Land Environments of New Zealand:

A Technical Guide

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For further information on the environmental classification system described in this publication, please contact Landcare Research New Zealand Limited, Private Bag 3127, Hamilton, New Zealand, www.landcareresearch.co.nz.

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Fraser Morgan is a GIS/Spatial Analyst with broad interests in spatial modelling, 3D visualization and internet mapping. Fraser contributed to the development of the analyses behind the LENZ classification, the preparation of statistical summaries and the creation of the companion website. His major tasks have been leading the preparation of the Technical Guide and writing the environment descriptions.

Gareth Wilson is a spatial ecologist/GIS analyst with interests in ecological and resource management, environmental impacts, and biotic patterns. Gareth's responsibilities in this project included generating the underlying spatial data and the LENZ classification layers, production of maps, graphics and 3D images, and preparation of the case studies.

Daniel Rutledge is an ecologist with interests in broad-scale ecological questions related to landscape dynamics, biodiversity conservation and sustainability, and in modeling ecological systems. Daniel contributed substantially to the preparation of both volumes through his role both in overseeing and contributing to the development, external review, and revision of text and graphical material.

Malcolm McLeod is a soil scientist who worked for the Department of Scientific and Industrial Research (DSIR) before joining Landcare Research at its inception. He has particular interests in the mapping and description of soils, including use of new technologies such as remotely sensed data. Malcolm led the development of the GIS layers describing soil attributes used in the land environments classification.

Kirsty Johnston is a senior policy analyst with the Ministry for the Environment where she has played a leading role in the development of their Environmental Performance Indicators Programme. Her major contributions to LENZ have been the management of interactions between the Ministry and Landcare Research, and championing the use of spatial classifications as tools for environmental monitoring and reporting.

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Contents

CHAPTER ONE
Introduction

WHAT IS LAND ENVIRONMENTS OF NEW ZEALAND?

This Technical Guide and a parallel volume, Land Environments of New Zealand, describe an environmental classification of New Zealand that is designed to provide a framework for addressing a range of conservation and resource management issues. This classification has been produced by Landcare Research with funding and support from the Ministry for the Environment. While the role of Landcare Research staff in this project reflects their interests in providing robust tools for conservation management, the objectives of the Ministry for the Environment focus more on the provision of tools to underpin indicator-based monitoring of the state of New Zealand's environment.

In large measure, the production of Land Environments of New Zealand (or LENZ) reflects a wider global trend towards ecosystem-oriented approaches to resource management. In New Zealand, this trend is evident in the prominence given to ecosystems and their integrated management in legislation such as the Environment Act (1986) and the Resource Management Act (1991). The New Zealand Department of Conservation is also embracing this trend through their development of an overarching natural heritage framework to facilitate more robust and accountable management of the assets for which it is responsible. Chapter One of Land Environments of New Zealand contains a more extended discussion of related conceptual issues and the consequent need for ecosystem-based classifications of New Zealand's landscapes.

Distinctive Features of LENZ

Two main features distinguish LENZ from previous ecological classifications of New Zealand. The first of these is its use of numerical data layers describing various aspects of New Zealand's climate, landforms and soils. These variables were selected using results from an extended study of relationships between New Zealand's forest pattern and environment. This involved use of an extensive set of plot data describing forest composition, which was coupled with estimates of climate derived from long-term meteorological station data, and soil attributes derived mostly from the New Zealand Land Resource Inventory. In a series of analyses, the environmental variables used to predict forest pattern were progressively refined, allowing a final set of variables for use in LENZ to be chosen on both functional and statistical grounds. Chapter Two of Land Environments of New Zealand discusses these variables in-depth and why they were selected, while Chapter Two of this volume describes the methods used to derive each variable and their consequent reliability. The rationale for focussing on variables relevant to forest trees and the resulting implications for using LENZ with other biotic groups are addressed in Chapters Three and Five of this volume.

The second point of difference between LENZ and previous classifications of New Zealand landscapes is its use of a computerised classification procedure that is described in Chapter Three of both Land Environments of New Zealand and this volume. One important feature of classifications defined using this approach is their ability to identify similar environments, including small distinctive environments that are otherwise easily overlooked, regardless of their geographic location. Other benefits stem from the hierarchical nature of such classifications, which allows results to be displayed at widely varying levels of detail, in turn facilitating their use over a wide range of map scales (in this case 1: 5 000 000 to 1: 50 000). While the classification can be viewed at varying levels of detail, LENZ is presented at four standard levels of classification detail (I-VI) that have been selected for documentation, these containing 20, 100, 200 and 500 environments nationally. Detailed descriptions of Level I environments are contained in Chapter Four of Land Environments of New Zealand, while the remaining levels are described in Chapter Four of this volume.

Case Studies

To encourage uptake by conservation and resource managers, case studies are presented that demonstrate practical applications of LENZ. The cases studies address a range of resource management issues including loss and fragmentation of indigenous ecosystems, ecological restoration of degraded sites, assessment of biosecurity risks both within and outside New Zealand, and the identification of sites having suitable climates for high value crops. Chapter Five of Land Environments of New Zealand contains detailed descriptions of the case study results, while Chapter Five of this volume provides broader guidelines for the use of LENZ and its underlying data layers, and outlines the methods used to develop the case studies and any corresponding technical issues. The applications presented were developed using ESRI®'s ArcView® 3.2 and its accompanying Spatial Analyst extension; however, any geographic information system capable of raster processing could be used to produce similar results.

Availability of LENZ

In contrast to previous classifications, LENZ is designed primarily for electronic use; Land Environments of New Zealand and this volume are currently its only printed products. This development is made possible by both the enormous growth in the power of desktop computers and the increasing availability of user-friendly geographic information systems. Together, these allow the flexible and powerful combination of geographic data from a wide range of sources, in turn enabling managers to quickly assemble custom maps to expedite a range of management activities as illustrated in Chapter Five. For details concerning the availability of LENZ contact:

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For information about the Ministry for the Environment's use of LENZ in environmental reporting or policy work contact:
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CHAPTER TWO
The underlying data layers

INTRODUCTION

This chapter describes the environmental layers used in the creation of LENZ, including technical definitions of the various layers, methods used to create them, and assessments of their accuracy. Chapter Two of *Land Environments of New Zealand* provides a broader discussion of both our rationale for choosing them and their individual effects on biological distributions.

THE LENZ CLIMATE LAYERS

Lack of reliable climate data at sites remote from meteorological stations has often frustrated the ability of ecologists to relate their observations of species distributions to climate factors such as temperature, solar radiation and rainfall. In the absence of such data, many studies have used measures of geographic location such as latitude and elevation as surrogates for climate. Substantial progress has been made over the last two to three decades in the development of techniques for interpolating climate statistics, mainly through use of mathematical surfaces fitted to meteorological station data.[1] This has in turn made it much easier to estimate reliably climate parameters for ecological studies at sites distant from meteorological stations, and enables indirect measures such as latitude and elevation to be replaced with explicit data describing climatic factors that are directly relevant to biota.

All seven climate layers used in LENZ were derived either directly or indirectly from mathematical surfaces (thin-plate splines) that use information about the climate, location and elevation of a number of meteorological stations. Locations are described either in terms of their latitude and longitude or their coordinates on a map projection such as the New Zealand Map Grid (NZMG). Each surface is calculated using a process in which data values for each climate station are omitted in turn and its climate is predicted from the surrounding stations. This process is repeated until no further improvement can be made to the fit of the surface to the raw data. Surfaces can be simultaneously fitted to up to 12 variables, typically monthly data for various climate parameters, e.g., monthly estimates of temperature or rainfall. An important measure derived from this process is the generalised cross validation (GCV) that indicates the average deviation of the actual station values from those predicted from the surrounding stations. This provides a robust measure of the overall fit of the surface to the underlying data.

In some cases, the fit of a surface can be improved through use of additional information that is relevant to the variable being predicted. For example, in creating vapour pressure deficit and rainfall surfaces for New Zealand, a measure of east-west topographic protection derived by analysis of a national digital elevation model (D. Giltrap, unpublished data) was used. Similarly, when fitting the solar radiation surface, measurements of humidity were used as an indicator of cloudiness, substantially improving its generalised cross validation values.

Once the surface has been fitted, predictions can be made for any point of known location and elevation. For example, coupling the surface with a digital elevation model, a regular grid of elevation values, allows the generation of digital climate maps as used in the creation of LENZ. Finally, maps that show the standard errors of the predicted values can be derived using results from more sophisticated analyses of the errors associated with the climate surfaces.[2]

The majority of the climate station data used in the development of our climate surfaces were derived from summaries of climate observations published by the New Zealand Meteorological Service.[3] Temperature and rainfall data were collected over the period from 1950 to 1980, while data describing humidity and solar radiation consisted of averages of all data collected up until 1980. Some additional short-duration records of rainfall, including information from storage rain gauges, were used to describe geographic variation in high-rainfall mountainous areas of the South Island. Details of any other processing required to create the LENZ climate layers, either before or after fitting the climate surfaces, are described in the following sections.

Mean annual temperature

The LENZ layer describing mean annual temperature was derived directly from a thin-plate spline surface fitted to data from 300 meteorological stations. Following conventions used in the calculation of climate summary statistics, the values used to fit the surface consisted of the mean of the 12 monthly averages for daily average temperature. Standard errors about the predictions are mostly less than 0.35ºC, but errors generally increase with increasing elevation (Fig. 2.1), reflecting the paucity of climate records from montane environments.

Table 2.1: Annual temperature statistics

Number of data points	300
Period over which climate data collected	1950–1980
Predictor variables	NZMG coordinates, elevation
Meteorological station data – mean	12.03 ºC
– standard deviation	2.03 ºC
Generalised cross validation statistic	0.42 ºC
LENZ data layer – mean	10.1 ºC
– range	-6.9–16.2 ºC
– standard deviation	2.9 ºC

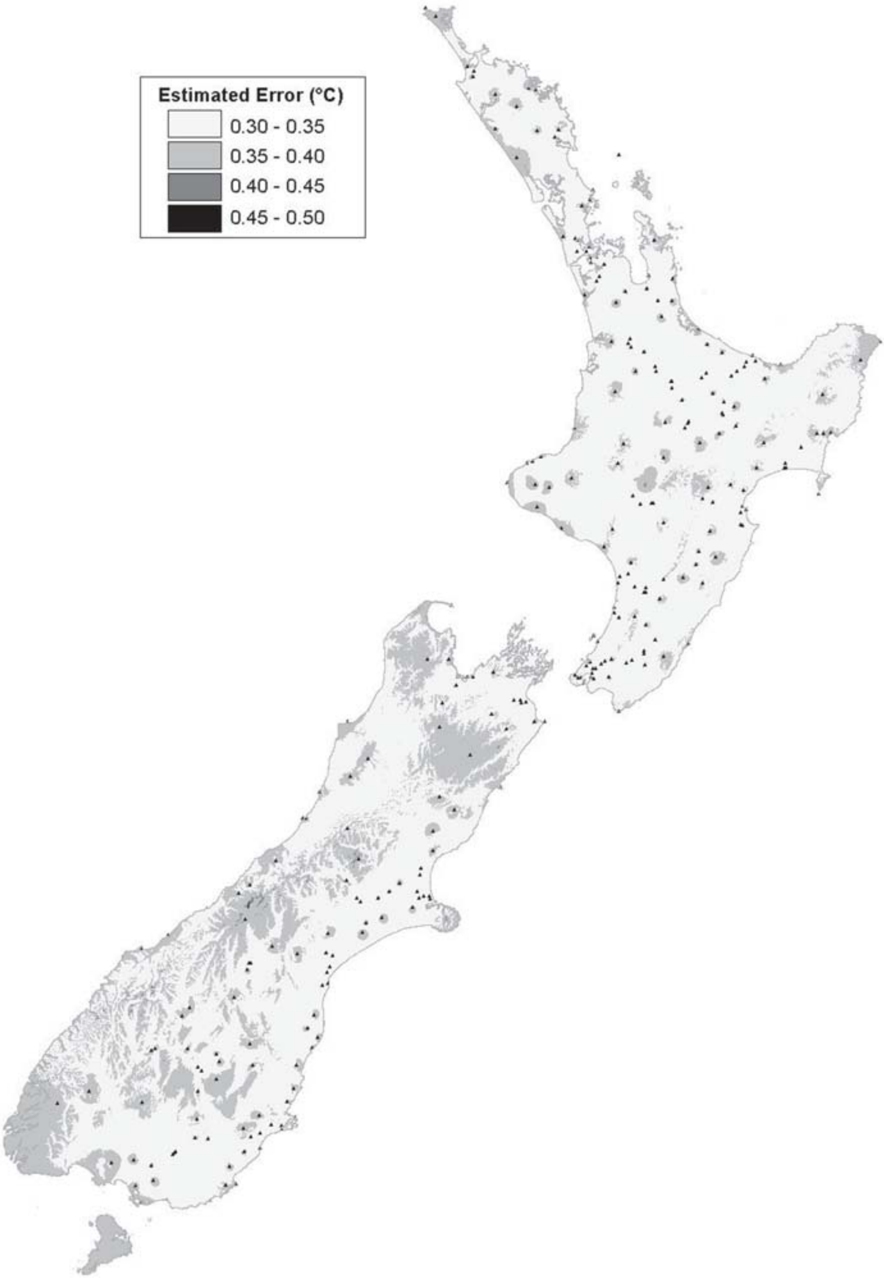


Figure 2.1: Geographic variation in the standard errors of the predictions of mean annual temperature used in LENZ. Triangular symbols indicate the locations of the meteorological stations used in fitting the climate surface.

