Soil Quality for Indigenous Vegetation Sites in the Auckland Region 2012

September 2013 Technical Report 2013/041

Auckland Council
Technical report, TR2013/041
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-927266-18-2 (Print)
ISBN 978-1-927266-19-9 (PDF)

This report has been peer reviewed by the Peer Review Panel using the Panel's terms of reference
Submitted for review on 11 June 2013 Review completed on 5 September 2013 Reviewed by two reviewers
Approved for Auckland Council publication by:    Name: Greg Holland Position: Manager, Research, Investigations and Monitoring Unit
Date: 5 September 2013

Recommended citation:
Curran-Cournane, F (2013). Soil quality for indigenous vegetation sites in the Auckland region 2012. Auckland Council technical report, TR2013/041

© 2013 Auckland Council

This publication is provided strictly subject to Auckland Council's copyright and other intellectual property rights (if any) in the publication. Users of the publication may only access, reproduce and use the publication, in a secure digital medium or hard copy, for responsible genuine non-commercial purposes relating to personal, public service or educational purposes, provided that the publication is only ever accurately reproduced and proper attribution of its source, publication date and authorship is attached to any use or reproduction. This publication must not be used in any way for any commercial purpose without the prior written consent of Auckland Council. Auckland Council does not give any warranty whatsoever, including without limitation, as to the availability, accuracy, completeness, currency or reliability of the information or data (including third party data) made available via the publication and expressly disclaim (to the maximum extent permitted in law) all liability for any damage or loss resulting from your use of, or reliance on the publication or the information and data provided via the publication. The publication, information, and data contained within it are provided on an "as is" basis.

Soil Quality for Indigenous Vegetation Sites in the Auckland Region 2012

Dr Fiona Curran-Cournane

Research, Investigations and Monitoring Unit

Auckland Council

Executive Summary

The land and soil in the Auckland region are important and valuable resources. They support the growing population by providing food, a place to live and work, and recreational and tourism opportunities. Some soil and landform combinations also have cultural and/ or historical significance to different groups of people.

The Resource Management Act 1991 Section 35 requires councils to carry out State of the Environment reporting every five years for marine, freshwater, groundwater, terrestrial, air and soil quality monitoring. Soil quality monitoring within the Auckland region was instigated in 1995 as part of a national 500 Soils Project. Soil quality refers to the ability of the soil to sustain biological production, maintain environmental quality, and promote plant and animal health. Land uses sampled within Auckland as part of the programme include horticulture, dairy, drystock and plantation forestry sites and were last sampled in 2008, 2009, 2010 and 2011, respectively. Indigenous sites were last sampled between 1996-2000 and were the focus of 2012 soil sampling. This included 14 previously sampled sites (between 1996-2000) and the sampling of 15 new sites, and when combined, represent five widespread Soil Orders, namely Allophanic, Brown, Granular, Recent and Ultic. These correspond to sixteen soil series.

Key soil quality properties of interest include soil acidity (pH), organic carbon (OC), total nitrogen (TN), Olsen P (plant available phosphorus), anaerobic mineralisable nitrogen (AMN- plant available nitrogen), bulk density and macroporosity (at -10kPa). Trace element concentrations measured include arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. However, the majority of the report will focus and report on key soil quality results.

For the 29 sites sampled in 2012, soil quality indicators were lower than, or within the range of, guidelines set for the closest equivalent land use (plantation forestry), with one exception. Anaerobic mineralisable nitrogen was higher at nine out of 29 sites. These levels are interpreted as ‘background’ ranges for the indicators, in soils under natural or regenerating vegetation cover where there is little or no alteration by land use. Median trace element concentrations were within previously reported ‘background’ ranges for all analytes.

At the 14 resampled sites, there were no significant changes in any of the soil quality indicators suggesting that soil quality under natural vegetation cover has remained stable.

Re-iterating, indigenous sites can be expected to indicate ‘background’ conditions, so determining if measurements fall within or outside target ranges should only be used to provide some context for discussing soil quality changes.

Since the establishment of the 500 Soils Project in Auckland, the original sites first sampled between 1995-2000 for all land use types have had a complete round of re-sampling representing the 2008-2012 period. It is recommended that a review of all sites be conducted to determine soil quality for all land uses and soil types for sampling period 2008-2012, and to determine soil quality trends for repeat sites (originally sampled in the first round between 1995-2000). This will help decisions about

which indicators are of most concern for various land uses; which can be used as a guide as to where problems exist; and where resources need to be targeted.

It is also recommended that these indigenous sites be re-sampled in 5-10 years time to align with a third round of soil quality sampling across all land use and soil type sites in Auckland. Assuming that indigenous sites are relatively stable, re-sampling repeat sites will allow us to ascertain whether soil quality background conditions are changing in response to the climate.

Contents

1.0 Introduction

The land and soil in Auckland are important and valuable resources. They support the growing population by providing food, a place to live and work, and recreational and tourism opportunities. Some soil and landform combinations also have cultural and/ or historical significance to different groups of people (Dominati *et al.* 2010).

Soil forms into many different types, depending on the parent material and the environment that it has come from. The dominant soil types in Auckland are the Ultic soils, representing about 38-40% land area which are located predominantly in north Auckland (Curran Cournane and Taylor 2013; Hewitt 1998). Granular soils, representing about 17% of land area, are dominant in south Auckland. Some of these Granular soils are some of the best soils in New Zealand. Other Soil Orders in Auckland include Brown, Recent, Allophanic, Gley, Raw, Organic, Anthropic, Melanic, Oxidic and Podzol (Hewitt 1998).

The Resource Management Act 1991 Section 35 requires councils to carry out State of the Environment reporting every five years for marine, freshwater, groundwater, terrestrial, air or soil quality monitoring. Auckland Council monitors soil quality to observe and report any changes that occur in the extent, quality or health of the region's soil resources. Soil quality refers to the ability of the soil to sustain biological production (for example the amount of tiny microbes in the soil), maintain environmental quality (for example water purification), and promote plant and animal health. Soil quality monitoring within the Auckland region was instigated in 1995 as part of a national 500 Soils Project (Hill *et al.* 2003) and continued until 2000 after which time it was not again established until 2008. Annual soil sampling events contribute to State of the Environment reporting. Sites are selected based on representative land uses and Soil Orders in Auckland. Land uses sampled in recent years include horticulture, dairy, drystock and plantation forestry sites sampled in 2008 (Sparling 2009b), 2009 (Stevenson 2010), 2010 (Fraser and Stevenson 2011) and 2011 (Curran-Cournane 2013), respectively. Indigenous sites were the focus of soil sampling in 2012.

Key soil quality properties of interest include soil acidity (pH), organic carbon (OC), total nitrogen (TN), Olsen P (plant available phosphorus), anaerobic mineralisable nitrogen (AMN- plant available nitrogen), bulk density and macroporosity (at -10kPa). A key soil quality indicator is one that should be quantitative and measurable; responsive within the time scale specified; interpretable; cost effective; scientifically justifiable; and socially acceptable (Hill and Sparling 2009).

The following trace element concentrations were also measured; arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. However, the report will focus on the key soil quality parameters listed above.

Study objectives included:

- Soil sampling for sites classed as 'indigenous' which were previously monitored between 1996-2000, and are currently still under this land use, to determine changes in soil quality over time;

- Selecting new sampling sites that increase broad geographical coverage of representative soil types in the Auckland region;
- Identifying whether any key soil quality indicators are of concern under indigenous cover;
- Determining trace element concentrations for all sites;
- Reporting findings from the study and providing results to landowners, for not only educational and feedback purposes, but to establish better relationships between Council and landowners.

2.0 Materials and methods

2.1 Sample sites

Twenty-nine indigenous sites were sampled across the Auckland region during 03-21 September 2012 (Figure 1). Twenty indigenous sites were originally sampled during sampling period 1996-2000, fourteen of which were re-sampled in September 2012. Access to the six remaining original sites was not permitted, and it is envisaged that these six sites will be re-sampled during the next 2013 sampling period. Fifteen new sites were selected from within the Waitakere Ranges, Hunua Ranges and Great Barrier Island to broaden the geographical coverage of sampling sites and increase representation of indigenous forests within Auckland. These new sites represent four new soil series; Waitakere, Huia, Te Kie and Awapuku (Table 1)

