington region. As part of the 500 Soils Project a standard set of sampling methods, as well as physical, chemical and biological soil properties, were identified to assess soil quality, particularly for state of the environment and regional council reporting (Land Monitoring Forum 2009). A value or range of values for each of the properties was derived enabling the relationship between the quantitative measure of the soil attribute and its soil quality rating to be determined. The use of these standard methods and properties allows comparisons of similar soils and land uses both within the region and nationally. These sampling methods and soil quality indicators were adopted for use in GWRC's soil quality monitoring programme.

2.2 Monitoring objectives

The objectives of GWRC's soil quality monitoring programme are to:

- Provide information on the physical, chemical and biological properties of soils;
- Provide an early-warning system to identify the effects of primary land uses on long-term soil productivity and the environment;
- Track specific, identified issues relating to the effects of land use on long-term soil productivity;
- Assist in the detection of spatial and temporal changes in soil quality; and
- Provide information required to determine the effectiveness of regional policies and plans.

2.3 Monitoring sites and methods

GWRC's current soil quality monitoring programme includes over 100 monitoring sites on soils across the region under different land uses (Figure 2.1). The frequency of sampling is dependent on the intensity of the land use; dairying, cropping and market garden sites are sampled every 3–4 years, drystock, horticulture and exotic forestry sites are sampled every 5–7 years, while indigenous vegetation sites are sampled every 10 years. Soil quality data are evaluated periodically for 'State of the Environment' reporting (eg, Sorensen 2012).

2.3.1 Sites, soils and land uses sampled in 2011/12

Sixteen sites were sampled during 23, 24 and 26 April 2012 (Figure 2.1). Indigenous vegetation land use was sampled which included mainly native forest sites with some regenerating scrub sites.

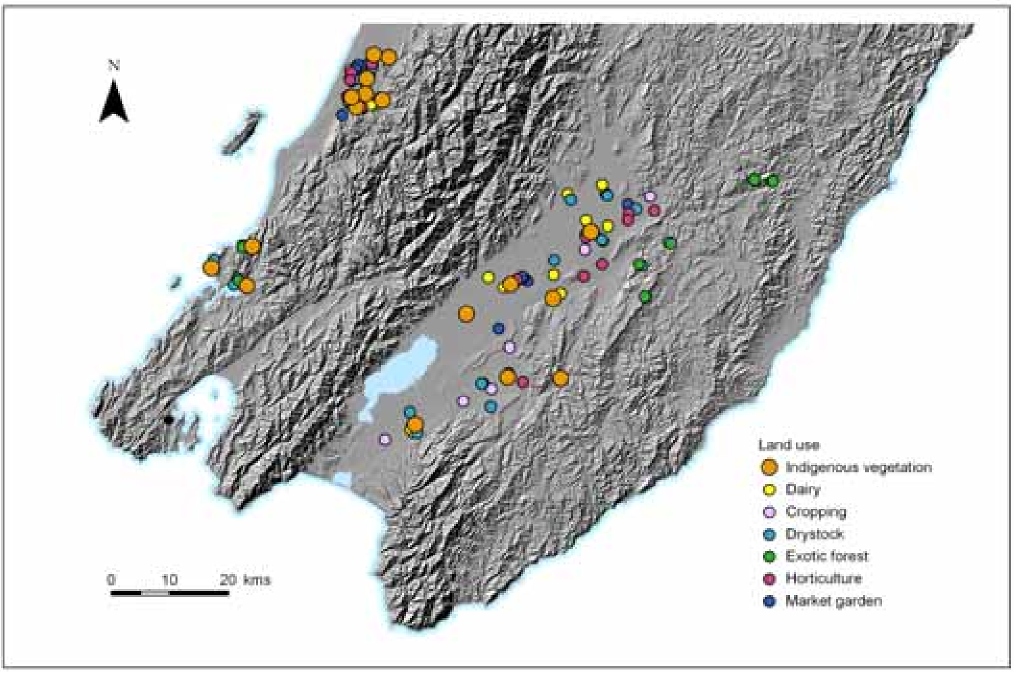

Figure 2.1: GWRC's soil quality monitoring sites. The indigenous vegetation sites were sampled in April 2012

A range of soil orders were sampled. Details of the soil order, group, subgroup, soil type and land use sampled are presented in Table 2.1. The soil classification used is the New Zealand Soil Classification. Soil classification was determined from sampling by Landcare Research staff during previous soil monitoring of the region. Further information and soil descriptions can be obtained from earlier reports such as Sparling (2005).