Mean minimum temperature of the coldest month

Estimates of the mean minimum temperature in July, the coldest month of winter, were derived from a surface fitted to monthly estimates of mean daily temperatures. The generalised cross validation errors for this surface are higher than for the annual temperature surface, reflecting the greater difficulty in predicting minimum temperatures, which are more sensitive to local topographic effects during nocturnal temperature inversions. Such effects reach a maximum in winter, as reflected in the high GCV value for July minimum temperatures. As a consequence of these difficulties, standard errors associated with predictions of minimum winter temperatures (Fig. 2.2) are also higher than for mean annual temperature but show similar geographic variation.

Table 2.2: Minimum temperature statistics

Number of data points	346
Period over which climate data collected	1950–1980
Predictor variables	NZMG coordinates, elevation
Meteorological station data – mean	2.51 ºC
– standard deviation	2.92 ºC
Generalised cross validation statistic	Average for 12 months – 0.86 ºC GCV for July – 1.00 ºC
LENZ data layer – mean	0.86 ºC
– range	-9.6–10.2 ºC
– standard deviation	3.0 ºC

Figure 2.2: Geographic variation in the standard errors of the predictions of mean minimum temperature of the coldest month used in LENZ. Triangular symbols indicate the locations of the meteorological stations used in fitting the climate surface.

Mean annual solar radiation

Development of surfaces for annual and monthly solar radiation required substantially more data preparation than for the other climate surfaces, reflecting the small number of stations at which solar radiation has traditionally been measured. Monthly estimates of average daily solar radiation to 1980 were available for 22 meteorological stations, but measurements of sunshine hours were available for a total of 98 stations, including 18 of the stations for which solar radiation measurements were available.

To extract as much information as possible from these data, a surface was fitted first that predicted for each month the ratio of solar radiation reaching the earth's surface to that reaching the top of the atmosphere, with the latter calculated from solar geometry equations. In fitting this surface, only the 18 data points where measurements were made of both solar radiation and sunshine hours were used. In addition to NZMG coordinates, it used as an additional predictor the ratio of measured sunshine hours for each month to the maximum possible sunshine hours given no cloud. This surface was then used to estimate the monthly solar radiation received at each of the 80 sites for which measurements of sunshine hours alone were available.

Using a total of 98 sites for which solar radiation data were either measured directly or estimated from sunshine hours, surfaces predicting annual and monthly solar radiation were then fitted. In fitting similar surfaces in Australia, rainfall data has been used as a surrogate measure of cloudiness to improve the fit of the surface to the underlying data.[4] When this approach was tried with New Zealand data it was found to degrade rather than improve the surface fit. After exploring alternative predictors, it was found that data describing monthly humidity[5] substantially improved the surface predictions in all months. This also increases the local accuracy of the surface predictions, as the number of meteorological stations used to fit the humidity surface is more than three times greater than the number of sites used to fit the solar radiation surface.

Standard errors of the predictions of mean annual solar radiation (Fig. 2.3) are mostly less than 0.25 MJ/m^2/day but increase in the southwest of the South Island and about East Cape.

Table 2.3: Annual solar radiation statistics

Number of data points	98
Period over which climate data collected	Averages to 1980
Predictor variables	NZMG coordinates, humidity
Meteorological station data – mean	14.2 MJ/m^2/day
– standard deviation	0.95 MJ/m^2/day
Generalised cross validation statistic	0.36 MJ/m^2/day
LENZ data layer – mean	13.9 MJ/m^2/day
– range	11.5 – 15.5 MJ/m^2/day
– standard deviation	0.93 MJ/m^2/day

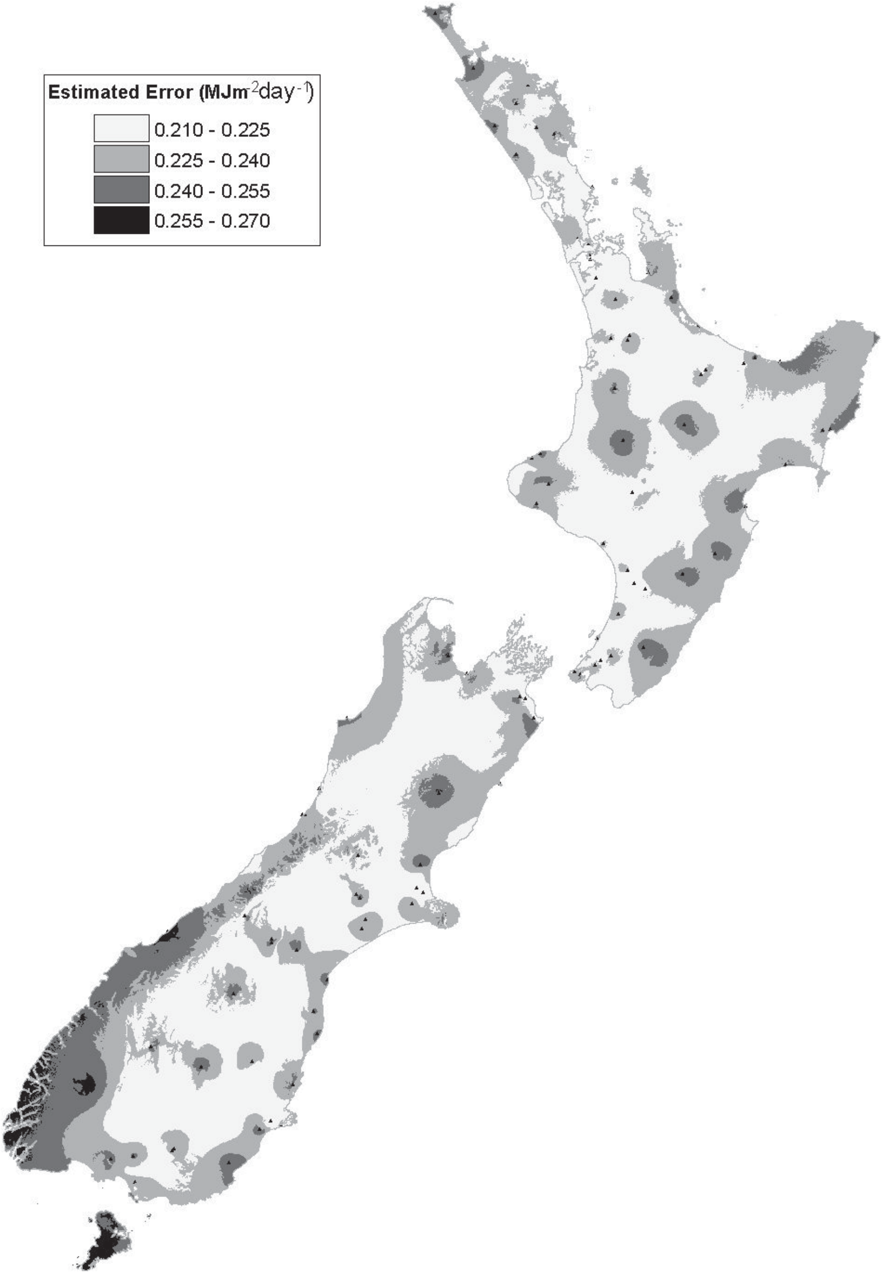


Figure 2.3: Geographic variation in the standard errors of the predictions of mean annual solar radiation used in LENZ. Triangular symbols indicate the locations of the meteorological stations used in fitting the climate surface.

Winter solar radiation

Estimates of winter solar radiation across New Zealand were derived from a surface fitted to monthly solar radiation estimates for 98 sites as described for annual solar radiation. Winter solar radiation reaches a minimum in June, the month when the sun is lowest in the sky and day lengths are at their shortest. Standard errors for predictions of winter solar radiation (Fig. 2.4) are higher than for annual solar radiation, with highest values occurring on the South Island's West Coast and about Wellington.

Table 2.4: Winter solar radiation statistics

Number of data points	98
Period over which climate data collected	Averages to 1980
Predictor variables	NZMG coordinates, humidity
Meteorological station data – mean	5.6 MJ/m^2/day
– standard deviation	0.92 MJ/m^2/day
Generalised cross validation statistic	0.20 MJ/m^2/day
LENZ data layer – mean	4.61 MJ/m^2/day
– range	2.7–7.1 MJ/m^2/day
– standard deviation	0.93 MJ/m^2/day