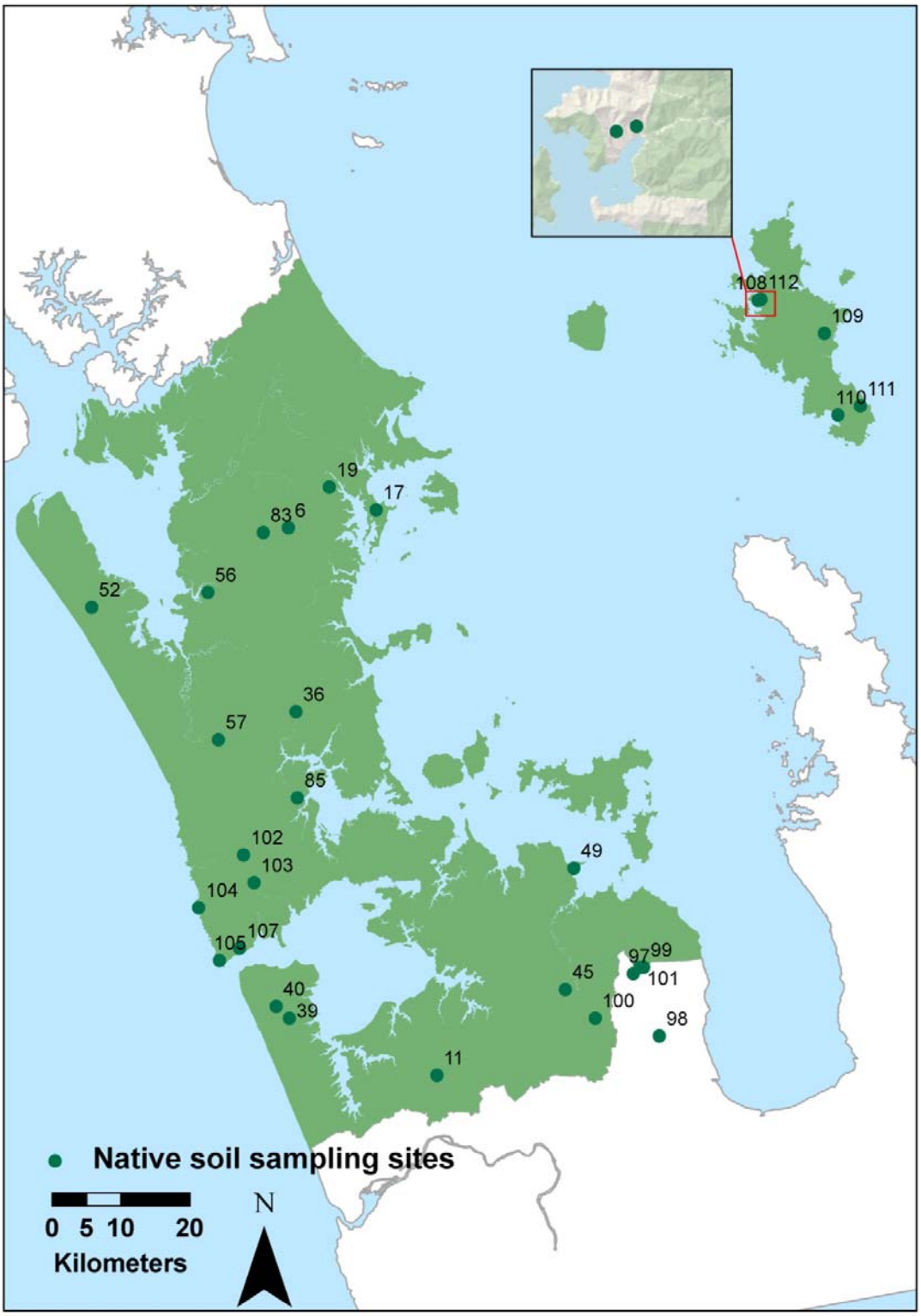


Figure 1. Location of the 29 indigenous sites sampled within Auckland in 2012.

Table 1. Soil classification and soil series for 29 indigenous sites sampled in the Auckland region in 2012 for soil quality attributes.

ARC code	Site number	Year established	NZSC subgroup	Soil series
ARC96_04	2012-06-02	1996	Typic Yellow Ultic	Whangaripo clay loam
ARC97_03	2012-11-02	1997	Typic Oxidic Granular	Patumahoe clay loam
ARC98_05	2012-17-02	1998	Typic Yellow Ultic	Warkworth clay loam
ARC98_07	2012-19-02	1998	Typic Yellow Ultic	Warkworth clay loam
ARC98_24	2012-36-02	1998	Typic Orthic Allophanic	Otao silt loam
ARC99_02	2012-39-02	1999	Typic Orthic Granular	Matakawau clay loam
ARC99_03	2012-40-02	1999	Typic Sandy Brown	Red Hill sandy loam
ARC99_08	2012-45-02	1999	Typic Orthic Granular	Ararimu clay
ARC99_12	2012-49-02	1999	Typic Orthic Brown	Marua clay loam
ARC99_15	2012-52-02	1999	Typic Sandy Recent	Pinaki sand
ARC99_19	2012-56-02	1999	Typic Orthic Granular	Cornwallis clay
ARC99_20	2012-57-02	1999	Typic Orthic Granular	Parau clay loam
ARC00_21	2012-83-02	2000	Mottled Orthic Brown	Waipuna clay loam
ARC00_23	2012-85-02	2000	Mottled Orthic Brown	Albany clay
New	2012-97-01	2012	Typic Mafic Ultic[1]	Marua clay loam
New	2012-98-01	2012	Typic Yellow Ultic[1]	Marua clay loam
New	2012-99-01	2012	Typic Yellow Ultic[1]	Marua clay loam
New	2012-100-01	2012	Typic Yellow Ultic[1]	Marua clay loam
New	2012-101-01	2012	Typic Yellow Ultic[1]	Marua clay loam
New	2012-102-01	2012	Typic Orthic Granular[1]	Waitakere clay
New	2012-103-01	2012	Typic Orthic Granular[1]	Waitakere clay
New	2012-104-01	2012	Typic Mafic Brown[1]	Huia steepland soil
New	2012-105-01	2012	Typic Mafic Brown[1]	Huia steepland soil
New	2012-107-01	2012	Mottled Orthic Granular[1]	Waitakere clay
New	2012-108-01	2012	Weathered Orthic Recent	Te Kie steepland
New	2012-109-01	2012	Weathered Orthic Recent[1]	Te Kie steepland
New	2012-110-01	2012	Typic Mafic Brown[1]	Awapuku clay loam
New	2012-111-01	2012	Mottled Mafic Brown[1]	Awapuku clay loam
New	2012-112-01	2012	Weathered Orthic Recent[1]	Te Kie steepland

[1]Provisional soil classification pending a comprehensive pedological assessment

2.2 Soil sampling

The soil samples collected at each site were analysed for a suite of seven key soil chemical, biological and physical indicators which included soil pH, organic carbon (OC), total nitrogen (TN), anaerobic mineralisable nitrogen (AMN), Olsen P, bulk density and macroporosity at -10kPa (pore sizes >30 microns). Organic Carbon is used instead of total Carbon because where pH >7, carbonate carbon is insignificant. Although not regarded as a key soil quality indicator, the carbon/nitrogen (C/N) ratio was also calculated for each site. A suite of 38 trace element analytes were also analysed (Appendix 7.4) and analytes reported in the study include arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. Nitrate, ammonium, initial water content, particle density and total porosity were also analysed and are presented in Appendices 7.1 and 7.2.

For key soil quality indicators all chemical results will be discussed on a gravimetric basis according to the guidelines presented in Sparling *et al.* (2003) and Taylor (2011) (Table 2). Guidelines for OC and bulk density are determined for Soil Orders while the remaining are specified for land use. Regarding the latter, guidelines have been poorly defined for indigenous land use. However, to provide some context, Table 2 presents guidelines for TN, AMN, pH, Olsen P and macroporosity which are based on those defined for plantation forestry. It should be noted that these guidelines are provided for the purpose of discussing background conditions or inherent characteristics at indigenous sites that are not influenced by human use of land.

Table 2. Provisional target ranges for soil quality under indigenous land cover.

Soil order	pH[1]	OC[1] mg/kg	TN[1] mg/kg	Olsen P[2] mg/kg	AMN[1] mg/kg	Bulk[1] density g/cm[3]	Macroporosity[3] -10kPa	C/N[4]
Allophanic	4-7	4+	0.2-0.7	5-30	40-175	>0.5-1.3	8-30	7-30
Brown	4-7	3.5+	0.2-0.7	5-30	40-175	>0.6-1.4	8-30	7-30
Granular	4-7	3.5+	0.2-0.7	5-30	40-175	>0.6-1.4	8-30	7-30
Recent	4-7	3+	0.2-0.7	5-30	40-175	>0.7-1.4	8-30	7-30
Ultic	4-7	3.5+	0.2-0.7	5-30	40-175	>0.6-1.4	8-30	7-30

Adapted from Sparling *et al.* 2003[1], Taylor 2011[2], Mackay *et al.* 2006[3]

[4] C/N ratio is coloured grey as it is not considered a key soil quality indicator but a guideline range for Soil Orders is provided.

The soil sampling methodology used in this study is comparable to previous soil sampling by the Auckland Council e.g. Fraser and Stevenson (2011). A 50m long transect was laid out at each site based on GPS points from previous sampling. For new sites the transect was laid out randomly and GPS coordinates recorded. Soil plugs were collected every 2m along the transect at 0 – 10cm depth using a 2.5cm diameter bucket corer. The 25 individual samples were bulked together and homogenised by both hand in the field and later in the laboratory. This was repeated twice for chemical and trace element analyses.

Physical soil parameters were also measured using stainless steel rings (10cm in diameter and 7.5 cm in depth). The rings were pressed or hammered directly into the soil and then removed with the soil sample intact. These soil cores were collected at the 15, 30 and 45m distances along the 50m transect (Figure 2).

All equipment was cleaned of excess soil in between sites, and sterilised with the disinfectant Trigene, to protect against the spread of Kauri dieback disease.

Figure 2. An intact soil core used to establish the physical quality of the soil.

2.2 Laboratory analysis

Methods for determination of all soil physical, chemical and biological analyses were those outlined in Hill *et al.* (2003). Briefly, the composite samples were well mixed, air-dried and sieved (<2mm) for Olsen P (Olsen *et al.* 1954). High temperature combustion methods (1050°C) were used for OC and TN analyses (Blakemore *et al.* 1987). Soil pH was measured in deionised water at a 2.5:1 water to soil ratio (Blakemore *et al.* 1987) and AMN was determined under the anaerobic (waterlogged) incubation method from field moist conditions (Keeney and Bremner 1966).

In the soil physics laboratory, smaller stainless steel rings (5.5cm width and 3cm depth) were used to sub-sample the larger rings by pressing into the larger core using a bench mounted drill press. The sub-sampling of the larger rings is to correct for any sampling error or bias between field staff and to ensure the measurement of a fully intact soil core. The smaller cores were saturated and equilibrated at both -5 and -10kPa on ceramic tension plates to determine macroporosities. Dry bulk densities and total porosities were calculated from oven (105°C) dry weights.

Soil samples for trace element concentrations were mixed air dried and sieved to <2mm before chemical analysis. Total recoverable arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc were determined by digestion of soil in nitric/hydrochloric acid and trace elements were analysed in digest by inductively coupled plasma mass spectrometry (ICPMS) (USEPA 200.8).

2.3 Statistical analysis

Soil physical properties, OC, TN, AMN and Olsen P were tested for normality and transformed if necessary before being subjected to ANOVA to determine changes in soil quality attributes for years sampled between 1996-2000 and 2012. Organic C, TN, AMN and Olsen P are expressed on a gravimetric basis. All statistical analyses were carried out using the statistical package Genstat 14 (GenStat 2011) and graphics using Sigmaplot 11 (SigmaPlot 2008). Summary data for trace element concentrations for eight analytes are presented as Box and Whisker plots. The boxes represent the inter-quartile range (25^{th} to 75^{th} percentile) and the whiskers show the range of values that fall within the inner fences. Outliers are illustrated with black circles. The median is shown as a line in each box.