Five soil orders were sampled including Allophanic, Brown, Gley, Pallic, and Recent soils. Briefly, Allophanic Soils are strongly influenced by allophanic or iron minerals; Brown Soils are characterised by brown colours due to iron oxide and are the most extensive soil order; Gley Soils are poorly or very poorly drained; Pallic Soils generally have high erosion potential and high subsoil density; and Recent Soils have minimal soil profile development (McLaren & Cameron 1996; Hewitt 2010). Allophanic soils occur mostly in volcanic parent material but also occur in greywacke sandstone (Hewitt 2010).

2.3.2 Soil sampling methods

At each site a 50 m transect was used to sample soil cores. Soil cores 2.5 cm in diameter to a depth of 10 cm were taken approximately every 2 m along the transect. The individual cores were bulked and mixed in preparation for chemical and biological analyses.

Table 2.1: Soil order, group, subgroup, and soil type for indigenous vegetation sites sampled during 2011/12 (see Appendix 1 for site photos)

Site No.	Soil Order	Soil Group	Subgroup	Soil type	Vegetation
GW007	Brown	Orthic Brown	Mottled Orthic Brown	Te Horo silt loam	Indigenous forest
GW009	Brown	Allophanic Brown	Acidic Allophanic Brown	Kawhatau silt loam	Indigenous bush
GW011	Recent	Fluvial Recent	Mottled Fluvial Recent	Rangitikei silt loam	Indigenous forest
GW014	Gley	Recent Gley	Typic Recent Gley	Ahikouka silt loam	Indigenous forest
GW020	Pallic	Perch-gley Pallic	Argillic Perch-gley Pallic	Kokotau silt loam	Indigenous forest
GW029	Pallic	Perch-gley Pallic	Typic Perch-gley Pallic	Bideford silt loam	Indigenous bush
GW039	Recent	Fluvial Recent	Mottled Fluvial Recent	Rangitikei loamy silt	Indigenous forest
GW045	Brown	Orthic Brown	Mottled Orthic Brown	Rahui silt loam	Indigenous forest and bush
GW049	Recent	Fluvial Recent	Typic Fluvial Recent	Manawatu silt loam	Indigenous forest and bush
GW052	Brown	Orthic Brown	Pallic Orthic Brown	Paramata hill soils	Indigenous bush
GW057	Brown	Firm Brown	Typic Firm Brown	Korokoro hill soils	Indigenous bush
GW059	Recent	Orthic Recent	Typic Orthic Recent	Tairawhiti steepland soils	Indigenous bush/scrub
GW102	Recent	Orthic Recent	Weathered Orthic Recent	Greytown silt loam	Indigenous forest
GW104	Pallic	Immature Pallic	Typic Immature Pallic	Tauherenikau silt loam	Indigenous forest and bush
GW110	Brown	Orthic Brown	Typic Orthic Brown	Ashhurst stony silt loam	Indigenous forest and bush
GW113	Allophanic	Orthic Allophanic	Typic Orthic Allophanic	Kawhatau silt loam	Indigenous forest and bush

Soil classifications were from original soil description details and classification per site provided from Landcare Research.

Three undisturbed (intact) soil samples were also obtained from each site. The intact soil cores were collected at approximately 15, 30 and 45 m intervals along the transect by pressing steel liners (10 cm in width and 7.5 cm in depth) into the top 10 cm of soil, taking care to preserve the soil structure. From these intact cores a 3 cm subsample ring was used in the laboratory to determine the physical properties of the soil such as bulk density, porosity, macroporosity and selected water holding contents. Further details on field methods are presented in Land Monitoring Forum (2009).

2.3.3 Soil analytical methods

The soil analytical methods are presented in Appendix 2. Further details on laboratory methods are presented in Land Monitoring Forum (2009).

Olsen P measurements were undertaken by Landcare Research on a gravimetric (weight) basis and therefore avoid the influence of soil bulk density. In New Zealand several large commercial laboratories measure soil received in the laboratory by volume prior to the Olsen P chemical extraction. Several fertiliser industry guidelines for Olsen P use the volumetric method. Further information and interpretation are discussed in Drewry et al. (2013).

2.4 Soil quality indicators and target values

Soil properties are measured and used as indicators of soil quality. Soil quality indicators include bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen, pH, and Olsen P, as well as heavy metal trace elements. The soil properties can be grouped into four specific areas of soil quality – physical condition, organic resources, fertility and trace elements (Table 2.2 and Appendix 3) – which together help provide an overall assessment of soil health.

Values of soil quality indicators can be interpreted to assess how land use and management practices influence soil for plant growth or for potential risks to the environment.

To help improve interpretation of soil quality indicators, an expert panel in several workshops developed guidelines for the soil quality indicators now commonly used by regional councils (Hill & Sparling 2009). The panel determined target ranges for the assessment of soil quality (eg, very low, optimal, very high etc) for the predominant soil orders under different land uses (Hill & Sparling 2009). The interpretative ranges from Hill and Sparling (2009) are presented in Appendix 4.