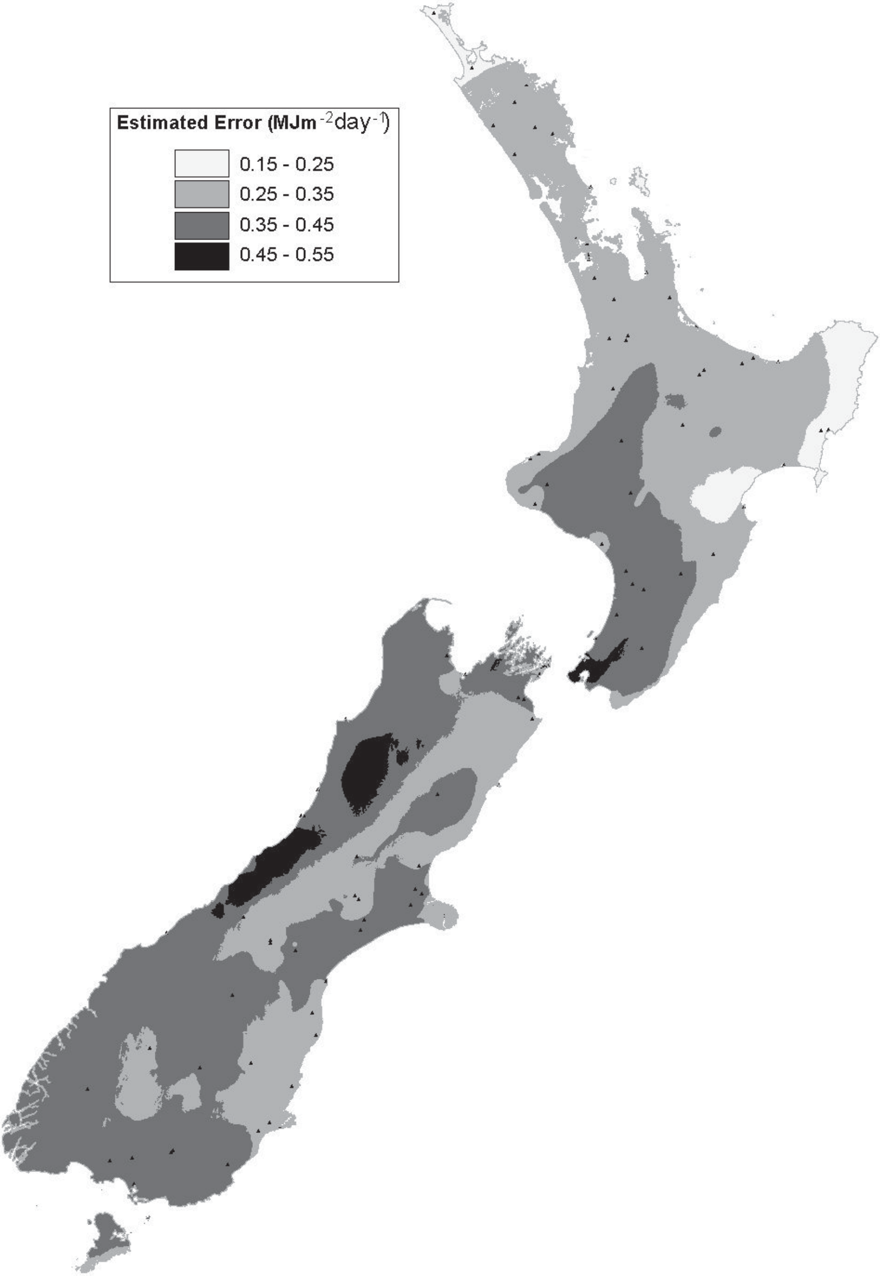


Figure 2.4: Geographic variation in the standard errors of the predictions of mean winter solar radiation used in LENZ. Triangular symbols indicate the locations of the meteorological stations used in fitting the climate surface.

October vapour pressure deficit

Estimates of the vapour pressure deficit for each month were derived from measurements of humidity and temperature made at 287 meteorological stations. Calculation of the vapour pressure deficit first required estimation of the temperature at 0900 hours, the time at which humidity measurements are made. This was calculated from the measured mean daily minimum and maximum temperatures for each month using a function that simulates the temperature course through the day.[6] The estimated temperature at 0900 hours was then used to calculate the saturation water vapour pressure (*e*)[7] , which indicates the maximum amount of water vapour able to be held in the air given its temperature. As the relative humidity (*RH*) indicates the percentage of this maximum that is actually occupied, the vapour pressure deficit (ð*e*) can then be calculated as

$$ðe = \frac{100 - RH}{100} \times e$$

Vapour pressure deficits in October were used in LENZ as this is the month when westerly winds are generally most persistent, resulting in strong geographic variation in vapour pressure deficits across New Zealand. Standard errors associated with predictions of October vapour pressure deficits (Fig. 2.5) are mostly less than 0.05 kPa but increase at higher elevation, particularly in the South Island.

Table 2.5: Vapour pressure deficit statistics

Number of data points	287
Period over which climate data collected	Averages to 1980
Predictor variables	NZMG coordinates, topography, elevation
Meteorological station data – mean	0.39 kPa
– standard deviation	0.09 kPa
Generalised cross validation statistic	Average for 12 months – 0.057 kPa October – 0.053 kPa
LENZ data layer – mean	0.33 kPa
– range	0.0–0.66 kPa
– standard deviation	0.12 kPa

Figure 2.5: Geographic variation in the standard errors of the predictions of October vapour pressure deficits used in LENZ. Triangular symbols indicate the locations of the meteorological stations used in fitting the climate surface.

Annual water deficit and monthly water balance ratio

Three sets of 12 monthly climate estimates were used to calculate geographic variation in annual water deficits and monthly water balance ratios across New Zealand. These were derived from surfaces fitted to monthly data describing daily average temperature, daily solar radiation and monthly rainfall. The rainfall surface was fitted using NZMG coordinates, elevation, and a model describing relationships between topography and westerly winds. Having derived the 36 input climate layers, an empirical model[8] was first used to calculate the monthly potential evaporation from the monthly estimates of solar radiation and temperature. These estimates of evaporation were then compared with the monthly rainfall estimates. Where the rainfall exceeded evaporation, the monthly deficit was assumed to be zero, but where monthly evaporation exceeded monthly rainfall, the shortfall was accumulated through the year to derive an estimate of the annual water deficit. To calculate the monthly water balance ratio, the ratio of rainfall to evaporation was computed for each month, and then the average of these twelve ratios was calculated. Because of conceptual difficulties in combining the errors of the contributing surfaces, no estimates have been made of the likely errors associated with the resulting water deficit and water balance ratio layers. Because of the alternative method used to fit a surface to the large number of data points used to fit the rainfall surface (Fig. 2.6), it was not possible to map spatial estimates of uncertainties associated with the estimates of rainfall, although GCV values (Table 2.6) indicate that these are typically around 10% of the monthly mean rainfall. Errors for the temperature and solar radiation surfaces are illustrated in the previous descriptions of temperature and solar radiation layers.

It should be noted that this approach to calculating water deficits could be extended by calculating losses of water by evaporation and inputs from rainfall on a daily basis and/or by making allowance for the buffering effects of soil water storage.[9] Although use of such models would be desirable in LENZ, given their greater precision, they require more reliable descriptions of soil attributes than are currently available. They are also much more computationally demanding than the model used here. Further improvements could also be made by taking account of the effects of geographic variation in vegetation cover on both the interception of rainfall and the evaporation of water. In this case, a choice would have to be made between using a description of current vegetation cover or of potential vegetation cover, i.e. that expected in the absence of human modification.

Table 2.6: Water deficit and water balance ratio statistics

Number of data points	Solar radiation – 98 Temperature – 346 Rainfall – 2202
Period over which climate data collected	Solar radiation – to 1980 Temperature – 1950–1980 Rainfall – 1950–1980
Predictor variables	Solar radiation – NZMG coordinates, humidity Mean temperature – NZMG coordinates, elevation Rainfall – NZMG coordinates, topography, elevation
Generalised cross validation statistic (average of 12 monthly values)	Solar radiation – 0.45 MJ/m^2/day Temperature – 0.50 °C Rainfall – 16.7 mm
LENZ data layer – mean	Annual water deficit – 36.2 mm Monthly water balance ratio – 4.73
– range	Annual water deficit – 0–396 mm Monthly water balance ratio – 0.6–48.8
– standard deviation	Annual water deficit – 56.9 mm Monthly water balance ratio – 4.15

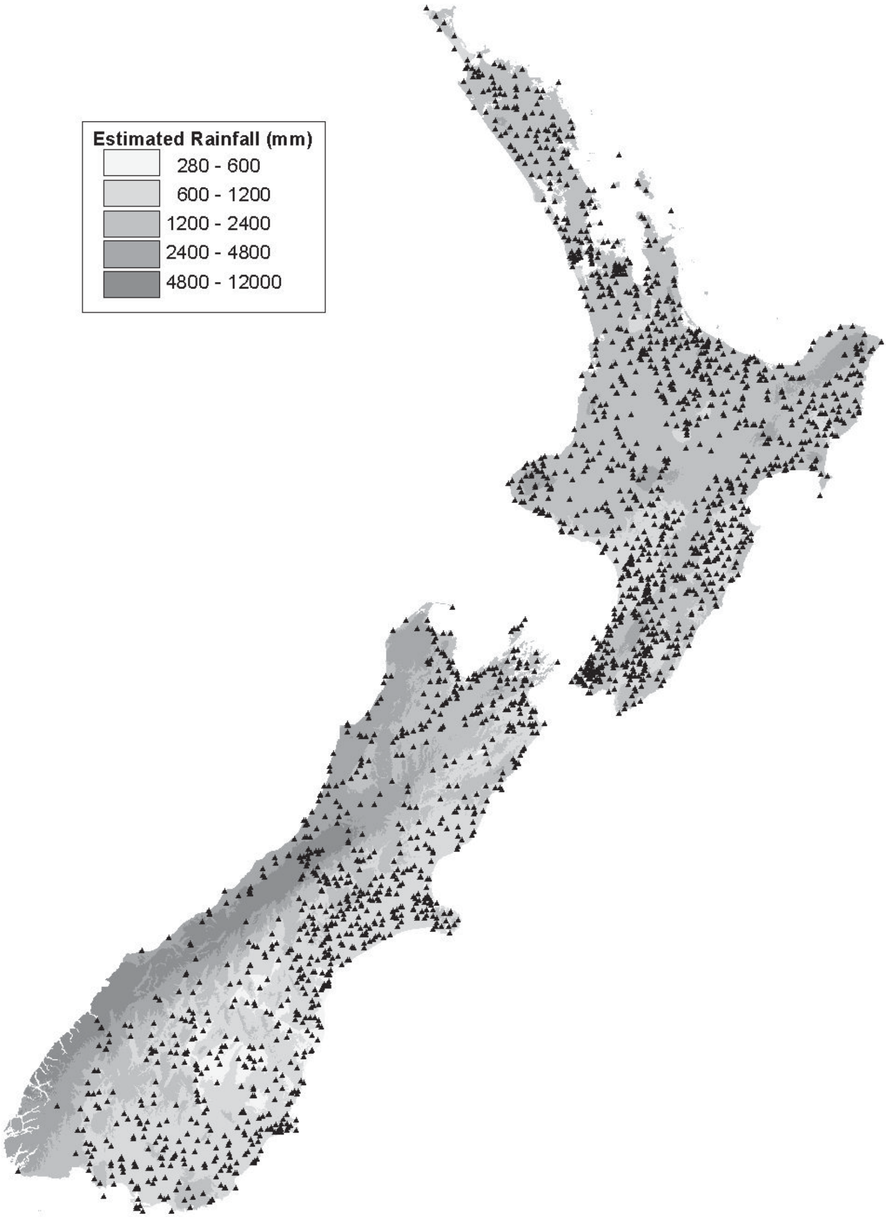


Figure 2.6: Distribution of rainfall stations underlying the rainfall surface used in the estimation of annual water deficits and monthly water balance ratios. Shading shows variation in mean annual rainfall.

THE LENZ SLOPE LAYER

The slope data layer used in LENZ was created from a 25-metre digital elevation model (DEM) fitted to 20-m digital contour data derived from New Zealand's NZMS 260 map series using in-house software developed at Landcare Research. All contours were originally derived photogrammetrically from stereo photographs for final map reproduction at a scale of 1: 50 000. Additional intermediate contours and spot heights were used in generating the DEM where available, while coastlines and shorelines (for lakes greater than 10 ha in extent) were used to constrain the DEM surface around water bodies. The linear interpolation method used to create the DEM threads contours through the cells before interpolation so that any cell intersected by a contour will be given the elevation value of that contour, leading to a high percentage of cells with elevations that are multiples of 20 or 10 in steep areas.

The accuracy of the DEM was assessed using over 2500 independent geographic positioning system (GPS) data points (Landcare Research unpublished data) taken from locations throughout the South Island. All GPS data were collected using a Trimble Pro XL system, post-processed to (nominally) sub-metre accuracy in all three dimensions. Results of this analysis indicate a mean elevation error for the DEM of 0.41 m and standard error of 6.13 m (Landcare Research unpublished data).

Because of storage limitations, the slope layer was created from an integer version of the DEM. Smoothing of the DEM followed by storage of the resulting layer as real numbers would have reduced the number of slope artefacts created by the 1 m steps in the integer DEM, particularly in extensive areas of low slope, but the working data layers would have required substantially more disk storage than was available.