3.0 Results and discussion

Twenty-nine sites representing a broad geographical coverage of the Auckland region and covering five Soil Orders (Allophanic, Brown, Granular, Recent and Ultic) in the New Zealand soil classification (Hewitt 1998), corresponding to sixteen soil series, were sampled in 2012 (Tables 2 and 3). Fourteen sites were originally sampled between 1996 and 2000 and 15 were newly selected sites.

Ten percent of sites met all the suggested targets. Fifty-two percent of sites did not meet target criteria for one indicator followed by 28%, 7% and 3% failing to meet two, three and four indicators, respectively (Figure 3A). The indicator failing to meet guidelines on most occurrences was Olsen P with the majority of sites being <5 mg/kg (Figure 3B and Table 3). Items highlighted in bold represent values outside the recommended guideline target range (Table 3). In colour print copies, the bold numbers in red are values below the recommended target range and bold numbers in blue exceed the recommended target range. Sparling (2009a) did not report Olsen P concentrations <5µg/cm^3 to be a concern for indigenous sites when the original 14 sites were first sampled between 1996-2000, albeit the latter being recorded in volumetric. Low Olsen P concentrations are not a concern in this instance because sites under indigenous cover do not receive fertiliser applications. It has been reported that unintended nutrient applications to indigenous forest fragments have the potential to alter plant successional dynamics and species composition (Stevenson 2004). Olsen P concentrations of 25 and 21 mg/kg for site numbers 49 and 83, respectively, suggest that fertiliser drift may be the result for the higher than background concentrations observed at these sites.

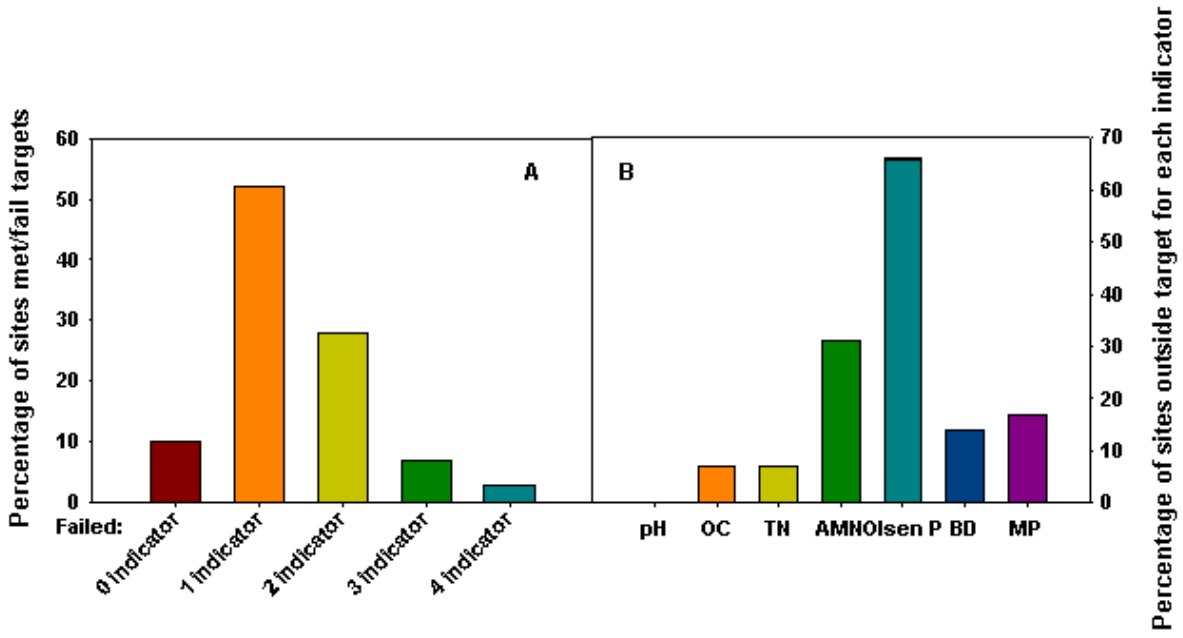


Figure 3. Percentage of indigenous sites outside targets for (A) a number of key soil quality indicators and for (B) specific key soil quality parameters.

Anaerobic mineralisable nitrogen concentrations exceeded guidelines for 31% of sites (Table 3). When AMN concentrations for the fourteen sites originally sampled between 1996-2000 were

compared with concentrations for the same sites re-sampled in 2012 there were no significant differences (Table 4). Mean AMN concentrations were 121 mg/kg (range 57-235mg/kg) when originally sampled versus 134 mg/kg (range 57-234 mg/kg) when re-sampled in 2012. This suggests that these sites have naturally high AMN concentrations. Two sites with AMN concentrations at the upper end of the range had correspondingly high TN contents. These two sites also had high OC contents above13% (Table 3).

Macroporosities for five sites were outside suggested targets, four of which were below the 8%v/v guideline for this land use. However, in contrast to other land uses, particularly pastoral land (Curran-Cournane *et al.* 2013), macroporosities were within guidelines at the majority of sites (24 out of 29). Four sites had very low bulk density which corresponds to the high organic carbon content also measured at these sites (Table 3) (Curran-Cournane *et al.* 2013; Milne and Haynes 2004). A C/N ratio considered acceptable is within the 7-30 range and all sites met this target.

Table 3. Soil chemical, physical and biological characteristics for 2012 indigenous sampled sites within Auckland. Results for macroporosity (-5kPa) and C/N ratio are presented in the shaded column but excluded from the determination of whether sites meet the soil quality guideline procedure.

Site no.	NZSC	pH	OC%	TN%	AMN mg/kg	Olsen P mg/kg	Bulk density g/cm^3	Macro -10kPa	Macro -5kPa	C/N
6	Ultic	5.1	6.1	0.30	122	**2**	0.62	11.4	7.7	20.1
11	Granular	6.0	7.0	0.50	169	**4**	0.87	11.2	8.6	14.0
17	Ultic	5.5	4.5	0.29	99	**4**	1.05	**4.9**	3.6	15.6
19	Ultic	4.9	6.2	0.37	161	**2**	0.84	10.3	9.1	16.9
36	Recent	5.7	5.3	0.31	130	6	1.10	**3.1**	1.8	16.8
39	Allophanic	5.9	6.3	0.35	151	**3**	0.76	21.5	18.3	18.1
40	Brown	5.8	9.6	0.49	141	**2**	**0.56**	29.0	26.1	19.4
45	Granular	4.4	10.4	0.55	84	**3**	0.64	27.0	24.5	18.8
49	Brown	6.5	4.7	0.33	116	25	0.97	12.6	10.5	14.0
52	Recent	5.8	**2.9**	0.19	57	12	0.98	**37.6**	28.9	15.4
56	Granular	6.2	9.2	0.54	**198**	12	0.68	21.4	18.8	16.9
57	Granular	5.7	11.5	0.57	**234**	7	0.74	9.9	11.7	20.3
83	Brown	5.8	7.0	0.40	150	21	0.85	16.0	13.3	17.5
85	Brown	4.9	6.9	0.36	60	**3**	1.01	9.7	9.5	19.4
97	Ultic	5.3	6.4	0.36	**176**	5	0.66	22.5	18.9	18.0
98	Ultic	5.3	4.6	0.31	158	6	0.94	12.7	9.5	15.0
99	Ultic	5.2	12.5	**0.73**	**249**	5	**0.56**	10.2	6.7	17.0
100	Ultic	5.2	6.9	0.39	169	**4**	0.76	8.5	5.5	17.6
101	Ultic	5.1	10.0	0.60	**256**	**4**	0.60	12.0	9.2	16.7
102	Granular	5.1	9.4	0.51	**183**	**1**	**0.56**	11.5	9.2	18.4
103	Granular	4.7	14.9	**0.72**	**271**	**2**	**0.47**	19.8	17.5	20.7
104	Brown	5.6	7.8	0.42	175	**2**	0.82	8.5	6.5	18.5
105	Brown	6.3	**3.0**	0.24	123	**3**	1.14	14.7	12.2	12.8
107	Granular	5.2	8.2	0.46	**198**	**2**	0.75	15.9	13.8	17.8
108	Recent	5.4	7.3	0.46	165	**3**	0.75	15.2	13.4	15.7
109	Recent	4.9	8.2	0.38	134	**2**	0.89	14.6	13.0	21.4
110	Brown	6.0	7.8	0.49	**248**	6	0.95	**6.3**	4.1	16.0
111	Brown	5.9	5.9	0.47	165	**3**	0.77	**7.0**	4.5	12.7
112	Recent	4.6	10.8	0.44	87	**1**	0.65	16.8	14.7	24.5

There were no significant differences for soil quality indicators between the two sampling periods, 1996-2000 and 2012 (Table 4). On a site-by-site basis, soil quality fluctuation was observed for Olsen P and AMN. Site numbers 36, 45 and 83 experienced reductions of 19, 37 and 15 mg/kg, respectively, in Olsen P concentrations. Site number 57 more than doubled in concentrations of AMN from 110 mg/kg measured in 1999 to 234mg/kg in 2012. The reduction in Olsen P could be attributed to a natural decline over time (Dodd *et al.* 2012). Also, it is not possible to rule out spatial variability as an underlying factor. Spatial variability could also be attributed to the observed increase in AMN observed at site number 57. The observation of no significant differences when mean concentrations of soil quality indicators were compared for the two sampling periods indicates the relative stability of indigenous sites.

Median concentrations of trace elements (Figure 4) were all within background concentration levels (ARC 2001). For individual sites, site number 17 had chromium concentrations at 62 mg/kg for an Ultic soil and site number 104 had copper concentrations at 51 mg/kg for a Brown soil. These concentrations slightly exceed the background concentrations for non-volcanic soils but would not be considered to be near the upper limit for agricultural soils which is suggested to be 600 mg/kg and 100 mg/kg for chromium and copper, respectively (NZWWA 2003).

Table 4. Changes in soil quality attributes for repeat indigenous sites in Auckland for 1996-2000 and 2012 sampling periods. *F*-statistic and standard error of differences (SED) calculated on log transformed data.