For this report, the suggested target range for selected indicators is the reporting ‘by exception’ as recommended by Hill and Sparling (2009). These guidelines are currently used by other regional councils in reporting soil quality monitoring, so are used in this report for consistency. Many target ranges are not available for indigenous vegetation land use. Target ranges for soil orders, rather than land use, are available in Hill and Sparling (2009) for total carbon and bulk density.

Note that target values in Hill and Sparling (2009) were classified into target categories. Some interpretive target ranges are still under development, particularly when examining environmental rather than production criteria (Hill & Sparling 2009). Therefore some consideration to other guidelines or research information is also discussed in this report. Olsen P targets have been revised from those reported in Hill and Sparling (2009) with new target values reported in Taylor (2011a).

The trace element results in this report have been compared to the soil targets presented in the New Zealand Water and Wastes Association (NZWWA 2003) 'Guidelines for the Safe Application of Biosolids to Land in New Zealand'.

While guidelines containing soil contaminant values have been written for a specific activity (eg, biosolids application), the values are generally transferable to other activities that share similar hazardous substances (MAF 2008). For example, the NZWWA biosolids guidelines have been used by some regional councils to assess cadmium levels in soils as a result of fertiliser application (MAF 2008). Other guidelines are available such as the Health and Environmental Guidelines for Selected Timber Treatment Chemicals (MFE 1997) for assessing the concentrations of specific trace elements. The biosolids guideline values for the selected trace elements relevant to this study are presented in Appendix 3.

Cadmium results can also be compared against the Tiered Fertiliser Management System (TFMS) from the recent New Zealand Cadmium Management Strategy (MAF 2011). This strategy, developed in response to concerns about the accumulation of cadmium in soils from phosphate fertiliser usage, recommends different management actions at certain trigger values. Some caution is needed when interpreting values because the soil samples in this report were taken at a depth of 0–10 cm based on the methods in Hill and Sparling (2009), compared to a depth of 0–7.5 cm for uncultivated land which the TFMS is based on. Further information for soil quality indicators for these depths is available in Drewry et al. (2013).

Table 2.2: Indicators used for soil quality assessment (adapted from Hill & Sparling 2009)

Soil property	Indicator	Soil quality information	Why is this indicator important?
Physical condition	Bulk density	Soil compaction	Bulk density is a measure of soil density. A high bulk density indicates a compacted or dense soil. Movement of water and air through soil pores is reduced in compacted soils. High soil bulk density can restrict root growth and adversely affect plant growth. There is also potential for increased run-off and nutrient loss to surface waters in compacted soils.
	Macroporosity	Soil compaction and degree of aeration	Macropores are important for soil air movement and drainage. Large soil pores are the most susceptible to collapse when soil is compacted. Low macroporosity adversely affects plant growth due to poor root environment, restricted air movement and N-fixation by clover roots. It also infers poor drainage and infiltration.
Organic resources	Total carbon (C) content	Organic matter carbon content	Used as an estimate of the amount of organic matter. Organic matter helps soils retain moisture and nutrients, and gives good soil structure for water movement and root growth. Used to address the issue of organic matter depletion and carbon loss from the soil.
	Total nitrogen (N) content	Organic matter nitrogen content	Most nitrogen in soil is present within the organic matter fraction, and total nitrogen gives a measure of those reserves. It also provides an indication for the potential of nitrogen to leach into underlying groundwater.
	Anaerobic mineralisable N	Organic nitrogen potentially available for plant uptake and activity of soil organisms.	Not all nitrogen can be used by plants; soil organisms change nitrogen to forms that plants can use. Mineralisable N gives a measure of how much organic nitrogen is available to plants, and the potential for nitrogen leaching at times of low plant demand. Mineralisable nitrogen is also used as a surrogate measure of the microbial biomass.
Acidity	Soil pH	Soil acidity	Most plants have an optimal pH range for growth. The pH of a soil influences the availability of many nutrients to plants and the solubility of some trace elements. Soil pH is influenced by the application of lime and some fertilisers.
Fertility	Olsen P	Plant-available phosphate	Phosphorus (P) is an essential nutrient for plants and animals. Olsen P is a measure of the amount of phosphorus that is available to plants. Levels of P greater than agronomic requirements can increase P losses to waterways, and therefore contribute to eutrophication (nutrient enrichment).
Trace elements	Concentrations of total recoverable trace elements	Accumulation of trace elements	Some trace elements are essential micro-nutrients for plants and animals. Both essential and non-essential trace elements can become toxic at high concentrations. Trace elements can accumulate in the soil from various common agricultural and horticultural land use practices.