An initial slope layer was produced from a filtered DEM layer in which a 5 x 5 cell averaging filter was used to provide a smoothed elevation surface. A selective filtering procedure was then used in which values on this smoothed surface were first converted from degrees to dy/dx tangent values, expanding the slope scale on low slopes. This transformed layer was also subject to a 5 x 5 cell averaging filter, with greatest filtering occurring in areas of low slope. Finally, the filtered layer was converted back to degrees and a bilinear interpolation filter was used to resample the 25 m slope layer to 100 m resolution. Both the 25 m and 100 m slope layers are stored as integers, i.e. they record slopes rounded to the nearest degree. No assessment has been made of the errors associated with the slope layer.

Table 2.7: Slope statistics

LENZ data layer – mean	12.2 ^{o}
– range	0–67 ^{o}
– standard deviation	10.9 ^{o}

THE LENZ SOIL LAYERS

Accuracy and reliability of the LENZ soil layers

Accuracies associated with the LENZ soil data layers were much more difficult to quantify than for the climate layers. For the latter, data were generally derived from a single source, and errors were quantified as part of the interpolation process used to model climate variation across the country. By contrast, derivation of soil values relied on mapped data of widely varying quality and resolution, coupled with limited measurements of soil chemical and physical attributes. The following material first describes the two major data sources, the New Zealand Land Resource Inventory and the New Zealand Soils Database, on which the LENZ soil layers are based. Consideration is then given to the likely errors associated with these databases and how they might be improved.

The New Zealand Land Resource Inventory

All seven layers used to describe soil attributes in LENZ rely heavily on data from the New Zealand Land Resource Inventory or NZLRI database. This national database, development of which started in the 1970s, describes New Zealand's land resources with the objective of improving patterns of land use. It is based on field mapping at a map scale of 1: 63 360, with units mapped according to variation in five factors: rock type, soils, slope, erosion and vegetation.[10] Additional polygons within the NZLRI identified areas such as lakes and rivers, riverbeds, quarries and opencast mines. Data collected during this inventory were subsequently stored in a Geographic Information System (GIS) database, and provide the most comprehensive and detailed mapping of New Zealand's soil resources currently available in a unified source.

Spatial variation in the quality of soil mapping stored in the NZLRI database depended largely on the availability of soils maps at the time of field survey. Over large areas, and particularly in areas less favourable for agricultural use, soil units mapped in the NZLRI are taken from national soil maps produced at a scale of 1: 253 440 (Fig. 2.7). However, soils had been mapped at greater detail in many areas with high agricultural potential, providing a more comprehensive basis for soil mapping during the NZLRI field inventory. In total, soils data were drawn from approximately 40 different soil surveys in the North Island, while around 20 were used to underpin survey in the South Island.

Recent work by Landcare Research scientists has resulted in continued improvement and enhancement of the NZLRI database. For example, substantial improvements have been made over the last decade in the quality of land resource mapping in Northland, Wellington, central and southern Marlborough and the Gisborne District. In producing the underlying data layers for use in LENZ, Landcare Research scientists also extended the coverage of soil parent material mapping to include towns and cities using published soil survey reports, geological maps and other miscellaneous data. In some lowland areas, higher resolution soil maps have been produced since the NZLRI inventory, but this information has yet to be incorporated into a single, nationally consistent dataset such as the NZLRI.

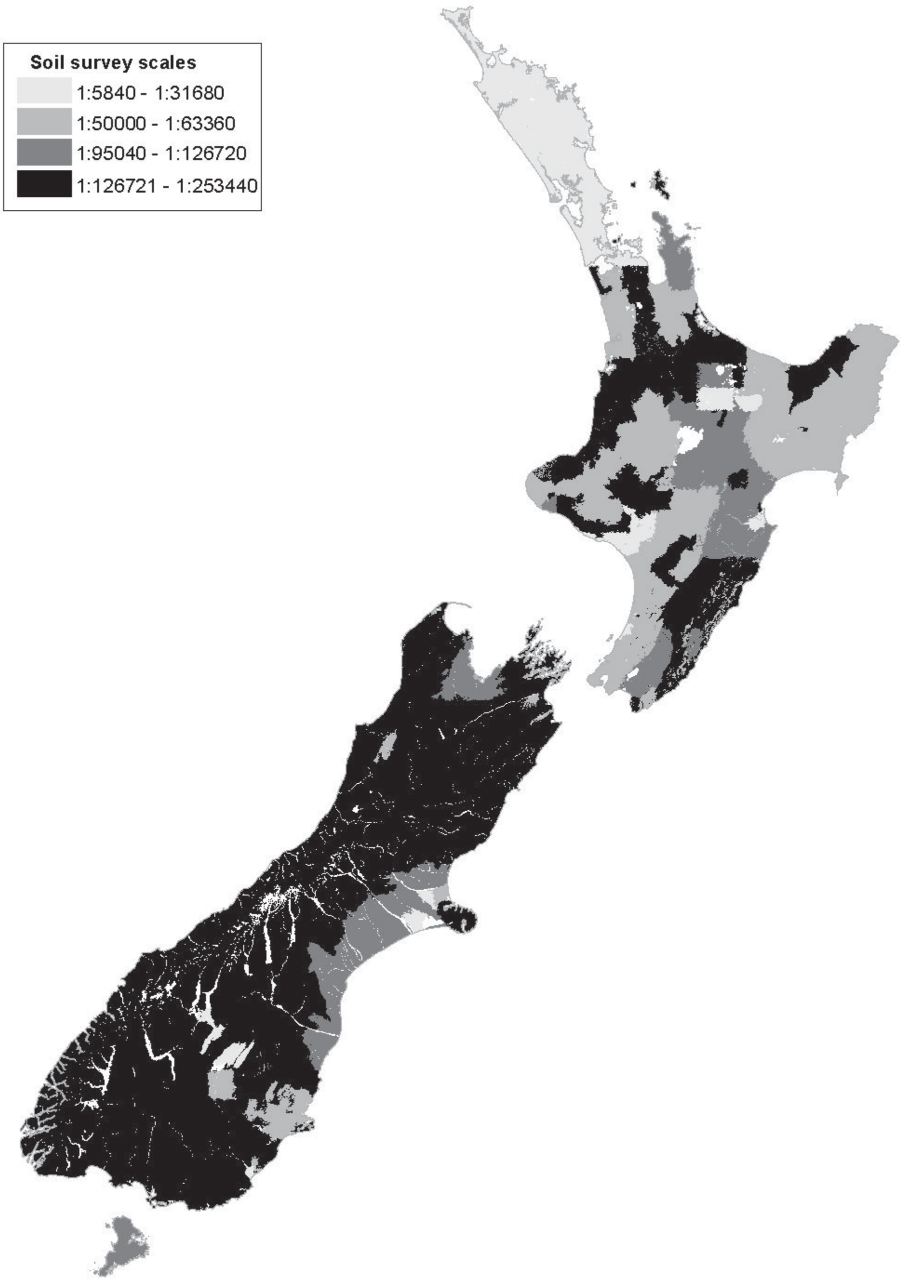


Figure 2.7: Geographic scales of underlying soil survey maps used in field survey for the New Zealand Land Resource Inventory.

Other work has concentrated on the development of a new classification for New Zealand's soils[11] that is based on their observed properties rather than their presumed genesis as in the preceding national classification. The New Zealand Soil Classification arranges soils in a hierarchical fashion where the coarsest level distinguishes 15 Orders, while more comprehensive levels describe Groups and Subgroups. All soil units mapped in the NZLRI database have been subsequently allocated to orders, groups and subgroups in this new classification. Lastly, by drawing on data contained in reports associated with the soil surveys underlying the NZLRI inventory, Landcare Research scientists have assembled an extended range of soil attribute data for all soil units mapped in the NZLRI. This includes descriptions of the physical and chemical attributes of each soil along with estimates of data reliability.

The National Soils Database

The National Soils Database (NSD) provided much of the remaining information used in the development of the LENZ soils layers. This contains results from analyses of the chemical and physical properties of soil samples from nearly 1500 sites throughout New Zealand (Fig. 2.8). Analyses from sub-soil samples, where effects of fertiliser application are generally minimal, provided invaluable descriptions of the natural fertility of soils formed on different parent materials as described below.

Issues of data reliability

Many of the problems associated with the inconsistent mapping of soils in the NZLRI database and the predominance of agricultural soils in the National Soils Database were reduced by using information from underlying soil surveys to group soils according to their parent material. The following discussion describes more fundamental sources of error associated with both the core NZLRI data and with the National Soils Database.

The wide variation in map scale and quality of the underlying soil surveys used to underpin the NZLRI poses perhaps the most serious problem with the LENZ soil layers. Particularly in non-agricultural landscapes, early maps at a scale of 1: 253 440 provided very limited separation of soils so that significant variation in soil attributes might be encompassed within a single soil class. Although the spatial resolution of LRI units was significantly increased compared with the underlying soil mapping, the limited number of classes in the underlying soil classification placed varying limitations on the ability of the LRI field crews to differentiate adequately soils of significantly different character. In one example west of the Alpine Fault in South Westland, soils on small areas of steep greywacke hill country are mapped as Haast silt loams derived from schist. Although the discrepancy between the parent material ascribed to this soil and the geology recorded in the NZLRI could be used to identify and correct such problems, this would require manual checking of data from over 100 000 polygons.

A second source of error in the LENZ soil data layers is likely to arise from variation in the size of units mapped in the NZLRI database (Fig. 2.9). In part, this reflects natural variation in the spatial scales over which soils vary with some landscapes containing more inherent variability in soil attributes than others (e.g., parts of the Canterbury and Southland plains). However, significantly more detail was often mapped in areas with

Figure 2.8: Locations of National Soils Database soil sample sites.

potential for agriculture or forestry than on land that had either severe land-use limitations or was set aside for catchment protection or conservation, reflecting the NZLRI's objectives of improving land use. Overall, lowest resolution generally occurs in montane environments with the largest polygons found in the eastern Bay of Plenty. Much smaller polygon sizes have been used in revised NZLRI mapping in areas such as Marlborough and north of Gisborne.

The third source of potential error in the LENZ soil layers arises from a lack of required topographic detail in some of the older NZLRI mapping and reflects the LRI's original production mode of over-printing polygon boundaries onto monochrome versions of one inch to one mile (NZMS 1) topographic maps. As a consequence, many features such as smaller rivers and lakes were not discriminated by the NZLRI polygon boundaries, as the underlying topographic layer was relied on to indicate their locations. Unfortunately, not all this additional topographic detail was included when the polygon boundaries were captured in an electronic form. Examples of the resulting loss in detail can be seen throughout the LENZ classification and underlying data layers where rivers and small lakes are merged into the surrounding landscape. For example, while approximately 30 small lakes are mapped in the Hamilton basin on topographic maps even at a scale as coarse as 1: 250 000, only two of these are mapped in the NZLRI despite its finer mapping scale. Similar problems occur with a number of major rivers throughout the country that disappear over parts of their course with the lowermost reaches of the Motueka River, for example, omitted for five kilometres upstream from its mouth. Here, the required line work is shown on the original field sheets, but was omitted in the digital version of the NZLRI, presumably because the river was considered too narrow to justify differentiating it from the adjacent land, which shared the same classification on both sides of the river.

A fourth source of potential error arises from considerable variation in the quality of data sources used in deriving parent material mapping within town and city 'holes' in the NZLRI. For this reason, parts of the LENZ classification layers covering towns and cities for which original field-survey based NZLRI mapping was not available should be treated as having lower inherent reliability than the rest of LENZ.

The main problem associated with use of the National Soils Database arises from its uneven distribution of sample points, and this results in inadequate information being available for many soils. As with the NZLRI, much of the research that led to the collection of these samples was motivated by a desire to improve agricultural and forest productivity. Consequently, the geographic distribution of these samples is biased towards lowland environments (Fig. 2.10), so that sites with elevations of less than 250 m constitute less than 40% of New Zealand's land area but make up nearly 70% of the samples held in the NSD. The main information gaps are associated with soils of montane environments.