Site number	First sampled	Second sampled	NZSC	pH	OC %	TN %	Olsen P mg/kg	AMN mg/kg	Macro -5kPa	Bulk density g/cm^3
6	1996	2012	Ultic	-0.2	-0.68	-0.10	-3	-20	-2	-0.16
11	1997	2012	Granular	0.6	-0.58	0.01	1	32	-11	0.05
17	1998	2012	Ultic	0.7	-0.25	0.05	1	4	-3	-0.13
19	1998	2012	Ultic	-0.2	0.26	0.02	-1	44	-4	-0.02
36	1998	2012	Recent	0.5	-1.61	-0.13	-19	22	-11	0.24
39	1999	2012	Allophanic	0.0	-2.07	-0.13	0	12	-13	0.08
40	1999	2012	Brown	0.2	0.22	0.05	-1	-23	-5	-0.09
45	1999	2012	Granular	0.2	-2.60	-0.09	-37	-13	13	-0.24
49	1999	2012	Brown	0.3	-1.21	-0.08	13	7	-2	-0.09
52	1999	2012	Recent	0.5	-1.01	-0.01	7	-7	1	-0.01
56	1999	2012	Granular	-0.3	-2.45	-0.11	2	-37	4	-0.03
57	1999	2012	Granular	0.3	2.22	0.17	6	124	7	-0.09
83	2000	2012	Brown	0.1	1.43	0.12	-15	26	3	-0.19
85	2000	2012	Brown	0.3	1.08	0.09	1	3	-1	-0.05
		Mean change		0.21	-0.52	-0.01	-3.2	12.4	-1.7	-0.05
		SED		0.043	0.134	0.126	0.367	0.146	0.251	0.075
		F-statistic		ns	ns	ns	ns	ns	ns	ns
		% mean change		4.2	-6.0	1.8	27.9	12.3	-1.8	-5.5

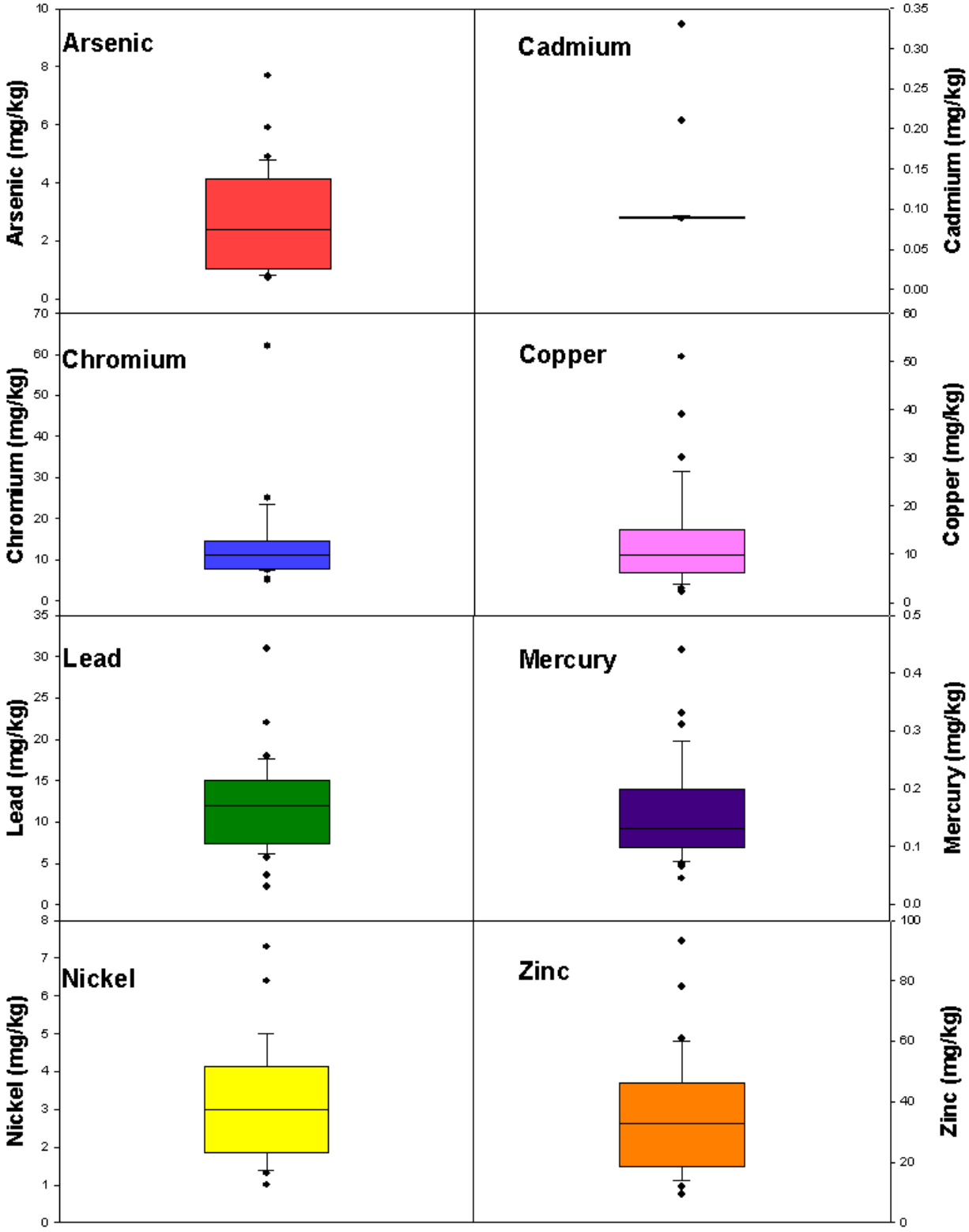


Figure 4. Trace element concentrations (mg/kg) at the 29 indigenous soil quality monitoring sites. The boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within the inner fences. Outliers are illustrated with black circles. The median is shown as a line in each box. Note that the scales differ on each plot.

4.0 Conclusions

Twenty-nine indigenous sites across the Auckland region were sampled for a suite of key soil quality indicators in 2012. Target ranges for indigenous sites are not well-defined so guidelines are based largely on those for plantation forestry. The indicator most frequently falling outside target ranges was Olsen P, with 66% of sites having low Olsen P concentrations. Indigenous sites can be expected to indicate background conditions, uninfluenced by human use of land, so low Olsen P concentrations are typical for such sites and not considered a concern. Anaerobic mineralisable nitrogen (AMN) concentrations exceeded guidelines for 31% of sites. There were no significant changes in AMN concentrations for repeat sites suggesting that these sites have naturally high AMN concentrations.

There were no significant differences for soil quality measurements for repeat sites indicating the relative stability of indigenous vegetation. Median trace element concentrations were all within background concentration levels for all analytes.

Re-iterating, indigenous sites can be expected to indicate background conditions so determining if measurements fall within or outside target ranges should only be used to provide some context for discussing soil quality changes. These background conditions are therefore, to some extent, the inherent characteristics of these soil types at these sites.

Since the establishment of the 500 Soils Project in Auckland, the original sites first sampled between 1995-2000 for all land uses have had a complete round of re-sampling representing the 2008-2012 sampling period, except for those sites where access was not permitted. It is recommended that a review of all re-sampled sites is conducted to determine soil quality for all land uses and soil types for sampling period 2008-2012 and to determine soil quality trends for repeat sites originally sampled in the first round (1995-2000). This will help decisions about which indicators are of most concern for various land uses; which can be used as a guide as to where problems exist; and where resources need to be targeted.

It is also recommended that these indigenous sites are re-sampled in 5-10 years time to align with a third round of soil quality sampling across all land use and soil type sites in Auckland. Assuming that indigenous sites are relatively stable that are uninfluenced by human use of land, and whereby no significant differences for soil quality measurements for repeat sites were recorded, re-sampling will allow us to ascertain whether soil quality background conditions are changing in response to climate.

5.0 Acknowledgements

The Environmental Monitoring and Land Management teams are thanked for assisting with soil sampling, with particular thanks to Jade Khin and Stacey Lockie. Expert soil advice was greatly appreciated from Dr. Douglas Hicks. Laboratory analyses were carried out by Landcare Research and Watercare Laboratory Services. Alyssa Stent is thanked for assisting with report formatting. The Auckland Council peer review panel and the reviewers of this report are thanked for their suggestions and valuable comments. Sincere thanks go to the landowners for allowing access to sites.

6.0 References

Auckland Regional Council (2001). *Background concentrations of inorganic elements in soils from the Auckland region*. Auckland Regional Council, technical publication, TP153

Blakemore L C, Searle P L, Daly B K (1987). *Methods for chemical analysis of soils*. NZ Soil Bureau Scientific Report 80, Lower Hutt: DSIR Soil Bureau

Curran-Cournane F (2013). *Soil quality of plantation forestry sites in the Auckland region 2011*. Auckland Council technical report, TR2013/013

Curran-Cournane F, Fraser S, Hicks D L, Houlbrooke D J, Cox N (2013). Changes in soil quality and land use in grazed pasture within rural Auckland. *New Zealand Journal of Agricultural Research* 56: 102-116

Curran Cournane F, Taylor A (2013). *Land and soil monitoring programme*. Auckland Council technical report, TR 2013/019

Dodd R, McDowell R, Condron L (2012). Predicting the changes in environmentally and agronomically significant phosphorus forms following cessation of phosphorus fertiliser applications to grassland. In Soil Science Proceedings of the fifth Joint Australian and New Zealand Soil Science Conference. Soil solutions for diverse landscapes. Wrest Point hotel and convention centre, Hobart, Tasmania 2-7 December 2012

Dominati E, Patterson M, Mackay A (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics,* 69: 1858–1868

Fraser S, Stevenson B (2011). *Soil quality of drystock sites in the Auckland region 2010*. Prepared by Landcare Research for Auckland Council. Auckland Council, technical report TR2011/011

GenStat (2011). Genstat for Windows. Fourteenth Edition. VSN International Ltd, Oxford

Hewitt A E (Ed.) (1998) *New Zealand soil classification* Lincoln: Manaaki Whenua Press

Hill R B, Sparling G P (2009). Soil quality monitoring. Chapter 3 in *Land and soil monitoring: a guide for SoE and regional council reporting*; New Zealand

Hill R B, Sparling G P, Frampton C, Cuff J (2003). *National soil quality review and program design*. Ministry for the Environment, technical report 74, Wellington: Ministry for the Environment

Keeney D R, Bremner J M (1966). Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. *Agronomy Journal,* 58: 498-503