3. Soil quality results

This section summarises the results of the soil quality monitoring for 2011/12. Results are presented as means and summarised for comparison with the suggested ‘by exception’ target ranges reported in Hill and Sparling (2009) if available. New Olsen P target ranges were reported in Taylor (2011a). Many target ranges, however, are not available for native vegetation land use or are poorly defined. Some target ranges for other land uses may not be relevant but some such as forestry are included for context. The target ranges for total carbon and bulk density for soils are used from Hill and Sparling (2009). In some cases general comment is more appropriate than percentages of sites meeting or not meeting other land use (forestry) targets, so figures presented below should be used with caution.

Fourteen out of 16 sites sampled (88%) had bulk density within the soil target range suggested in Hill and Sparling (2009). All sites sampled had total carbon within the soil target range suggested in Hill and Sparling (2009). All 16 sites sampled had trace element soil quality indicators within the target range suggested in NZWWA (2003).

For all the physical, chemical and trace element soil quality indicators, six out of 16 sites sampled (38%) had all soil indicators within the soil and/or the forestry land use target range suggested in Hill and Sparling (2009) and Taylor (2011a). A further five sites sampled (31%) had one indicator that did not meet the soil and forestry target range, three sites (19%) had two indicators that did not meet the soil and forestry target range, one site (6%) had three indicators that did not meet the soil and forestry target range, and one site (6%) had four indicators that did not meet the soil and forestry target range.

Physical and chemical soil quality indicator means for indigenous vegetation and soil orders for the monitoring sites sampled are presented in Table 3.1 and Table 3.2, respectively. Results for individual soil quality monitoring sites are presented in Table 3.3. Values are compared with the suggested target range for the site’s soil order and forestry land use target to provide context as reported in Hill and Sparling (2009) and Taylor (2011a).

3.1 Soil physical properties

Mean soil bulk density for all sites was 0.92 Mg/m^3 (Table 3.1). Mean bulk density was greatest on Recent Soils than the other soils (Table 3.2). Fourteen out of 16 sites sampled (88%) had bulk density within the soil target range (Table 3.3) suggested by Hill and Sparling (2009).

Mean soil macroporosity for all sites was 18.1% v/v (Table 3.1). Mean macroporosity was less on Recent Soils than for the other soils. Fourteen out of 16 sites sampled had macroporosity values within the target range for forestry suggested by Hill and Sparling (2009; Table 3.3).

3.2 Soil chemical properties

Mean soil pH was 5.9 (Table 3.1) and all sites had soil pH within the forestry target range suggested by Hill and Sparling (2009).

Mean soil carbon was 7.8%. Mean soil carbon was less for Pallic and Recent Soils than for Brown (Table 3.2). All sites (Table 3.3) had total carbon levels within the target range for soils suggested by Hill and Sparling (2009).

Three of the 16 sites (Table 3.3) did not meet the total nitrogen target range for forestry suggested by Hill and Sparling (2009). The C:N ratio ranged from 12 to 17. Four of the 16 sites did not meet the anaerobic mineralisable nitrogen target range for forestry suggested by Hill and Sparling (2009).

Mean soil Olsen P was 37 mg/kg and highly variable ranging from 6 to 106 mg/kg (Table 3.3). Seven of the 16 sites did not meet (ie, exceeded) the Olsen P target range for forestry suggested by Taylor (2011a). Some caution should be applied because, as expected, there is no Olsen P target for indigenous vegetation land use.

When presented on a volumetric basis, using the bulk density measurements, the calculated soil Olsen P values ranged from 6 to 90 mg/L. On a volumetric basis, six of the 16 sites exceeded a calculated Olsen P value of 30 mg/L, and three sites with the greatest Olsen P values had calculated values of 85, 86 and 90 mg/L.

3.3 Soil trace elements

Trace element (total recoverable) concentrations in samples from soil monitoring sites were below the NZWWA (2003) guidelines (Table 3.4). All samples recorded cadmium concentrations below the MAF (2011) TFMS proposed tier 1 trigger value of 0.6 mg/kg.

Mean trace element concentrations by soil order for sites sampled are presented in Table 3.5. Although based on a small number of samples, mean trace element concentrations for Brown Soils were lower than on Pallic and Recent Soils.