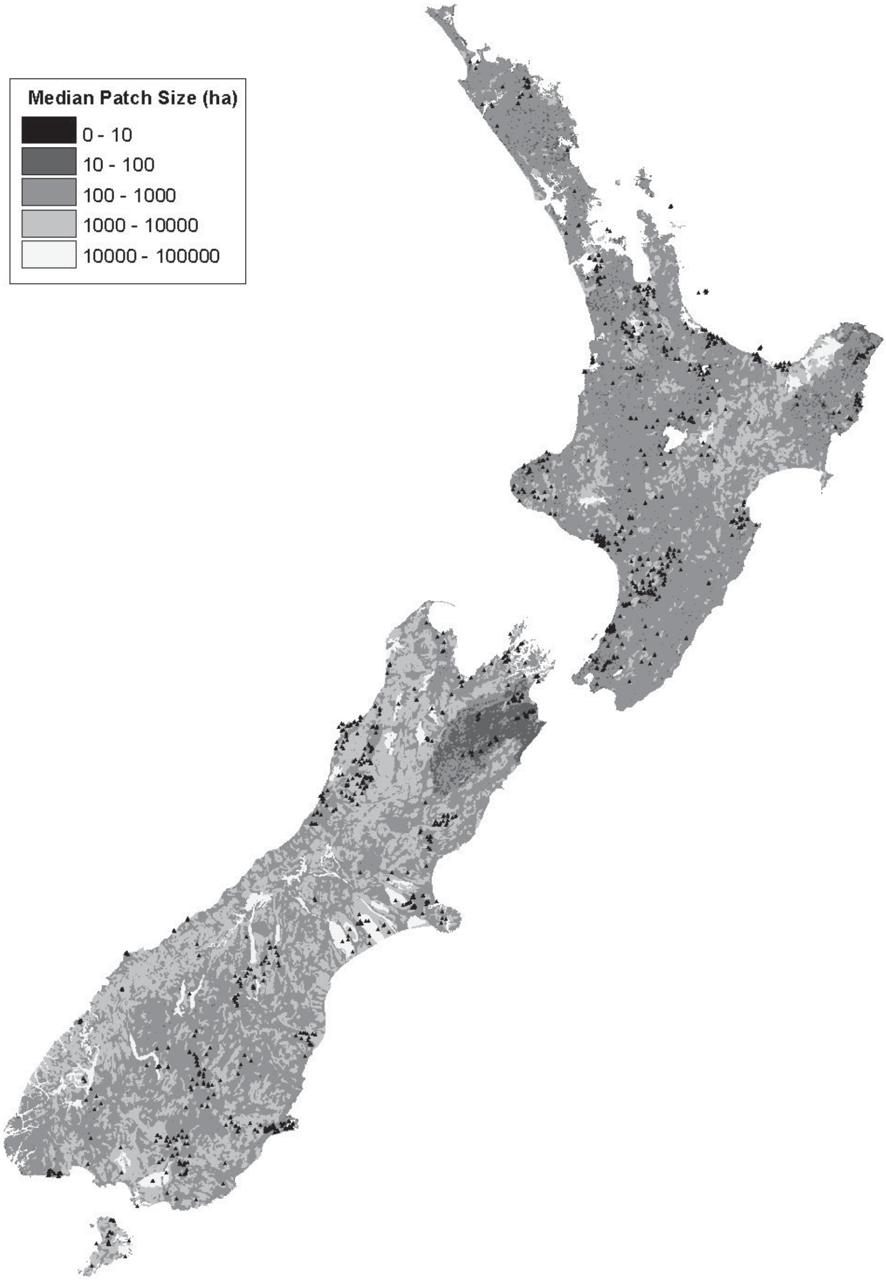


Figure 2.9: Variation in the size of polygons in the New Zealand Land Resource Inventory. Map values show the median polygon size for polygons within one km of each grid cell.

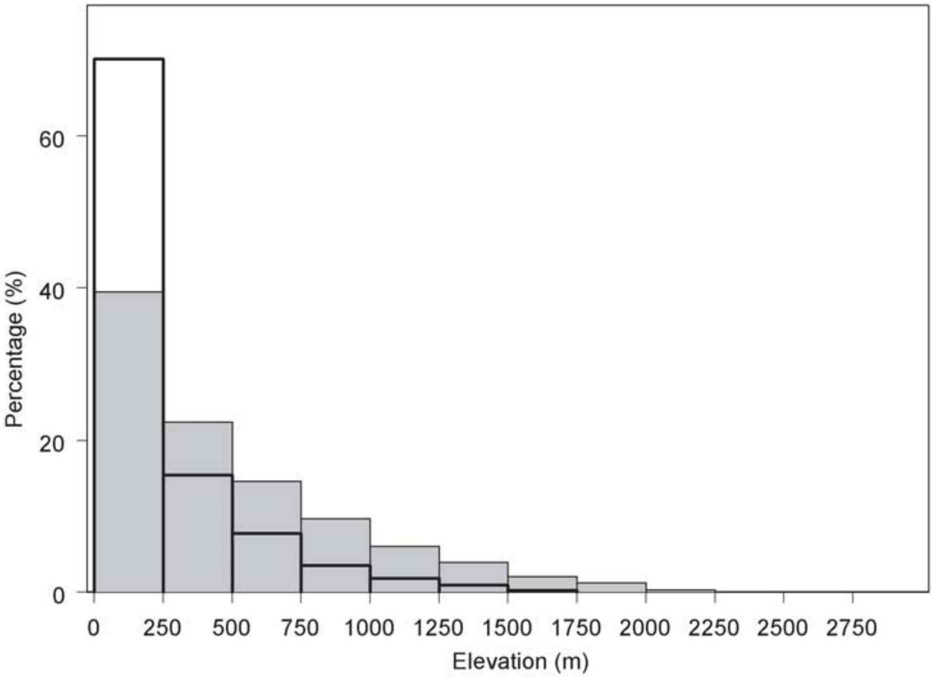


Figure 2.10: Altitudinal distribution of all land in New Zealand (grey bars) compared with the altitudinal distribution of soil profile descriptions contained in the New Zealand Soils Database (open bars).

Improving the LENZ soil layers

Although improving the accuracy of the underlying soil-attribute layers presents a considerable challenge, separate advances in remote sensing, terrain analysis and statistics are all likely to assist this process substantially. For example, use of gamma radiometric data offers considerable promise for mapping soil parent materials,[12] while high resolution digital elevation models are capable of providing considerable information about topographic variation that in turn controls variation in some soil attributes. When coupled with more recent detailed soil mapping and appropriate climate data, such tools are likely to collectively deliver substantial improvements in both the accuracy and reliability of descriptions of spatial variation in the physical and chemical attributes of soils. However, development of such data layers would require significant research effort and ongoing funding to bring together relevant existing data, collect additional data as required to fill gaps, and apply recently developed analysis techniques.

This process will also be made substantially more efficient by recently enabled access to the digital topographic data layers from which New Zealand's 1: 50 000 topographic maps are produced.

Technical definitions of the LENZ soil layers

Drainage

The drainage layer used in LENZ describes the internal drainage of soils. While earlier definitions of drainage emphasised the speed of removal of water from the soil,[13] the scale used in LENZ was developed as part of the diagnostic features used in conjunction with the New Zealand Soil Classification, and was defined in terms of the soil attributes that develop under different drainage conditions (Table 2.8).[14] Spatial variation in the reliability and lineage of the LENZ drainage estimates is shown in Figures 2.11 and 2.12. Some discrepancies in drainage descriptions may also arise because many published assignments used the older drainage scale, and a different assignment might be made on the basis of the new soil morphology-based drainage scale. While soils with very poor to moderate drainage may be described in the Chapter Four descriptions as 'very poorly drained' or 'moderately drained', the term 'well-drained' is occasionally used in the environment descriptions to describe a soil with good drainage.

Table 2.8: Drainage classes, their definition and extent

Class	Diagnostic criteria	Area (km^2)	Area (%)
Very poor	Having an organic horizon with pale colours due to water-logging in the horizon immediately below	4884	2
Poor	Have pale colours due to water-logging immediately below the topsoil	10,597	4
Imperfect	Have pale mottled colours due to water-logging at intermediate depths in the subsoil	36,923	14
Moderate	Have pale mottled colours due to water-logging at lower depths in the subsoil	56,999	22
Good (=well)	Lacking significant mottling or pale colours	150,297	58

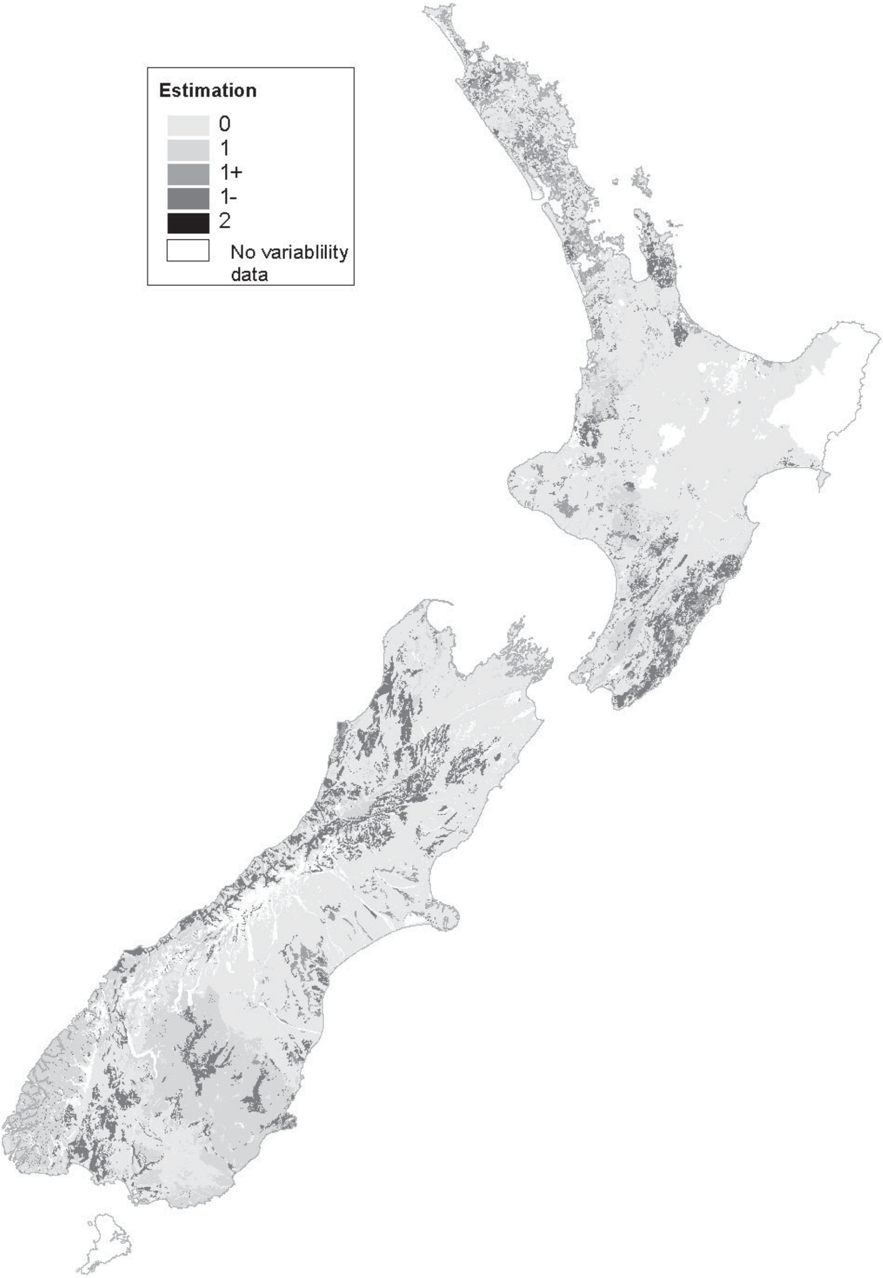


Figure. 2.11: Reliability of drainage estimates as recorded in the NZLRI extended legends. 0 – values occur mostly within the nominated class; 1 – values straddle the class above and below; 1- – values straddle the class and the class below; 1+ – values straddle the class and the class above; 2 – values straddle 2 classes above and below.