Milne R, Haynes R (2004). Comparative effects of annual and permanent dairy pastures on soil physical properties in the Tsitsikamma region of South Africa. *Soil Use and Management,* 20: 81-88

NZWWA (2003). *Guidelines for the safe application of biosolids to land in New Zealand*. Wellington: Water and Wastes Association, New Zealand

Olsen S R, Cole C V, Watanabe F S, Dean L A (Eds) (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate.* United States Department of Agriculture Circular No. 939. Washington, D C USA

SigmaPlot (2008). Version 11.0 for Windows

Sparling G (2009a). *An overview of soil quality in the Auckland region using data from the 500 soils project 1995-2001*. Prepared by Landcare Research for Auckland Regional Council. Auckland Regional Council, technical report TR2009/00

Sparling G (2009b). *Soil quality of horticultural sites in the Auckland region*. Prepared by Landcare Research for Auckland Regional Council. Auckland Regional Council technical report, TR2009/008

Sparling G, Lilburne L, Vojvodic-Vucovic M (2003). *Provisional targets for soil quality indicators in New Zealand*. Landcare Research Science Series No. 34. Lincoln: Manaaki Whenua Press

Stevenson B (2010). *Soil quality of dairy sites in the Auckland region 2010*. Prepared by Landcare Research for Auckland Regional Council. Auckland Regional Council technical report, TR2010/026

Stevenson B, A (2004). Changes in phosphorus availability and nutrient status of indigenous forest fragments in pastoral New Zealand hill country. *Plant and Soil,* 262: 317-325

Taylor M D (2011). *Towards developing targets for soil quality indicators in New Zealand: Findings of a review of soil quality indicators workshop, 6th May 2011*. Unpublished report, Land Monitoring Forum

7.0 Appendices

7.1 2012 Soil chemistry data

Site number	Lab number	Water Content (method 104 (ii)) (%dry wt)	pH (2:5 Water) (method 106 (i))	Organic C (method 114) (%)	Total N (method 114) (%)	C/N ratio calculation	NO3-N KCL-extractable (method 118) (mg/kg)	NH4-N KCL-extractable (method 118) (mg/kg)	Anaerobic Mineralisable N (method (120) (mg/kg	Olsen P (method 124) (mg/kg)
6	M12/1421	97	5.1	6.1	0.30	20.1	0.4	3.4	122	2
11	M12/1433	66	6.0	7.0	0.50	14.0	12.8	3.0	169	4
17	M12/1422	56	5.5	4.5	0.29	15.6	2.9	0.8	99	4
19	M12/1437	70	4.9	6.2	0.37	16.9	0.9	6.4	161	2
36	M12/1423	65	5.7	5.3	0.31	16.8	1.8	2.3	130	6
39	M12/1438	56	5.9	6.3	0.35	18.1	2.2	7.8	151	3
40	M12/1436	73	5.8	9.6	0.49	19.4	1.3	10.8	141	2
45	M12/1439	75	4.4	10.4	0.55	18.8	4.7	9.4	84	3
49	M12/1434	63	6.5	4.7	0.33	14.0	17.3	0.8	116	25
52	M12/1424	25	5.8	2.9	0.19	15.4	4.6	7.0	57	12
56	M12/1427	68	6.2	9.2	0.54	16.9	2.9	2.7	198	12
57	M12/1425	94	5.7	11.5	0.57	20.3	2.7	6.9	234	7
83	M12/1435	51	5.8	7.0	0.40	17.5	7.1	2.0	150	21
85	M12/1426	60	4.9	6.9	0.36	19.4	0.5	2.4	60	3
97	M12/1428	77	5.3	6.4	0.36	18.0	0.1	4.4	176	5
98	M12/1429	61	5.3	4.6	0.31	15.0	1.5	9.0	158	6
99	M12/1430	145	5.2	12.5	0.73	17.0	4.2	14.1	249	5
100	M12/1431	83	5.2	6.9	0.39	17.6	0.3	4.9	169	4
101	M12/1432	118	5.1	10.0	0.60	16.7	2.4	14.7	256	4
102	M12/1440	101	5.1	9.4	0.51	18.4	1.3	3.9	183	1
103	M12/1441	149	4.7	14.9	0.72	20.7	0.9	2.0	271	2
104	M12/1442	80	5.6	7.8	0.42	18.5	0.8	1.2	175	2
105	M12/1443	38	6.3	3.0	0.24	12.8	10.6	1.0	123	3
107	M12/1444	82	5.2	8.2	0.46	17.8	2.6	14.8	198	2
108	M12/1445	81	5.4	7.3	0.46	15.7	0.9	7.9	165	3
109	M12/1446	71	4.9	8.2	0.38	21.4	1.0	2.4	134	2
110	M12/1447	70	6.0	7.8	0.49	16.0	10.2	13.0	248	6
111	M12/1448	93	5.9	5.9	0.47	12.7	2.3	3.6	165	3
112	M12/1449	88	4.6	10.8	0.44	24.5	1.2	2.4	87	1

7.2 2012 Soil physics data

Lab number	Client ID	Liner number	Initial water content (% w/w)	Dry Bulk Density (t/m3)	Particle density (t/m3)	Total porosity (%/v/v)	Macro - 5kPa (% v/v)	Macro (-10kPa) (% v/v)	Vol. WC 5kPa (% v/v)	Vol. WC 10kPa (% v/v)
HP5466a	Site 6, 15 m	0070	186	0.48	2.59	81.6	3.8	10.4	77.8	71.2
HP5466b	Site 6, 30 m	0071	89	0.67	2.52	73.5	15.9	18.4	57.7	55.1
HP5466c	Site 6, 45 m	0072	98.3	0.71	2.59	72.7	3.5	5.4	69.2	67.3
HP5467a	Site 17, 15 m	0064	50.6	1.13	2.62	56.8	<1	<1	58.7	57.9
HP5467b	Site 17, 30 m	0065	59	1.05	2.67	60.6	<1	<1	62.2	60.8
HP5467c	Site 17, 45 m	0066	56	0.98	2.61	62.5	3.6	4.9	58.9	57.6
HP5468a	Site 36, 15 m	0019	55.9	1.07	2.64	59.5	<1	<1	60.9	59.6
HP5468b	Site 36, 30 m	0020	54	1.06	2.59	59.1	1.8	3.7	57.3	55.4
HP5468c	Site 36, 45 m	0021	47.8	1.17	2.6	55.1	<1	2.5	54.5	52.7
HP5469a	Site 52, 15 m	0022	26.4	0.97	2.61	63	31.7	39.5	31.3	23.5
HP5469b	Site 52, 30 m	0023	30.2	0.93	2.62	64.6	27.3	37.4	37.2	27.2
HP5469c	Site 52, 45 m	0024	24.3	1.05	2.73	61.6	27.6	35.8	34	25.8
HP5470a	Site 57, 15 m	0028	95.5	0.68	2.47	72.5	6.2	9.4	66.3	63.1
HP5470b	Site 57, 30 m	0029	95.6	0.74	2.5	70.5	<1	1.4	71.2	69.1
HP5470c	Site 57, 45 m	0030	53.6	0.79	2.58	69.2	17.2	18.8	52.1	50.4
HP5471a	Site 85, 15 m	0052	62.4	0.87	2.46	64.7	9.4	13.9	55.3	50.7
HP5471b	Site 85, 30 m	0053	43.5	1.06	2.53	58.2	9.5	12.7	48.8	45.5
HP5471c	Site 85, 45 m	0054	51.6	1.11	2.61	57.5	<1	2.5	56.6	55
HP5472a	Site 56, 15 m	0025	63.2	0.78	2.57	69.7	16.8	18.9	52.8	50.8
HP5472b	Site 56, 30 m	0026	75.5	0.6	2.39	75.1	21.9	25.1	53.1	49.9
HP5472c	Site 56, 45 m	0027	76.7	0.65	2.48	73.8	17.6	20.3	56.2	53.4
HP5473a	Site 97, 15 m	0001	48.1	1.02	2.76	62.9	10.4	13.3	52.4	49.6
HP5473b	Site 97, 30 m	0002	297.6	0.19	2.66	92.8	41.2	46.7	51.6	46.2
HP5473c	Site 97, 45 m	0003	84.5	0.77	2.58	70	5.2	7.6	64.8	62.4
HP5474a	Site 98, 15 m	0004	51.8	0.94	2.55	63.2	13.6	16.1	49.6	47
HP5474b	Site 98, 30 m	0005	53.7	0.91	2.54	64.4	12.3	15.2	52	49.1
HP5474c	Site 98, 45 m	0006	66.3	0.96	2.6	63.2	2.7	6.7	60.5	56.5
HP5475a	Site 99, 15 m	0007	113.1	0.63	2.41	73.9	4.7	7.5	69.3	66.4
HP5475b	Site 99, 30 m	0008	94.6	0.69	2.51	72.6	7.3	9.4	65.3	63.2