Table 3.1: Physical and chemical soil quality indicators for indigenous vegetation soil monitoring sites sampled in April 2012. Means and standard deviations (sd) are presented

No. of samples	pH		Organic carbon (%)		Total N (%)		Anaerobic mineralisable-N (mg/kg)		Olsen P (mg/kg)		Bulk density (Mg/m³)		Macroporosity (-10kPa % v/v)	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
16	5.9	0.6	7.8	2.8	0.55	0.19	154	50	37	36	0.92	0.17	18.1	7.8

Table 3.2: Physical and chemical soil quality indicators by soil order for monitoring sites sampled in April 2012. Means and standard deviations (sd) are presented

Soil Order	No. of samples	pH		Organic carbon (%)		Total N (%)		Anaerobic mineralisable-N (mg/kg)		Olsen P (mg/kg)		Bulk density (Mg/m³)		Macroporosity (-10kPa % v/v)	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Brown	6	5.6	0.58	8.8	3.60	0.57	0.22	160	38	40	50.2	0.86	0.19	21.2	8.4
Pallic	3	6.1	0.88	6.8	0.18	0.50	0.04	135	20	43	34.4	0.96	0.18	23.1	10.5
Recent	5	6.1	0.55	6.8	2.82	0.50	0.22	150	80	40	29.9	1.01	0.12	13.1	3.7

Table 3.3: Physical and chemical results for each soil quality monitoring site sampled in April 2012. Values in bold are outside the suggested target range for the site's soil order and forestry land use as reported in Hill and Sparling (2009). Updated Olsen P targets for forestry from Taylor (2011a) are used, but at are not available for indigenous vegetation

Site No.	Soil order	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)	Bulk density (Mg/m^3)	Macroporosity (-10kPa % v/v)
GW007	Brown	4.85	8.66	0.52	145	**106**	0.85	21.8
GW009	Brown	5.05	13.3	0.91	150	**104**	**0.63**	28.5
GW011	Recent	5.98	6.78	0.56	175	**85**	1.01	11.1
GW014	Gley	5.96	7.79	0.62	143	10	0.81	14.4
GW020	Pallic	5.37	6.62	0.46	114	**41**	0.75	**34.2**
GW029	Pallic	7.10	6.80	0.54	137	9	1.03	21.8
GW039	Recent	6.17	6.85	0.46	122	**48**	0.92	8.5
GW045	Brown	6.09	4.63	0.32	104	9	1.07	13.0
GW049	Recent	6.93	10.8	**0.79**	**277**	**42**	0.89	16.5
GW052	Brown	6.24	6.50	0.41	155	6	1.09	14.3
GW057	Brown	5.99	6.82	0.49	**208**	6	0.86	16.0
GW059	Recent	5.73	2.87	0.19	75	7	1.19	17.2
GW102	Recent	5.50	6.73	0.51	102	19	1.06	12.1
GW104	Pallic	5.97	6.98	0.51	153	**78**	1.09	13.3
GW110	Brown	5.49	13.1	**0.78**	**196**	10	**0.68**	**33.6**
GW113	Allophanic	6.02	9.31	**0.77**	**213**	15	0.73	13.4
Target range for soils								
Pallic and Recent soil							0.4-1.4	
Allophanic soil			>3				0.3-1.3	
Other soils			>2.5				0.7-1.4	
Recent soil			>2					
Soil (all land uses)		N/A		N/A	N/A	N/A		N/A
Target range for Forestry		3.5-7.6		0.1-0.7	20-175	5-30		8-30
Number of sites not meeting target (soil only)			0/16				2/16	2/16
Number of sites not meeting target (forestry or soil)		0/16	0/16	3/16	4/16	7/16	2/16	2/16

Table 3.4: Trace element concentrations (total recoverable) in soil samples from monitoring sites sampled in April 2012. No samples were greater than the NZWWA (2003) guideline

Site No.	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW007	2	0.075	10.1	9.4	10.7	7.2	48
GW009	2.9	0.166	8	10.9	12.8	5.2	53
GW011	6.3	0.156	12.6	16.8	20	13.4	81
GW014	0.8	0.093	6.8	8.7	11.8	5.8	44
GW020	2.8	0.164	10.6	10.1	12.5	8.9	58
GW029	7	0.12	16	6	8.1	18	38
GW039	3.6	0.21	13	12.4	12.8	13.8	66
GW045	1.3	0.052	6	4	4	3.5	23
GW049	6.7	0.21	13	16.1	28	15.1	100
GW052	4.5	0.062	8.7	15.5	13.7	7.5	53
GW057	4.4	0.082	12.2	7.9	14	7.3	36
GW059	1	0.037	5.6	2.6	5.3	3.7	17.8
GW102	5.1	0.085	15.5	12.5	25	13	76
GW104	5.9	0.169	14.2	13.6	33	14.9	97
GW110	2	0.066	5.6	5.3	24	3.5	41
GW113	3.1	0.175	10.4	17.5	15.2	8.3	66

Table 3.5: Mean trace element concentrations (total recoverable) by soil order for sites sampled in April 2012

	No. of sites	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
Brown	6	2.9	0.08	8.4	8.8	13.2	5.7	42.3
Pallic	3	5.2	0.15	13.6	9.9	17.9	13.9	64.3
Recent	5	4.5	0.14	11.9	12.1	18.2	11.8	68.2

4. Discussion

As discussed previously, there are no specific targets for soil quality indicators for indigenous vegetation land use, so some results when related to 'targets' for forestry, should be used with caution.