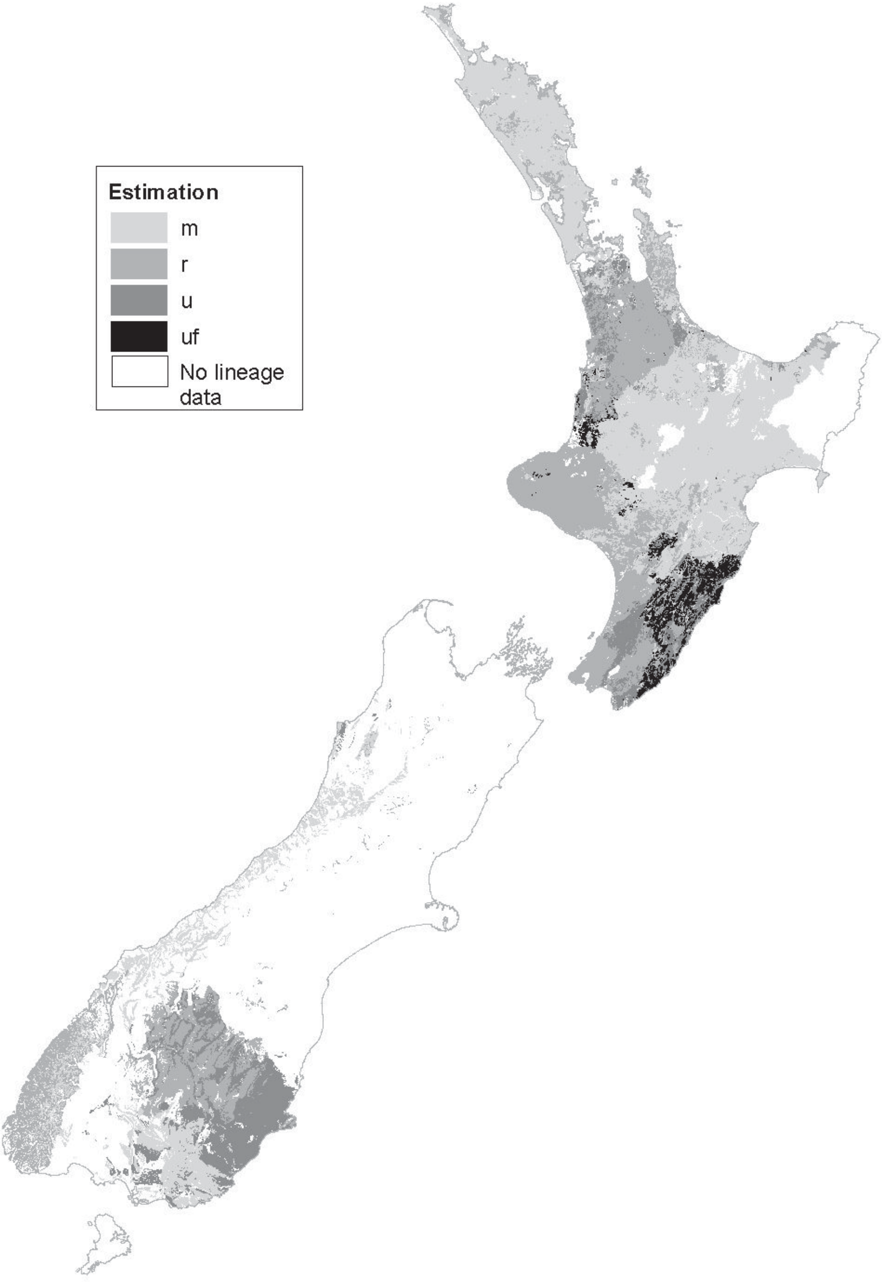


Figure 2.12: Lineage of drainage estimates as recorded in the NZLRI extended legends. m – estimated from measurements on the named soil; r – estimated from relationships with other soils – estimate thought to be reliable; u – estimated from relationships with other soils – estimate quality unknown; uf – estimated

Soil Fertility

As described in *Land Environments of New Zealand,* the four data layers used to describe soil fertility in LENZ were derived by grouping soils together by their parent material – the surface rock or other material from which the soil develops. This was necessary both to derive soil layers that indicate the long-term nutrient status of different parent materials independent of the modifying effects of climate and to accommodate variability in the mapping of soils in the NZLRI database. Variation in the numbers of classes used for different broad groupings of soil parent materials is shown in Table 2.9.

Table 2.9: Broad parent material groups used in the development of the LENZ soils layers, and their extent

Parent material group	No. of parent material classes	Area (km^2)
Sedimentary rocks – older, including schist	15	41,001
Sedimentary rocks – Tertiary – non-calcareous	19	32,345
Sedimentary rocks – Tertiary - calcareous	6	7476
Sedimentary rocks – limestone, and marble	10	2069
Intrusive rocks, including gneiss	5	15,867
Volcanic rocks – basaltic and ultramafic	15	7695
Volcanic rocks – andesitic	7	12,397
Volcanic rocks – rhyolitic	9	30,451
Loess	5	19,207
Peat	1	3044
Dune sand	6	4610
Total	129	259,679

Table 2.10: Acid soluble phosphorous classes, their definition and extent

Class	Range (mg/100 g)	Area (km^2)	Area (%)
Very low	0–7	69,958	26.2
Low	7–15	47,917	17.9
Moderate	15–30	107,139	40.1
High	30–60	30,412	11.4
Very high	60–100	4281	1.6

Table 2.11 Exchangeable calcium classes, their definition and extent

Class	Range (mg/100 g)	Area (km^2)	Area (%)
Low	0–1	135,563	50.7
Moderate	1–10	109,584	41.0
High	10–40	12,490	4.7
Very high	>40	2070	0.8

Table 2.12: Induration classes, their definition and extent

Class	Definition	Area (km²)	Area (%)
Non-indurated	A specimen disaggregates or slakes within one hour when placed in water	20,520	7.7
Very weakly indurated	A specimen does not slake in water but can be crushed with the thumb and forefinger when wet	66,105	24.7
Weakly indurated	A wet test specimen cannot be crushed with the thumb and finger but fails when subjected to average body weight applied slowly with the foot	26,507	9.9
Strongly indurated	A wet test specimen can only be broken when struck a sharp blow with a hammer	131,948	49.4
Very strongly	Indurated cannot be broken when struck a sharp blow with a hammer	14,627	5.5

Table 2.13: Particle size classes, their definition and extent

Class	Average particle size	Area (km²)	Area (%)
Silt and clay	less than 0.06 mm	65,582	24.5
Sand	0.6–2.0 mm	26,155	9.8
Gravel	2–60 mm	26,868	10.1
Coarse to very coarse gravel	60–200 mm	83,562	31.3
Boulders to massive	greater than 200 mm	57,540	21.5

Soil age

Soils were classified into two age classes based on their membership in the New Zealand Soil Classification. This describes soil age using morphological features associated with soil development rather than criteria based on chronological ages. As a consequence, soils classified as recent in dry cool environments may be much older than recent soils from warm, wet environments.

Table 2.14: Age classes, their definition and extent

Class	Definition	Area (km^2)	Area (%)
Younger	All NZLRI soil units belonging to the Recent or Raw soil orders in the New Zealand Soil Classification, but excluding soils classified as recent because of erosion of an original intact soil	16,210	6.1
Older	All other NZLRI soil units	243,498	91.1

Chemical limitations to plant growth

Soils were classified into three classes based on factors that lead to the accumulation of chemicals that limit plant growth. Classes were differentiated either by their parent material or by their position in the New Zealand Soil Classification. Although it would have also been desirable to include geothermal soils within this classification, insufficient information was available within the NZLRI database to enable this to be implemented.

Table 2.15: Chemical limitations to plant growth—class definitions and their extent

Class	Definition	Area (km^2)	Area (%)
Low	Most soils	258,722	96.8
Moderate	Fluid-saline and sandy-saline sulphuric gley soils, saline recent gley soils, saline orthic gley soils, saline gley raw soils, saline fluvial recent soils	641	0.2
High	Ultramafic soil parent materials	339	0.1

CHAPTER THREE
Creation of LENZ

INTRODUCTION

This section describes the processes used in defining LENZ, including the pre-processing required to assemble the input data layers, the two-stage classification process, and the subsequent post-processing, including evaluation of the classification results. We finish by identifying the main subjective choices required in constructing LENZ and the criteria used in making these decisions.

PRE-PROCESSING

Storage of the environmental data layers

All the data used to define LENZ were produced as raster layers in which values are stored for a regular grid of points across New Zealand. To reduce storage requirements, all values normally represented as real numbers (i.e. a number containing a decimal point and one or more following numbers) were multiplied by an appropriate scale factor and converted to integers. For example, rather than storing annual temperature estimates as real numbers with one decimal point, all values were multiplied by a scale factor of 10 and converted to an integer, e.g., a value of 10.1 is stored as 101. This typically reduced the sizes of the individual data layers by 80–90%.

Insuring concordance of the data layers

To run the classification, all data layers had to have the same geographic extent with no missing values. To achieve this, an analysis mask was created using the DEM described in the previous chapter trimmed to the NZMS 260 coastline. The analysis mask consisted of a grid layer in which all ‘land’ cells had an integer value of 1.

No problems were encountered in matching the seven climate data layers to the analysis mask. As described in the previous section, five of these were derived by directly coupling the digital elevation model with climate surfaces to derive climate estimates for each grid point. Similarly, estimates of water deficit and the ratio of rainfall to potential evaporation for each grid point were derived by combining monthly estimates of temperature and solar radiation to estimate monthly evaporation and then comparing these with estimates of monthly rainfall.

Estimates of slope were also directly derived from the digital elevation model and so shared the same geographic extent. The remaining landform variables were more problematic, as these were derived by converting data stored in polygon format in the New Zealand Land Resource Inventory (NZLRI) into raster coverages. This required use of an Avenue™ script in ArcView to correct the numerous, generally small, discrepancies between New Zealand’s extent as described in the NZLRI compared with the extent defined by the analysis mask. All cells included within the extent of the NZRLI but falling outside the analysis mask were accorded a null value, while cells within the mask but not within the LRI were given the same value as their closest adjacent cell using the Avenue command “nibble”.

Exporting the raster data to PATN

Approximately 2.7 million data points are contained in a 100-m resolution raster layer covering New Zealand — too many to analyse feasibly in PATN[1] , the software in which the classification was carried out. To make the analysis more tractable, a 25% subset of the occupied data cells was used to define the classification, with these selected by taking every second cell of every second row.

To overcome the lack of a multi-layer raster export routine in ArcView, software was written in C++ and linked to a library provided with Spatial Analyst that allows direct access to the ESRI grid data structures. Using our New Zealand extent mask as a template, data points were systematically selected, their associated values were retrieved from the 15 data layers, multiplied by a scale factor where appropriate, and written to a text file consisting of one row of 15 values for each point. This file was then read into PATN using the DATN module and summaries were produced using the HIST module. Finally, the summaries were compared with summaries of the source raster data layers to insure all values had been transferred correctly.

Transformations before classification

Two variables that have strongly skewed distributions were mathematically transformed to prevent the effect of more extreme values dominating their contribution to the analysis outcome. Estimates of monthly water balance were transformed using a $\log_{10}$ transformation, while a square root transformation was used for slope. Both of these transformations apply greater compression to values at the higher end of the data range, so that the effect on the classification outcome of the same difference on the scale of the raw data progressively decreases as the value along that scale increases. For example, after transformation, the shift from 1 to 2 degrees on the raw data scale has the same effect on the classification as a shift from 15 to 19 degrees or from 30 to 36 degrees. This implies that progression from 1 to 2 degrees on the raw data scale has greater ecological significance than an equivalent shift on steep slopes, e.g., from 31 to 32 degrees. The log transformation used for the average monthly water balance estimates has a more dramatic effect in this regard than the square root transformation used for slope, with differences in monthly water balance on dry sites given greater weight than the same difference on wet sites.