HP5475c	Site 99, 45 m	0009	228.2	0.35	2.03	83	8.2	13.6	74.8	69.4
HP5476a	Site 100, 15 m	0010	69.6	0.88	2.58	65.8	5.1	7.6	60.7	58.2
HP5476b	Site 100, 30 m	0011	121.7	0.57	2.25	74.7	5.1	9.5	69.6	65.2
HP5476c	Site 100, 45 m	0012	76.1	0.83	2.55	67.3	6.2	8.5	61.2	58.8
HP5477a	Site 101, 15 m	0013	130.7	0.54	2.38	77.3	9.7	12.5	67.6	64.8
HP5477b	Site 101, 30 m	0014	101.1	0.67	2.53	73.4	6.6	9.2	66.8	64.2
HP5477c	Site 101, 45 m	0015	110.4	0.59	2.44	75.7	11.4	14.3	64.3	61.5
HP5525a	Site 11, 15 m	0067	73.3	0.83	2.5	66.8	7.8	10.7	59	56.1
HP5525b	Site 11, 30 m	0068	67.4	0.85	2.47	65.4	4.9	7.8	60.5	57.6
HP5525c	Site 11, 45 m	0069	42.7	0.94	2.5	62.2	13	15	49.3	47.2
HP5526a	Site 49, 15 m	0061	39.1	1.13	2.68	57.9	13.7	15	44.1	42.8
HP5526b	Site 49, 30 m	0062	59.1	0.94	2.6	63.8	7.5	9.6	56.2	54.2
HP5526c	Site 49, 45 m	0063	69.6	0.83	2.55	67.6	10.3	13.1	57.3	54.5
HP5527a	Site 83, 15 m	0058	50.8	0.72	2.43	70.2	18.8	23.9	51.5	46.3
HP5527b	Site 83, 30 m	0059	56.3	0.99	2.54	61.2	6.3	8	54.9	53.2
HP5527c	Site 83, 45 m	0060	49	0.85	2.47	65.6	14.7	16.1	50.9	49.5
HP5528a	Site 40, 15 m	0055	141.2	0.35	1.95	82.1	33.7	37.9	48.4	44.1
HP5528b	Site 40, 30 m	0056	68.8	0.7	2.47	71.5	20.2	21.9	51.3	49.5
HP5528c	Site 40, 45 m	0057	69.3	0.63	2.45	74.3	24.3	27.2	50	47.1
HP5529a	Site 19, 15 m	0049	54.1	0.86	2.57	66.6	12.6	14	54	52.6
HP5529b	Site 19, 30 m	0050	83.5	0.72	2.52	71.3	9.1	10.3	62.2	61.1
HP5529c	Site 19, 45 m	0051	59.8	0.94	2.6	63.8	5.6	6.7	58.2	57.1
HP5530a	Site 39, 15 m	0046	77.5	0.71	2.61	72.9	15.4	19	57.5	53.8
HP5530b	Site 39, 30 m	0047	95.2	0.59	2.41	75.6	21.3	25.6	54.3	50
HP5530c	Site 39, 45 m	0048	44.6	0.97	2.65	63.4	18.1	20	45.3	43.5
HP5531a	Site 45, 15 m	0016	65.5	0.7	2.49	71.9	24.1	25.8	47.9	46.1
HP5531b	Site 45, 30 m	0017	99	0.43	2.36	81.8	35.4	38.9	46.5	42.9
HP5531c	Site 45, 45 m	0018	63.1	0.79	2.47	68	14.1	16.3	53.9	51.7
HP5532a	Site 102, 15 m	0034	74.7	0.76	2.64	71.4	12.5	14.4	58.9	57
HP5532b	Site 102, 30 m	0035	155.8	0.47	2.46	80.8	8	10.6	72.8	70.1
HP5532c	Site 102, 45 m	0036	159.7	0.46	2.33	80.5	7.2	9.4	73.3	71
HP5533a	Site 103, 15 m	0040	107.9	0.59	2.44	75.6	9.6	11.2	66	64.4
HP5533b	Site 103, 30 m	0041	111.5	0.55	2.41	77.2	15.7	17.1	61.4	60.1
HP5533c	Site 103, 45 m	0042	232.3	0.28	2.22	87.2	27.3	31	60	56.2

HP5534a	Site 104, 15 m	0037	81.8	0.78	2.61	70.2	5.6	7.5	64.6	62.7
HP5534b	Site 104, 30 m	0038	72.1	0.84	2.6	67.8	6.6	8.5	61.2	59.4
HP5534c	Site 104, 45 m	0039	72.5	0.84	2.62	68.1	7.4	9.6	60.7	58.6
HP5535a	Site 105, 15 m	0043	34.7	1.24	2.72	54.4	10.4	12.5	44	42
HP5535b	Site 105, 30 m	0044	43.8	1.14	2.75	58.7	9.2	11.9	49.5	46.8
HP5535c	Site 105, 45 m	0045	42.4	1.04	2.79	62.6	17.1	19.7	45.5	43
HP5536a	Site 107, 15 m	0031	58.3	0.9	2.57	65	9.5	11	55.5	54
HP5536b	Site 107, 30 m	0032	84.2	0.7	2.56	72.6	13.4	16.4	59.2	56.2
HP5536c	Site 107, 45 m	0033	80.3	0.66	2.57	74.1	18.4	20.2	55.7	53.9
HP5537a	Site 108, 15 m	0074	72.9	0.77	2.56	69.8	12.7	14.2	57.1	55.6
HP5537b	Site 108, 30 m	0075	65	0.85	2.55	66.8	10.6	12.2	56.2	54.6
HP5537c	Site 108, 45 m	0076	90.1	0.62	2.42	74.3	17	19.3	57.3	55
HP5538a	Site 109, 15 m	0077	78.2	0.8	2.45	67.4	8.5	11.1	58.9	56.3
HP5538b	Site 109, 30 m	0078	53.6	0.83	2.52	67	19.3	20.6	47.7	46.4
HP5538c	Site 109, 45 m	0079	40.5	1.05	2.51	58	11.1	12	46.9	46.1
HP5539a	Site 110, 15 m	0080	72.6	0.87	2.59	66.5	2.7	4.8	63.8	61.7
HP5539b	Site 110, 30 m	0081	53.8	1.02	2.63	61.3	6	8.5	55.3	52.9
HP5539c	Site 110, 45 m	0082	62.8	0.95	2.59	63.4	3.6	5.6	59.8	57.8
HP5540a	Site 111, 15 m	0083	88.2	0.76	2.54	70.3	4.5	6.3	65.8	64
HP5540b	Site 111, 30 m	0084	88.8	0.74	2.56	70.9	5.3	8	65.6	62.9
HP5540c	Site 111, 45 m	0085	83.3	0.81	2.58	68.6	3.6	6.6	65	62
HP5541a	Site 112, 15 m	0086	95.5	0.63	2.38	73.5	13.8	16	59.8	57.6
HP5541b	Site 112, 30 m	0087	101.8	0.5	2.42	79.4	27.8	30.3	51.6	49.1
HP5541c	Site 112, 45 m	0088	79.2	0.81	2.55	68.1	2.4	4.2	65.7	63.8
HP5542a	Site 95, 15 m	0198	50.1	1.04	2.55	59.3	8	9.5	51.4	49.9
HP5542b	Site 95, 30 m	0199	39.7	1.12	2.56	56.3	10.7	12	45.6	44.2
HP5542c	Site 95, 45 m	0200	37.9	1.26	2.57	50.8	5.3	7.1	45.5	43.7

7.3 Archived soil chemical and physical data 1996/2000 for indigenous sites

ARC code	Site number	pH	TC mg/cm^3	TC%	TN mg/cm^3	TN%	AMN ug/cm^3	AMN mg/kg	Olsen P ug/cm^3	Olsen P mg/kg	BD g/cm^3	Macro - 5kPa
ARC96_04	6	5.32	53.0	6.8	3.12	0.40	110	142	4	5	0.78	10
ARC97_03	11	5.35	62.4	7.6	4.02	0.49	112	137	3	4	0.82	19
ARC98_05	17	4.83	56.1	4.8	2.80	0.24	113	96	5	4	1.18	7
ARC98_07	19	5.17	50.8	5.9	2.96	0.34	101	117	3	4	0.86	13
ARC98_24	36	5.18	59.2	6.9	3.78	0.44	93	108	21	25	0.86	13
ARC99_02	39	5.93	56.7	8.3	3.25	0.48	94	138	2	3	0.68	31
ARC99_03	40	5.56	60.9	9.4	2.90	0.45	107	165	2	3	0.65	31
ARC99_08	45	4.13	114.5	13.0	5.66	0.64	85	97	35	40	0.88	12
ARC99_12	49	6.26	62.4	5.9	4.36	0.41	116	109	13	12	1.06	13
ARC99_15	52	5.31	38.6	3.9	1.97	0.20	63	64	5	5	0.99	27
ARC99_19	56	6.55	82.8	11.7	4.66	0.66	167	235	7	10	0.71	15
ARC99_20	57	5.44	77.2	9.3	3.28	0.40	91	110	1	1	0.83	5
ARC00_21	83	5.72	57.8	5.5	2.91	0.28	130	124	38	36	1.05	10
ARC00_23	85	4.54	61.9	5.8	2.84	0.27	61	57	2	2	1.07	10

Appendix 7.4 Trace element concentrations for 2012 indigenous vegetation sites

Element	Site number														
	6	**11**	**17**	**19**	**36**	**39**	**40**	**45**	**49**	**52**	**56**	**57**	**83**	**85**	**97**
Aluminium	19000	13000	15000	10000	6500	11000	33000	17000	8100	4600	12000	8000	10000	8600	3200
Antimony	0.46	0.46	0.46	0.44	0.44	0.45	0.46	0.44	0.45	0.44	0.46	0.45	0.46	0.46	0.46
Arsenic	1.5	3.2	2.4	0.79	2.4	3.5	4.5	4.1	4.4	5.9	2.7	2.6	0.95	1.5	1.2
Barium	43	120	37	8.2	49	92	83	42	260	15	210	130	17	9.7	29
Beryllium	0.15	0.21	0.24	0.018	0.11	0.28	0.42	0.018	0.6	0.12	0.19	0.25	0.018	0.091	0.092
Bismuth	0.091	0.31	0.091	0.089	0.089	0.091	0.21	0.31	0.13	0.089	0.091	0.09	0.091	0.091	0.092
Boron	4.6	6.1	4.6	4.4	4.4	4.5	4.6	4.4	6.9	4.4	6.9	4.9	4.6	4.6	4.6
Cadmium	0.091	0.092	0.091	0.089	0.089	0.091	0.091	0.088	0.33	0.089	0.21	0.09	0.091	0.091	0.092
Calcium	600	3000	2000	490	1300	1300	1600	360	5900	1300	12000	4400	1800	780	1400
Cesium	0.58	2.6	0.13	0.57	0.18	1.1	1.1	1.5	0.15	0.41	0.21	0.63	0.64	0.26	0.092
Chromium	25	12	62	16	4.9	9.3	13	5.2	14	7.5	13	20	7.8	7.4	2.4
Cobalt	8	9	5.1	1.7	2.3	7.7	5.1	0.62	26	2.7	6.3	22	0.77	0.78	0.28
Copper	15	13	23	5.6	6.6	2.9	7.7	5.1	20	2.3	12	10	3.9	7.1	2.3
Gold	0.46	0.46	4.6	0.089	0.89	0.091	0.091	0.088	0.091	0.44	2.3	2.3	0.091	0.91	4.6
Iron	29000	23000	67000	21000	12000	21000	27000	15000	27000	8200	27000	30000	12000	17000	4800