Several sites had bulk density outside the soil order target range or outside the macroporosity target range for forestry. Values of macroporosity were generally greater under indigenous vegetation than for many other land uses in this region and elsewhere (Taylor et al. 2010; Taylor 2011b; Sorensen 2012). This is expected as soil macroporosity values are generally lower when soil is influenced by grazing stock or machinery compared to when these are not present (Drewry et al. 2004). Similarly, values of bulk density were generally less under indigenous vegetation than for many other land uses in this region and elsewhere (Taylor 2011b; Sorensen 2012).

All sites had total carbon levels within the target range for soils suggested by Hill and Sparling (2009). Values of total carbon were generally greater under indigenous vegetation and dairying than for several other land uses in this region and elsewhere (Taylor et al. 2010; Taylor 2011b; Sorensen 2012). The C:N ratio provides an additional indicator of soil organic quality and of the ability of the soil to supply inorganic nitrogen through mineralisation. Values of C:N <7 can be an indicator of excess N mineralisation and leaching (Sparling et al. 2008). For environmental purposes, a C:N ratio of 7-30 is considered optimal (Sparling et al. 2008). The C:N ratio for all sites ranged from 12 to 17. Site GW059 had the lowest values of total carbon, total N and anaerobic mineralisable nitrogen. This site had thick re-growth scrub in contrast to many other sites that had more mature forest cover.

It was unexpected to observe high Olsen P values in a number of the sites, especially in the three sites with the highest values. The Olsen P values in this report have been determined and expressed gravimetrically, ie, by weight. Even when calculated on a volumetric basis however, using the bulk density measurements, several of the calculated soil Olsen P values were greater than expected for indigenous vegetation. The measurement of Olsen P by gravimetric and volumetric methods is discussed further in Drewry et al. (2013).

Some sites that recorded high Olsen P levels are near or adjacent to pasture so may have been influenced by past fertiliser drift. Stevenson (2004) reported P availability in hill country forest fragments and showed that Olsen P values were approximately ten times greater in small (<6 ha) forest fragments than in larger reference (>20 ha) forest soils. That study also reported mean Olsen P was 42 mg/L in forest fragments, 13 mg/L in adjacent pasture and 4 mg/L in reference forest. Stevenson (2004) also reported a strong relationship between total P and cadmium, and suggested that increased P in forest fragments could be attributed to aerial topdressing. Depending on circumstances and inputs, Olsen P may be lost or gained in pastoral grazing systems due to a variety of transfers and nutrient cycling processes. Across all the sites monitored in 2012 there appeared to be no obvious relationship between Olsen P values and cadmium concentrations. Past fencing and stock management may also be an influence but the extent of influence, if any, is largely unknown. Site GW011, for example, was accessible by stock for shelter prior to fencing off the area to exclude cattle.

Trace element concentrations were below the NZWWA (2003) guidelines and all cadmium concentrations were below the MAF (2011) TFMS proposed tier 1 trigger value of 0.6 mg/kg. McDowell et al. (2013) estimated the background and anthropogenic contributions of cadmium for minimally disturbed conditions (eg, native bush) and other land uses. McDowell et al. (2013) showed that background concentrations via their regression technique accounted for about half the cadmium levels in different land uses. Mean values for trace element concentrations for the indigenous vegetation sites were generally similar to those reported in the study of Curran-Cournane and Taylor (2012).

5. Summary

Sampling of soils at 16 indigenous vegetation sites in 2011/12 found that all sites had soil total carbon within the recommended soil target range. Fourteen out of 16 sites sampled (88%) had bulk density within the soil target range. There are no specific targets for soil quality indicators for indigenous vegetation land use, so some results were compared with targets for forestry, but should be used with caution. Soil pH at all sites was within the forestry target range. Three of the 16 sites did not meet the total nitrogen target range for forestry. Four of the 16 sites did not meet the anaerobic mineralisable nitrogen target range for forestry. Seven of the 16 sites did not meet (i.e. exceeded) the Olsen P target range for forestry. It was unexpected to observe high Olsen P values in a number of the sites. Trace element concentrations were below the NZWWA (2003) guidelines and the cadmium concentrations were below the national Cadmium Management Strategy proposed tier 1 trigger value.