THE CLASSIFICATION PROCESS

The large number of grid points used in the classification analysis placed major constraints on the type of analysis procedure that could be used. Conventional agglomerative classification techniques operate by defining a triangular matrix describing multivariate distances between all possible pairs of sites. Because this results in memory requirements increasing with the square of the number of points analysed, analyses of more than a few tens of thousands of data points quickly become intractable.

To avoid such problems LENZ was defined in two stages. Initially, a non-hierarchical classification technique (ALOC/ALOB in PATN) in which memory requirements rise only linearly with the number of data points, was used to group together points located close to one another in environmental space. The average environmental values of the groups produced by this procedure can then be used as input to a conventional agglomerative classification process.

Environmental distance

The concept of environmental distance is fundamental to the classification process used to define LENZ. Given two data points, each of which is described by some set of environmental variables, the environmental distance between these points is the difference in environment, averaged across all environmental variables. Such measures are widely used in a range of multivariate clustering techniques, and numerous formulae have been proposed for their calculation.[2] In defining LENZ, the environmental distance, *D*, between points *j* and *k*, described by a set of variables $x_{1 \ldots n}$, is measured using the Gower metric,[3] defined as:

$$D = \frac{1}{n} * \sum_{i=1}^{n} \frac{|x_{ij} - x_{ik}|}{\text{range}(x_i)} .$$

In its normal formulation, the range standardisation of each variable implicit in this distance measure results in all variables by default having equal weight and therefore equal influence on the analysis outcome. However, a modified weighting system was used in defining LENZ in which all seven climate variables and the variables describing slope, drainage, soil age, and chemical limitations were given a weight of one, while the four soil parent material variables, i.e. phosphorus, calcium, induration, and particle size, were given a weight of 0.25. Values of the metric indicate the mean environmental difference between sites expressed as a proportion, e.g., a value of 0.30 indicates that environmental differences between two sites are 30% when averaged across the contributing variables.

Non-hierarchical classification using ALOB

Because ALOB can define a maximum of 400 groups, the data was split into two subsets consisting of the North Island and its surrounding inshore islands, and the South Island, Stewart Island, and their surrounding inshore islands. ALOB starts by sequentially reading the data using the first point to start the first group – any subsequent data points located at a distance greater than a pre-defined threshold distance from an existing group(s) are used to start a new group. Decreasing the threshold distance gives a larger number of groups, while increasing this radius gives a smaller number of groups. For the South Island, 393 groups were defined using a threshold distance of 0.0775, i.e. representing an average difference across the environmental variables of 7.75% of their respective ranges. The North Island data set was analysed using the same threshold distance, the slightly reduced number of groups (379) reflecting the lower environmental diversity of the North Island compared with the South Island.

The analysis for each island then proceeds with its iterative reallocation procedure in which each point is tested to see whether it is in the group to which it is most similar, with points moved to a different group if necessary. This process was repeated until less than 10 reallocations occurred in any one cycle, taking several days on a large workstation.

Hierarchical classification

In the second stage of the classification, the North and South Island output data sets from ALOB were combined to form a matrix with 772 groups, and this was classified using a conventional agglomerative clustering procedure. The PATN module GASO was used to calculate all inter-group distances as this allowed down-weighting of the influence of the four parent material variables in the same way as used in ALOB. Once the inter-group distances had been calculated, the classification was defined using the flexible UPGMA sorting strategy[4] as implemented in FUSE. Following the recommendation of Belbin et al,[5] a value for β of -0.1 was used which slightly dilates the data space. This dilation accentuates inter-group distances as groups become larger, discouraging chaining and the production of large numbers of units of small area. One consequence is that the maximum distance between environments shown on the dendrogram is 1.38 rather than being less than one if a space conserving strategy was used.

Output from the classification process consisted of a set of group centroids (=average environmental values for the 772 groups), a summary showing the order in which the input groups were progressively combined to form one large group, and a dendrogram showing inter-group relationships.

POST PROCESSING

Once the classification had been defined, there remained the challenge of mapping the geographic distribution of the environmental groups defined by the non-hierarchical classification. This was achieved using purpose written C++ code that calculated environmental distances between each point on the 100 m grid across New Zealand and the centroids for the 772 environmental groups used in phase two. Each grid point was then allocated to the group to which it was most similar with results written to a classification grid layer for viewing in ArcView.

Results of the hierarchical classification were then summarised to form a table with 772 rows and columns, with each row corresponding to an environmental group, and column entries indicating how these groups were progressively joined to form fewer and fewer numbers of groups. This table was then joined to the classification grid layer described in the previous paragraph, allowing the classification to be displayed at any level of detail from 772 groups down to one group.

Although such a product is useful in a research context, its continuous variation in classification detail is less practical in a management setting where classifications are generally required at only one to a few standard levels of detail. To identify a standard set of levels, the classification was examined at varying levels of detail and four levels were selected to cover a range of management applications (Table 3.1). These contain 20, 100, 200 and 500 groups or environments respectively, with the most general classification intended primarily for applications at a national level and at broad spatial scales, while the most detailed level is more suited to local-scale applications. Names for the groups or 'environments' identified at each level are constructed from combinations of upper and lower case letters and numbers (Table 3.1). For example, upper case letters (A-T) are used to identify the 20 environments of Level 1, while a number is added to form Level II environment names (A1-A7). Level III and IV names are formed by adding numbers and lower case letters respectively. Each of these classification levels was then created as a single grid data layer with an accompanying table containing summaries of the environmental character of each environment. Note that each of these classification layers contains both a single group composed of areas of land classified in the NZLRI as permanent snow and ice (Environment T), and an additional group containing unclassified cells, mostly in rivers and lakes but also including quarries and opencast mines.

Table 3.1: Levels I-IV of the LENZ classification

Level	Number of Environments	Naming Convention	Suggested map scale	Suggested geographic extent
I	20	Upper case letter – 'A'	1: 2-5,000,000	National
II	100	+ Number – 'A1'	c. 1: 1,000,000	National–Regional
III	200	+ Decimal – 'A1.1'	c. 1: 250,000	Regional
IV	500	+ Letter – 'A1.1a'	Down to 1: 50,000	Regional–District

Production of high resolution data and classification layers

To facilitate use of Levels III and IV at finer spatial scales, all environmental data layers were recreated at an increased resolution of 25 m. High resolution versions of the seven climate layers were produced from our existing 100-m climate layers using interpolation tools within ArcView rather than using the original climate surfaces to estimate values with a high resolution digital elevation model. This is because differences in elevation between adjacent cells at this fine spatial scale are only very rarely large enough to produce differences in climate larger than the inherent error in the surfaces. A 25 m slope layer was created from a 25 m digital elevation model using the same method as described for the 100 m slope layer in the previous section. Twenty-five metre versions of the soil layers were recreated from the NZLRI database, reflecting the significant improvement in spatial resolution to be gained from converting its polygon representation of spatial information to a raster format.

Once these higher resolution data layers had been created, 25-m resolution classification layers were calculated for Levels III and IV using the same procedure as that described above to create the 100 m classification layers.

Colour schemes

The colour classification files that are used with the four classification layers were created using an automated procedure based on results from a principal components analysis (PCA)[6] of the average environmental attributes for the 772 environments defined by the non-hierarchical classification. These data were standardised before performing the PCA analysis so that each environmental variable contributed equally to the analysis outcome. Two-thirds of the total variation in the data is explained by the first three axes, with a further 14% explained by axes four and five (Table 3.2a). Scores for the environments on each of the first three axes were rescaled into a range from zero to 255 and used to define their colours using a red-green blue colour scheme:[7] axis one was used to define the amount of blue coloration, axis two the red coloration and axis three the green coloration.

Axis one (blue) is strongly correlated with particle size, slope and induration and has moderate correlations with temperature, solar radiation and water balance. High scores (strong blue) are associated with montane environments having steep slopes with strongly indurated, coarse parent materials, well-drained soils and climates that are cool and wet with low solar radiation. Conversely, low scores (weak blue = yellow, the complimentary colour to blue) are associated with environments generally having low slopes, weakly indurated, fine-textured parent material, more poorly drained soils and warm, dry, high solar radiation climates.

Axis two (red) is strongly associated with solar radiation both annually and in winter, and to a lesser degree with warmer temperatures, particularly in winter. High scores (strong red) are associated with environments having high solar radiation and high temperatures, while low scores (weak red = cyan) are associated with environments having low solar radiation and cool temperatures.

Axis three (green) scores are most strongly correlated with variation in rainfall, and were reversed so that low values (strong green) indicate environments having low annual water deficits and October vapour pressure deficits, high monthly water balance ratios and a predominance of poorly drained soils. High scores (weak green = magenta) are associated with environments having dry climates and good soil drainage.

In some cases the resulting colour schemes do not differentiate contrasting environments. Most of these differences occur with respect to soil drainage and/or age, variables that are most strongly associated with axes four and five of the PCA analysis respectively (right of Table 3.2) and that could not be incorporated into the three-dimensional colour space used to define the red-green-blue colour scheme.

Variation in the appearance of the colours will also occur depending on the degree to which relief shading from an underlying digital elevation model is used to enhance their display. Using the standard relief shading options in ArcView Spatial Analyst, all colours are adjusted to a uniform average brightness, and this substantially alters the colours of some environments particularly those having low values on all three axes. A different technique is used to incorporate relief shading both in ESRI’s 3-D Analyst™ and in ArcGIS™, and this results in greater variation in colour brightness.

Table 3.2: Results from a principal components analysis (PCA) of mean environmental values for the 772 environments defined by the non-hierarchical classification. The variance explained by the first five axes is shown in (a), and loadings of the environmental variables on these axes are shown in (b).

(a)

	Axis One	Axis Two	Axis Three	Axis Four	Axis Five
Variance explained	35.1	18.9	12.6	8.5	5.7
Cumulative variance explained	35.1	54.0	66.6	75.1	80.8

(b)

	Axis One	Axis Two	Axis Three	Axis Four	Axis Five
Mean annual temperature	-0.22	0.26	-0.04	0.04	-0.15
Mean minimum temperature of the coldest month	-0.21	0.34	-0.19	0.04	-0.26
Mean annual solar radiation	-0.21	0.53	0.06	-0.11	0.11
Mean winter solar radiation	-0.19	0.51	-0.08	-0.08	0.02
Annual water deficit	-0.19	-0.04	0.51	0.24	0.12
Mean monthly water balance ratio	0.21	-0.09	-0.35	-0.13	-0.15
October vapour pressure deficit	-0.20	0.13	0.37	0.10	0.08
Slope	0.43	0.15	-0.12	-0.05	0.22
Drainage	0.24	0.16	0.31	-0.77	0.21
Acid soluble phosphorus	-0.02	-0.23	0.41	-0.08	0.03
Exchangeable calcium	-0.14	-0.03	0.12	0.11	-0.02
Particle size	0.51	0.26	0.25	0.32	-0.41
Induration	0.39	0.23	0.25	0.11	-0.22
Age	0.21	0.18	-0.13	0.41	0.74
Chemical limitations to plant growth	-0.01	-0.01	-0.02	0.04	-0.03

OBJECTIVE VERSUS SUBJECTIVE COMPONENTS

One philosophical stance that was important in developing LENZ was the attempt to inject as much objectivity and quantitative description into the classification process as was possible. As the work developed, it became clear that while this was achievable in many respects, major components of the classification remain dependent on decisions involving varying degrees of subjectivity. The most significant of these are outlined in Table 3.3.

The most important subjective decision, and one which strongly determined the final shape of LENZ, was the choice of environmental variables used. This clearly constrains the information available to the (objective) classification procedure, predetermining the degree to which different geographic areas can be differentiated. Variables used were chosen on the basis of experience gained in a series of statistical analyses of the distributions of major indigenous tree species.[8] Results from these were used to identify a set of variables having both strong functional links with major plant physiological processes, and high statistical correlation with the observed distributions of most of our major native tree species.