	6	11	17	19	36	39	40	45	49	52	56	57	83	85	97
Lanthanum	5.4	4.1	2	1.6	6.2	13	22	1.5	16	2.4	3.3	12	1.1	2.2	3.1
Lead	5.7	22	12	3.6	6.7	9.9	14	15	31	2.2	8.5	17	6.7	14	5.4
Lithium	6.7	5.4	3.5	1.8	3.8	5.5	9.5	2.2	1.7	7.6	4.2	1.7	2.5	2	0.69
Magnesium	2500	590	1500	440	1000	830	940	270	1600	1400	2700	1900	620	870	410
Manganese	340	1700	600	94	460	3500	800	110	4300	130	500	1900	180	29	38
Mercury	0.081	0.31	0.13	0.13	0.07	0.12	0.33	0.22	0.16	0.044	0.093	0.09	0.13	0.065	0.046
Molybdenum	0.46	0.58	0.46	0.44	0.44	0.45	0.72	0.57	0.45	0.44	0.46	0.45	0.46	0.46	0.46
Nickel	7.3	1.9	4.9	1.6	2.2	2.9	4	1.3	5	3.9	4.5	6.4	1.6	2.6	1.5
Phosphorus	150	300	390	160	300	150	210	150	680	330	730	240	410	140	600
Potassium	430	730	790	330	520	410	530	320	1200	490	1300	560	430	440	570
Rubidium	5.3	8.8	4.7	5.1	6.8	6.9	4	6.3	6.9	5.8	7	8.2	5.2	4.4	4
Selenium	0.79	0.9	0.93	1.2	0.49	0.73	2.5	1.7	0.79	0.18	0.46	0.57	1.1	0.25	0.73
Silicon	2400	5400	2600	5200	2200	5000	5800	5700	5400	1500	3300	2900	5500	2700	3700
Silver	0.46	0.46	0.46	0.44	0.44	0.45	0.46	0.44	0.45	0.44	0.46	0.45	0.46	0.46	0.46
Sodium	180	180	180	180	180	180	200	180	180	180	250	220	180	180	180
Strontium	5.1	54	19	5.5	16	24	35	7.7	69	15	100	63	19	5.5	14
Thallium	1.8	1.8	18	1.8	18	1.8	1.8	1.8	1.8	1.8	18	18	1.8	18	1.8

	6	11	17	19	36	39	40	45	49	52	56	57	83	85	97
Tin	0.69	0.75	0.68	0.67	0.67	0.68	0.99	1	0.68	0.67	0.68	0.68	0.68	0.68	0.69
Tungsten	0.091	0.092	0.091	0.089	0.089	0.091	0.091	0.088	0.091	0.089	0.091	0.09	0.091	0.091	0.092
Uranium	0.36	1	0.47	0.31	0.28	0.43	0.89	0.71	0.7	0.18	0.5	0.31	0.31	0.44	0.3
Vanadium	110	62	150	83	17	45	74	37	65	18	51	66	43	33	11
Zinc	32	44	33	14	14	54	61	22	93	19	32	59	46	9.3	7
Zirconium	2.4	6.5	5.8	1.4	0.44	4.2	13	18	1.4	0.44	1.1	3.5	0.99	2.5	0.46

Element	**Site number**														
	98	**99**	**100**	**101**	**102**	**103**	**104**	**105**	**107**	**108**	**109**	**110**	**111**	**112**	
Aluminium	12000	32000	14000	21000	23000	20000	14000	6200	11000	17000	12000	8000	14000	16000	
Antimony	0.46	0.46	0.45	0.46	0.45	0.45	0.44	0.45	0.45	0.45	0.46	0.44	0.46	0.44	
Arsenic	3.5	4.6	4.3	4.9	0.74	0.96	1.3	3.1	0.94	0.93	1.1	2	2.1	0.79	
Barium	84	21	46	17	9.3	7.9	26	54	14	30	7.8	27	85	9.1	
Beryllium	0.37	0.15	0.15	0.092	0.17	0.09	0.27	0.41	0.11	0.14	0.091	0.053	0.41	0.12	
Bismuth	0.11	0.2	0.14	0.15	0.09	0.15	0.1	0.091	0.12	0.095	0.091	0.088	0.15	0.2	
Boron	4.6	4.6	4.5	4.6	4.5	4.5	7.9	4.8	4.5	5.2	4.6	4.5	4.6	5.2	
Cadmium	0.091	0.092	0.089	0.092	0.09	0.09	0.089	0.091	0.09	0.09	0.091	0.088	0.091	0.089	

	98	99	100	101	102	103	104	105	107	108	109	110	111	112	
Calcium	1100	1300	1600	560	1300	890	2000	1800	1400	1300	330	3500	2600	1300	
Cesium	0.99	1.3	0.47	1.4	0.61	0.73	0.49	0.37	0.94	0.35	0.81	0.19	1.2	0.33	
Chromium	7.6	12	8	8.9	12	9.8	7.5	10	8.1	25	11	17	12	21	
Cobalt	9	2.5	3.5	1.5	3.4	0.96	13	9.5	2.1	3	0.45	0.83	35	1	
Copper	9.5	9.8	16	10	39	11	51	6.5	9.8	11	3.9	9.5	19	5.4	
Gold	4.6	4.6	4.5	4.6	0.09	0.09	0.089	0.091	0.09	0.09	0.091	0.088	0.091	0.089	
Iron	18000	30000	22000	30000	57000	32000	50000	26000	29000	27000	19000	27000	36000	26000	
Lanthanum	6.3	15	17	3.5	4.3	2.2	8.8	13	2.7	5.1	1.2	1.3	4.6	1.3	
Lead	15	15	15	15	15	15	12	6.7	10	15	7	7.5	9	8	
Lithium	12	11	4	6.8	1.6	1.9	2.9	1.6	2.2	2.3	1.2	1.1	1.3	1.1	
Magnesium	2500	1800	1600	1600	2100	830	1500	900	630	1800	360	860	1900	990	
Manganese	780	160	670	200	640	250	1700	700	1400	1200	57	370	2700	92	
Mercury	0.11	0.24	0.12	0.16	0.2	0.22	0.11	0.089	0.2	0.13	0.11	0.19	0.1	0.12	
Molybdenum	0.46	0.69	0.45	0.46	0.45	0.45	0.44	0.45	0.45	0.45	0.46	0.44	0.46	0.44	
Nickel	3.9	3.3	3	2.3	3.5	2.1	2.6	3.6	1.3	3.7	1	1.5	4.7	1.7	
Phosphorus	300	310	400	280	230	100	120	190	160	320	91	340	280	89	
Potassium	810	440	660	390	410	300	480	610	280	300	180	360	340	250	

	98	99	100	101	102	103	104	105	107	108	109	110	111	112	
Rubidium	13	5.4	9	8.3	1.7	1.4	3.9	7.9	1.6	1.9	1.9	1.5	2.5	1.4	
Selenium	0.26	2.2	0.69	1.9	2.7	1.9	1	0.2	2.6	1.1	1.2	0.84	1.1	1.9	
Silicon	2200	2300	2200	2700	6300	6600	6400	4600	5700	5700	5400	4700	6500	7300	
Silver	0.46	0.46	0.45	0.46	0.45	0.45	0.44	0.45	0.45	0.45	0.46	0.44	0.46	0.44	
Sodium	180	180	180	180	290	180	310	180	180	180	180	180	270	180	
Strontium	18	14	20	7.2	16	12	24	18	18	18	4.9	31	35	14	
Thallium	18	18	18	18	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
Tin	0.68	1.1	0.74	0.85	0.67	0.68	0.67	0.68	0.67	0.68	0.68	0.66	0.69	0.66	
Tungsten	0.091	0.092	0.089	0.092	0.09	0.09	0.089	0.091	0.09	0.09	0.091	0.088	0.091	0.089	
Uranium	0.61	1	0.64	0.87	0.83	0.86	0.85	0.33	0.56	0.55	0.47	0.36	0.44	0.49	
Vanadium	44	68	45	62	200	110	210	86	97	55	52	63	64	60	
Zinc	53	24	32	34	42	16	47	78	39	18	12	31	39	17	
Zirconium	0.56	13	1.7	1.9	9.9	7.6	11	1	7.6	2.7	5.2	0.94	2.6	9.9	

7.5 Site and soil type details for all 29 sites sampled

Site	6
Date sampled	10/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic or Mottled Yellow Ultic
Soil type	Whangaripo clay loam
Parent material	Strongly weathered fine sandstone

Sampling/field notes

The site is a privately owned bush lot and was first sampled in 1996. Vegetation included nikau, punga, kiekie and whitey wood.

Site	11
Date sampled	20/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Oxidic Granular or Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash

Sampling/field notes

The site is a privately owned native bush lot that was first sampled in 1997. Vegetation included puriri, rimu, totara, kahikatea, karaka, kauri, punga, titoki, nikau, supplejack and coprosma.

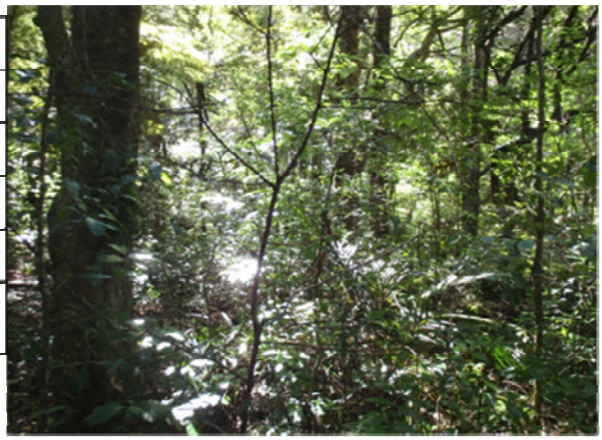
Note: The NZSC prior to 'or' is what was described during the 1995/00 sampling period and subsequent is what has been recently suggested.

Site	17
Date sampled	10/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic
Soil type	Warkworth clay loam
Parent material	Strongly weathered sandstone

Sampling/field notes

The site is a privately owned native bush lot and was first sampled 1996. Vegetation included kanuka, nikau and punga.