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Appendix 1: Soil quality monitoring sites sampled in 2011/12

Sites were sampled over 23-26 April 2012.

Site GW007

Site GW009

Site GW011

Site GW014

Site GW020

Site GW029

Site GW039

Site GW045

Site GW049

Site GW052

Site GW057

Site GW059

Site GW102

Site GW104

Site GW110

Site GW113

Appendix 2: Analytical methods

Analyses of the soil chemistry and soil physics were completed at the Landcare Research laboratory (Table A2.1). Trace element analyses were undertaken at Hill Laboratories in Hamilton. Where necessary, samples were stored at 4°C until analysis.

Note that Olsen P measurements undertaken at Landcare Research were undertaken on a gravimetric (weight) basis and therefore avoid the influence of soil bulk density. In New Zealand several large commercial laboratories measure soil received in the laboratory by volume prior to Olsen P chemical extraction. The fertiliser industry guidelines for Olsen P are using the volumetric method.

Table A2.1: Analytical methods

Indicator	Method
Bulk density	Measured on a sub-sampled core dried at 105°C.
Macroporosity	Determined by drainage on pressure plates at –10 kPa.
Total C content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Total N content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Mineralisable N	Waterlogged incubation method. Increase in NH_4^+ concentration was measured after incubation for 7 days at 40°C and extraction in 2M KCl.
Soil pH	Measured in water using glass electrodes and a 2.5:1 water-to-soil ratio.
Olsen P	Bicarbonate extraction method. Extracting <2 mm air dried soils for 30 mins with 0.5M $NaHCO_3$ at pH 8.5 and measuring the PO_4^{3-} concentration by the molybdenum blue method.
Trace elements	Total recoverable digestion. Nitric/hydrochloric acid digestion, USEPA 200.2.

Appendix 3: Soil quality indicators

Soil physical properties

The physical condition of the soil can affect transmission of water and air through soil and can subsequently affect plant yield. Soil physical conditions can also have implications on soil hydrology such as runoff and leaching and also the production of some greenhouse gases.

Bulk density and macroporosity are indicators of soil physical condition, and therefore indicators of soil compaction. Bulk density is the mass of soil per unit volume (McLaren & Cameron 1996). Macroporosity is an indicator of the volume of large pores in the soil, commonly responsible for soil drainage and aeration. Macroporosity describes the volume percentage of pores >30 micron diameter (McLaren & Cameron 1996; Drewry et al. 2004; 2008). Macropores are primarily responsible for adequate soil aeration and rapid drainage of water and solutes (McLaren & Cameron 1996). Note that macroporosity has also been defined with different pore diameters in the literature. For the purposes of this report macroporosity is measured at -10 kPa matric potential.

Macroporosity has been shown to be a good indicator of soil physical condition. It is commonly a more responsive indicator of soil compaction than bulk density. Macroporosity values of less than 10–12% have often used to indicate limiting conditions for plant health and soil aeration (Drewry et al. 2008). Optimum soil macroporosity, for example, for maximum pasture and crop yield ranges from 6–17% v/v (Drewry et al. 2008).

Soil compaction is commonly caused by either animal treading or the impact of machinery and tyres in wet soil conditions on horticulture orchards and cultivated land (Vogeler et al. 2006; Drewry et al. 2008). Soil compaction can also occur as a result of some forest harvesting management practices. Factors such as the loss of organic matter may also contribute to reduced soil physical quality.

Soil chemical properties

Soil organic matter helps retain moisture, nutrients and good soil structure for water and air movement. Soil carbon is used as an indicator of the soil organic matter content. Soil organic matter levels are particularly susceptible when land is used for market gardening and cropping. Intensive cultivation can lead to a reduction in soil organic matter through increasing the rate of organic matter decomposition, reducing inputs of organic residues to the soil and increasing aeration oxidation of the soil (McLaren & Cameron 1996).

Nitrogen (N) is an essential nutrient for plants and animals. Most nitrogen in soil is found in organic matter. Total nitrogen is used as an indicator. In general, high total nitrogen indicates the soil is in good biological condition. Very high total nitrogen contents increase the risk that nitrogen supply may be in excess of plant demand and lead to leaching of nitrate to groundwater and waterways (SINDI 2010).

Not all of the nitrogen in organic matter can be used by plants; soil organisms change the nitrogen to forms plants can use. Mineralisable nitrogen gives a measure of how much organic nitrogen is potentially available for plant uptake, and the activity of soil organisms (Hill & Sparling 2009). While mineralisable nitrogen is not a direct measure of soil biology, it has been found to correlate reasonably well with microbial biomass carbon, so mineralisable nitrogen can act as a surrogate measure for microbial biomass (SINDI 2010).