Site	19
Date sampled	14/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic
Soil type	Warkworth clay loam
Parent material	Strongly weathered sandstone



Sampling/field notes

The site is located in Warkworth and was first sampled in 1998. Vegetation included nikau, silver fern, hangehange, nikau, taraire, mapou, kanuka, kauri, tanekaha, coprosma (karamu) and totara.

Site	36
Date sampled	07/09/2012
Landuse	Indigenous vegetation
NZSC	Mottled Fluvial Recent or Typic Orthic Allophanic
Soil type	Otao silt loam
Parent material	Volcanic ash over alluvium

Sampling/field notes

The site is privately owned in Coatesville and was first sampled in 1998. Dominant forest vegetation included punga and nikau.

Site	39
Date sampled	09/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Allophanic or Typic Orthic Granular
Soil type	Matakawau clay loam
Parent material	Volcanic ash over weathered dune sand

Sampling/field notes

The site is located in Awhitu peninsula and was first sampled in 1999. Vegetation included celery pine, tall punga, kanuka, young kauri, whiteywood, wetaweta, punga, five-finger and miro.

Site	40
Date sampled	20/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Brown or Typic Sandy Brown
Soil type	Red Hill sandy loam
Parent material	Tephra and weathered dune sand

Sampling/field notes

The site is privately owned in Waiuku and was first sampled in 1999, sampled in 2012. Vegetation included tanekaha saplings, some large kauri, silver fern, rewarewa and taraire.

Site	45
Date sampled	19/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Granular
Soil type	Ararimu clay
Parent material	Volcanic ash over bedded sandstone

Sampling/field notes

The site is located in the Hunua Ranges and was first sampled in 1999. Forest vegetation included celery pine, rimu, mapou and punga.

Site	49
Date sampled	19/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Brown or Typic Yellow Ultic
Soil type	Marua clay loam
Parent material	Greywacke

Sampling/field notes

The site is located in Duders Regional Park and was first sampled in 1999. Vegetation included puriri, karaka, whitey wood, nikau.

Site	52
Date sampled	07/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Sandy Recent
Soil type	Pinaki sand
Parent material	Wind blown dune-sand

Sampling/field notes

The site is privately owned in South Head and was first sampled in 1999. Vegetation included kanuka, fern, pepper tree, pampas grass and tobacco tree.

Site	56
Date sampled	07/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Granular or Typic Oxidic Granular
Soil type	Cornwallis clay
Parent material	Andesitic conglomerate

Sampling/field notes

The site is located near Kaukapakapa and was first sampled in 1999. Vegetation included totara, kanuka, coprosma (karamu), silver fern, punga and titoki.

Site	57
Date sampled	07/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Granular or Typic Mafic Brown
Soil type	Parau clay loam
Parent material	Andesitic conglomerate (Manukau breccia)

Sampling/field notes

The site is a privately owned native bush lot in Waimauku and was first sampled 1999. Dominant vegetation included kauri and punga.

Site	83
Date sampled	14/09/2012
Landuse	Indigenous vegetation
NZSC	Mottled Orthic Brown or Mottled Fluvial Ultic
Soil type	Waitemata complex or Waipuna clay loam
Parent material	Alluvium and colluvium

Sampling/field notes

The site is a privately owned native bush lot and was first sampled in 2000. Vegetation included kuneri, kanuka, totara, kahikatea, rimu, nikau, mapau and silver fern.

Site	85
Date sampled	11/09/2012
Landuse	Indigenous vegetation
NZSC	Mottled Orthic Brown or Mottled Fluvial Ultic
Soil type	Waitemata complex or Albany clay
Parent material	Alluvium

Sampling/field notes

The site is managed by Auckland Council in West Harbour and was first sampled in 2000. Vegetation included punga, hangehange, hook grass, kanuka, and mapou.

Site	97
Date sampled	06/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Mafic Ultic?
Soil type	Marua Brown clay loam
Parent material	Igneous strata within greywacke

Sampling/field notes

The site is located in the Hunua Ranges and was first sampled in 2012. Vegetation included kanuka, pungas, supplejack, rimu, marble leaf (small) and large coprosma (karamu).

Site	98
Date sampled	06/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic
Soil type	Marua clay loam
Parent material	Greywacke

Sampling/field notes

The site is located in the Hunua Ranges and was first sampled in 2012. Vegetation was predominantly punga with emerging kanuka.

Site	99
Date sampled	05/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic
Soil type	Marua clay loam
Parent material	Greywacke

Sampling/field notes

The site is located in the Hunua Ranges and it was first sampled in 2012. The site is 1 km off Plows Road. The site was dominated by punga.

Site	100
Date sampled	06/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic
Soil type	Marua clay loam
Parent material	Greywacke

Sampling/field notes

The site is located in the Hunua Ranges and was first sampled in 2012. Vegetation included cabbage trees, ponga, coprosma (karamu), wineberry and abundant supplejack.

Site	101
Date sampled	06/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Yellow Ultic
Soil type	Marua clay loam
Parent material	Greywacke

Sampling/field notes

The site is located in the Hunua Ranges and was first sampled in 2012. Vegetation included tanekaha saplings, kauri, silver fern, rewarewa and taraire.

Site	102
Date sampled	24/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Granular
Soil type	Waitakere clay
Parent material	Volcanic conglomerate

Sampling/field notes

The site is located in the Waitakere Ranges and was first sampled in 2012. Vegetation included rimu, five finger, punga, kiekie, coprosma (karamu), lancewood, kauri and supplejack.

Site	103
Date sampled	24/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Orthic Granular
Soil type	Waitakere clay
Parent material	Volcanic conglomerate

Sampling/field notes

The site is located in the Waitakere Ranges and was first sampled in 2012. Vegetation included rimu, kiekie, kanuka, miro, kahikatea, mapou, lancewood and coprosma (karamu).

Site	104
Date sampled	24/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Mafic Brown
Soil type	Huia steepland
Parent material	Volcanic conglomerate

Sampling/field notes

The site is located in the Waitakere Ranges and was first sampled in 2012. Vegetation included lots of small koromiko (purple & white flower), lancewood, mapou, manuka, and punga.

Site	105
Date sampled	24/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Mafic Brown
Soil type	Huia steepland
Parent material	Volcanic conglomerate

Sampling/field notes

The site is located in the Waitakere Ranges and was first sampled in 2012. Vegetation included puriri, nikau, mahoe, kanuka, kowhai, pepper tree, supple jack and punga.

Site	107
Date sampled	24/09/2012
Landuse	Indigenous vegetation
NZSC	Mottled Orthic Granular
Soil type	Mottled Waitakere clay
Parent material	Volcanic conglomerate

Sampling/field notes

The site is located in the Waitakere Ranges and was first sampled in 2012. Vegetation included kanuka, rimu, kohuhu, totara, nikau, kiekie, grass sedge, lancewood, puriri, and hinau.

Site	108
Date sampled	17/09/2012
Landuse	Indigenous vegetation
NZSC	Weathered Orthic Recent
Soil type	Te Kie steepland
Parent material	Andesite

Sampling/field notes

The site is located in Fern Hill in Great Barrier Island and was first sampled in 2012. Forest vegetation included silverfern, punga, kohekohe, coprosma (karamu), whiteywood, supplejack and kanuka.

Site	109
Date sampled	17/09/2012
Landuse	Indigenous vegetation
NZSC	Weathered Orthic Recent
Soil type	Te Kie steepland
Parent material	Andesite

Sampling/field notes

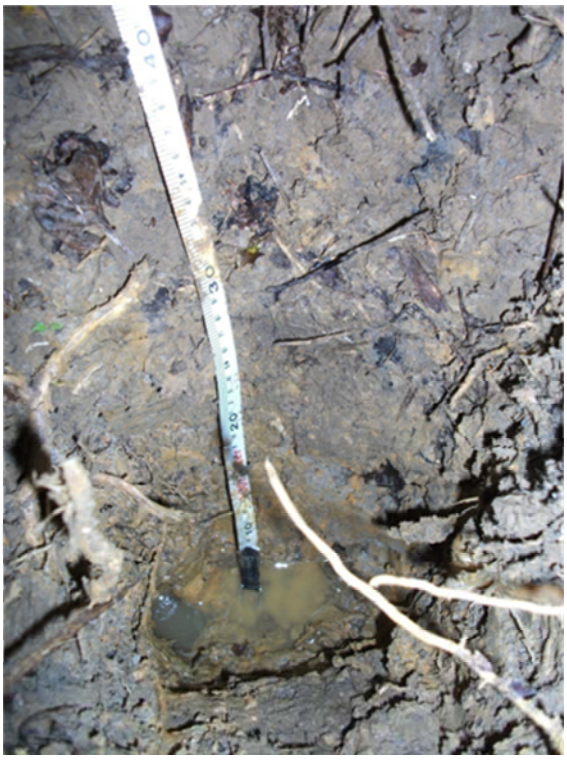
The site is privately owned land located in Great Barrier Island and was first sampled in 2012. Forest vegetation included kanuka kauri seedling, mapou, celery pine, totara, rimu, tanekaha, mapou and kohuhu.

Site	110
Date sampled	18/09/2012
Landuse	Indigenous vegetation
NZSC	Typic Mafic Brown
Soil type	Awapuku clay loam
Parent material	Andesite

Sampling/field notes

The site is located in Great Barrier Island and was first sampled in 2012. Forest vegetation included kanuka, pohutukawa, kohekohe, nikau palm, punga, taraire, kawakawa, hangehange, mapau, kowhai and coprosma (karamu).

Site	111
Date sampled	17/09/2012
Landuse	Indigenous vegetation
NZSC	Mottled Mafic Brown
Soil type	Awapuku clay
Parent material	Andesite



Sampling/field notes

The site is located in Great Barrier Island and was first sampled in 2012. Forest vegetation included nikau, mapou, taraire, silver fern, hangehange, lacebark. Farming ended in the 1960's at this location.

Site	112
Date sampled	17/09/2012
Landuse	Indigenous vegetation
NZSC	Weathered Orthic Recent or Weathered Mafic Recent
Soil type	Te Kie steepland
Parent material	Andesite

Sampling/field notes

The site is located in Fern Hill in Great Barrier island and was first sampled in 2012. Forest vegetation included kauri, akiraho, rimu, silver fern, kanuka, toropapa.