Soil pH is a measure of the degree of acidity or alkalinity of the soil (McLaren & Cameron 1996). Most plants and soil organisms have an optimum soil pH range for optimum growth. Soil pH can affect many chemical reactions in the soil such as availability and retention of nutrients. Commonly, lime is added to many New Zealand to change pH to the optimum range for plant growth.

Many New Zealand soils are inherently deficient in phosphorus, sulphur, to a lesser extent potassium and in some cases, trace elements (Roberts & Morton 2009). Inputs of fertiliser or other soil amendments (eg, effluent) are used to improve soil fertility. Olsen P is an indicator of the plant available fraction of phosphorus in the soil. Olsen P is a widely used soil test indicator in New Zealand and has been extensively used for calibration of pasture and plant yield responses (Roberts & Morton 2009) and crop responses (Nicolls et al. 2009). While soil Olsen P is a well recognised indicator of soil fertility, it is increasingly being used as a soil quality indicator of risk to waterways (McDowell et al. 2004). Phosphorus is commonly strongly bound to soils. Soil erosion causing sediment to reach waterways often carries sediment bound phosphorus, which may result in contamination of water and enhanced algal growth.

Soil trace elements

Trace elements such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) can accumulate in soils as a result of common agricultural and horticultural land use activities such as the use of pesticides and the application of some types of effluent and phosphate fertilisers. While trace elements occur naturally, and the natural concentrations of most trace elements can vary greatly depending on geologic parent material, trace elements can become toxic at higher concentrations (Kim and Taylor 2009).

Appendix 4: Soil quality guidelines

Soil quality indicator target ranges from Hill and Sparling (2009) are presented below. Soil quality indicator values in bold are the suggested 'by exception' target ranges from Hill and Sparling (2009). Guideline values for trace element concentrations in soil are adapted from NZWWA (2003).

Olsen P target ranges from Hill and Sparling (2009) are no longer used. Updated targets from Taylor (2011a) are now used and presented below.

Bulk density target ranges (t/m^3 or Mg/m^3)

	Very loose	Loose	Adequate	Compact	Very compact	
Semi-arid, Pallic and Recent soils	0.3	0.4	0.9	1.25	1.4	1.6
Allophanic soils		0.3	0.6	0.9	1.3	
Organic soils		0.2	0.4	0.6	1.0	
All other soils	0.3	0.7	0.8	1.2	1.4	1.6

Macroporosity target ranges (% v/v at -10 kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	6	10[1]	30	40
Forestry	0	8	10	30	40

Total carbon target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	
Allophanic	0.5	3	4	9	12
Semi-arid, Pallic and Recent	0	2	3	5	12
Organic	exclusion				
All other Soil Orders	0.5	2.5	3.5	7	12

Total nitrogen target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	High	
Pasture	0	0.25	0.35	0.65	0.70	1.0
Forestry	0	0.10	0.20	0.60	0.70	
Cropping and horticulture	exclusion					

Mineralisable nitrogen target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	Excessive	
Pasture	25	50	100	200	200	250	300
Forestry	5	20	40	120	150	175	200
Cropping and horticulture	5	20	100	150	150	200	225

Soil pH target ranges

	Very acid	Slightly acid	Optimal	Sub-optimal	Very alkaline	
Pastures on all soils except Organic	4	5	5.5	6.3	6.6	8.5
Pastures on Organic soils	4	4.5	5	6	7.0	
Cropping and horticulture on all soils except Organic	4	5	5.5	7.2	7.6	8.5
Cropping and horticulture on Organic soils	4	4.5	5	7	7.6	
Forestry on all soils except Organic		3.5	4	7	7.6	
Forestry on Organic soils	exclusion					

Olsen P target ranges (units not reported) from Taylor (2011)

Land use	Soil Type	Suggested Olsen P targets
Pasture, Horticulture and cropping	Volcanic	20-50
Pasture, Horticulture and cropping	Sedimentary and Organic soils	20-35
Pasture, Horticulture and cropping	Raw sands and Podzols with low AEC	5
Pasture, Horticulture and cropping	Raw sands and Podzols with medium and above AEC	15-25
Pasture, Horticulture and cropping	Other soils	20-45
Pasture, Horticulture and cropping	Hill country	15-20
Forestry	All soils	5-30

Guideline values for trace element concentrations in soil, adapted from NZWWA (2003)

Trace element	Soil limit (mg/kg)
Arsenic (As)	20
Cadmium (Cd)	1
Chromium (Cr)	600
Copper (Cu)	100
Lead (Pb)	300
Nickel (Ni)	60
Zinc (Zn)	300

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