The choice of classification techniques was largely constrained by the amount of data used as input to the analysis. However, some further decisions were required about weighting of variables, choice of a distance measure, and setting control parameters used in the hierarchical phase of classification.

Making a decision on how to weight the chosen variables posed one of the more difficult challenges. Although the potential to use comprehensive sets of data describing biological distributions to test the discriminating power of environmental classifications using different weightings was explored, this did not yield the gains expected. In part, this reflects a lack of biological databases with comprehensive spatial coverage, as even the best of these are biased strongly, mostly towards montane environments. However, it also reflects the very large sample sizes involved and the difficulties in identifying meaningful statistical tests with such data. In the end, all variables were weighted equally with the exception of the four soil nutrient variables, whose contribution was averaged so as to prevent their influence from becoming disproportionately large. This choice was made based on subjective comparison of classifications using both weighted and non-weighted approaches and assessed for their ability to recover major features of New Zealand’s environment known to be correlated with major features of New Zealand’s broad scale forest pattern. Although such an emphasis on forest ecosystems might be criticised by those interested in biotic groups other than forest trees, two factors are likely to result in this approach also having strong relevance to a wide range of other groups. First many of the variables used in defining LENZ are likely to also have strong functional linkages with the life processes of a wide range of other species groups. Secondly, forest was historically by far the dominant land cover of New Zealand, and variation in the character of those forests presumably once played a major role in defining habitat availability for many other species.

Choice of a distance measure was much more straightforward. The Gower metric incorporates an inherent range standardisation, obviating the need to range standardise all variables before analysis. In addition, its measurements of inter-site distances are not affected by their positions in relation to the range of the various attributes[9] . That is, a difference of three units in a particular variable contributes the same amount to the distance whether it is from 0 to 3 or from 97 to 100. By contrast, when using ratio measures such as the Bray-Curtis distance measure, the distance between two sites reflects both their environmental difference and the magnitude of their environmental attributes, e.g., for a variable with a total range of 100 units, two sites having values of 12 and 14 are indicted as being much more different than sites having values of 92 and 94.

As indicated above, a decision on the degree of space conservation or dilation used in the final classification phase was made on the basis both of results from published comparative studies and of practical tests. For the latter, the analysis was repeated with differing values of the control parameter corresponding to no, slight and moderate dilation. Histograms of the resulting group sizes were then plotted, and slight space dilation was selected given its significant reduction in numbers of groups of small geographic extent, and resulting improved separation of large-scale environmental differences.

Choice of the numbers of groups to include in the standard classification levels (Levels I–IV) was made by progressively increasing the number of groups included in the display of the full classification layer. The geographic distribution of groups at the various classification levels was then examined, along with their discrimination of features of New Zealand's landscape associated with significant variation in forest pattern.

Table 3.3: Significant subjective decisions that were made in defining LENZ, and the criteria used in making a choice.

Decision	Criteria
Choice of input variables	Variables chosen both for their correspondence with major physiological process of biota, and their strong statistical correlation with the distributions of trees[8]
Classification procedure	Equal weights assigned after qualitative assessment of classifications using varying weighting schemes
Weighting of variables	Gower metric chosen for its automatic equal-weighting of variables, and interval as opposed to ratio response
Distance measure	Non-hierarchical followed by hierarchical clustering chosen because of very large sample size.
Space dilation versus contraction	Slight space dilation chosen to minimise production of large numbers of groups of very small area
Post-analysis choice of classification levels	Qualitative decision based on feedback from experienced conservation and environmental managers

CHAPTER FOUR

The LENZ Environments Levels II – IV

While Land Environments of New Zealand provides descriptions of the 20 Level I environments, this volume focuses on Levels II, III and IV of the LENZ classification, containing 100, 200 and 500 environments respectively. We begin this chapter with a brief overview of the Level I environments, and then introduce the more detailed classification levels, starting with a section that provides guidance on how to interpret the later descriptive material.

The LENZ Level I Environments

In overview, Environments A through T form a sequence from northern lowland environments with warm temperatures and high solar radiation to the steep, cold environment of the South Island's Southern Alps with its extensive permanent snow and ice. Five groupings can be distinguished within these 20 environments:

- Environments A to F are widespread in the North Island and the north and east of the South Island and typically have warm temperatures, moderate to high solar radiation, low monthly water balance ratios, low to moderate water deficits and moderately high vapour pressure deficits. The vast majority of soils are mature, with the most common soil parent materials being rhyolitic rock and tephra from the Taupo volcanic zone; andesitic rock and tephra from the Tongariro and Taranaki volcanoes; and greywacke rock, mostly along the main mountain ranges with scattered outliers in western Waikato and Northland. Extensive areas of alluvium, peat and loess occur in the lowlands particularly in Waikato, Hawke's Bay, Manawatu and Wairarapa.

- Environments G to K occur throughout the North Island and the eastern South Island, and consist predominantly of recent soils of flood plains, sand dunes or recent volcanic deposits. Although much less extensive than Environments A to F, they share strong similarities in climate. Alluvium from a variety of sources is the most widespread parent material.

- Environments L to N encompass extensive areas of outwash glacial material and alluvium in the southern and eastern South Island, with more scattered occurrences on the South Island's West Coast. Climates in these environments are cooler than in more northern environments, with much lower solar radiation. Average monthly water balance ratios and October vapour pressure deficits vary widely, with sites east of the Southern Alps much drier than those in the west and south. The most common parent materials are loess and alluvium from greywacke or schist, with smaller areas of alluvium from granite, basic volcanic rocks and/or younger Tertiary rocks.

Mixtures of recent and older soils occur in the east and south, while recent soils predominate in the west.

- Environments O to S occupy the higher mountain ranges and central volcanoes of the North Island and the extensive mountainous terrain of the South Island. Climates are generally cool, with only low to moderate solar radiation, low deficits of rainfall and vapour pressure, and high average monthly water balance ratios. Slopes are moderate to steep. The most widespread soil parent materials are greywacke in the mountains of Canterbury, Marlborough and the North Island main ranges; schist in the mountains of Otago and along the eastern side of the South Island's main alpine fault; gneiss and granite on Stewart Island, in Fiordland, scattered along the South Island's West Coast and in Buller and Nelson; and Tertiary rocks, mostly in Buller and west Nelson. Small areas of ultramafic rocks occur in Southland, southern Westland and about Nelson.
- Environment T consists of the permanent snow and ice of the South Island's Southern Alps, occurring mostly at high elevations where the climate is cold and wet, and slopes are mostly steep.

Relationships between the LENZ classification levels

One reflection of the hierarchical nature of LENZ is the relationships between environments at different levels of classification detail. For example, the Northern Lowlands Environment (A) is progressively divided at each classification level, so that it contains seven environments at Level II (A1–A7), 14 environments at Level III (A1.1–A7.3), and 33 environments at level IV (A1.1a–A7.3b). The hierarchical relationships between environments at different classification levels are also reflected in the naming conventions described in Chapter Three. The number of components in an environment name indicates both the classification level it is drawn from and its relationships to other environments drawn from the same level. For example, Environment A7.2 occurs at Level III, as indicated by the three components that makes up its name. In addition, A7.2 is more closely related to Environment A7.3 than to Environment A6.1, while the latter is more closely related to Environment A6.2.

A formal account of the relationships between different environments is provided by the dendrograms presented in the latter descriptive section of this chapter. The example dendrogram shown in Fig. 4.1 shows how the position of vertical lines joining environments indicates the degree of similarity between different environments, with the position of these lines interpreted relative to the environmental distance scale shown along the foot of the dendrogram. Vertical lines to the left of the diagram join similar environments, while lines to the right join environments that are more dissimilar. In the example shown, Environment A7.2a in the lower part of the dendrogram is most closely related to Environment A7.2b, these two Level IV environments combining with A7.2c, A7.2d and A7.2e to form the Level III Environment A7.2. Environment A7.2 is in turn most closely related to A7.3 and then to A7.1, with these three environments collectively forming Environment A7 at Level II. Subsequent links to the right of the dendrogram indicate more distant similarities with the other Level II environments in A, i.e. A1–A6.

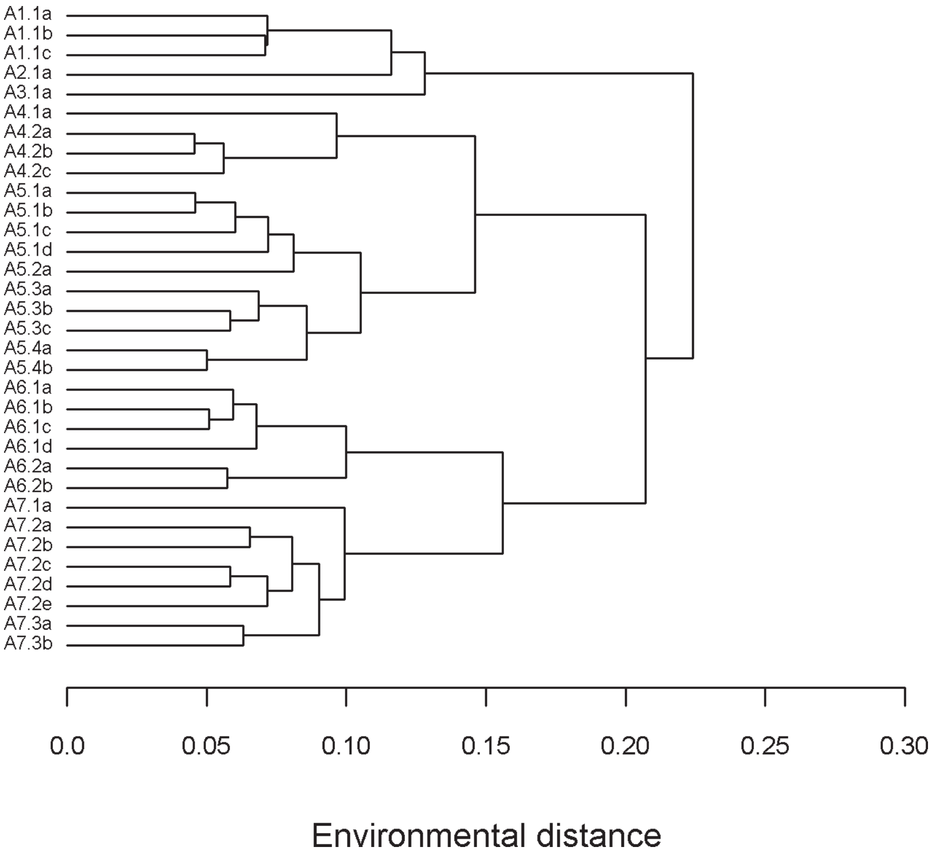


Figure 4.1: A typical dendrogram for a group of LENZ environments - see text for explanation.

Environmental and geographic variability

One consequence of the progressive increase in detail of the LENZ classification levels is a decrease in the average extent of the individual environments in both geography and environment. For example, while the average geographic extent of the 20 Level I environments is 1.3 million ha, the average extent of the Level IV environments is around 50 000 ha (Table 4.1). Similar trends also occur for environment, i.e. the environmental variability occurring within each environment decreases with progression from the more general to the more detailed classification levels. For example, using the standard deviation as a measure of within-environment variability in annual temperature (Table 4.1), there is a clear trend of decreasing environmental variability with progression from Level I environments to Level IV environments.

Table 4.1: Variation in the average geographic extent and environmental variability of environments at different levels of classification

	Level I (20 Groups)	Level II (100 Groups)	Level III (200 Groups)	Level IV (500 Groups)
Mean environment size (ha)	1,305,292	259,851	130,353	52,216
Mean of Standard Deviations of Mean Annual Temperature (°C)	1.257	0.768	0.655	0.525

Table 4.2: Numbers of Level-IV environments by Regional Council area.

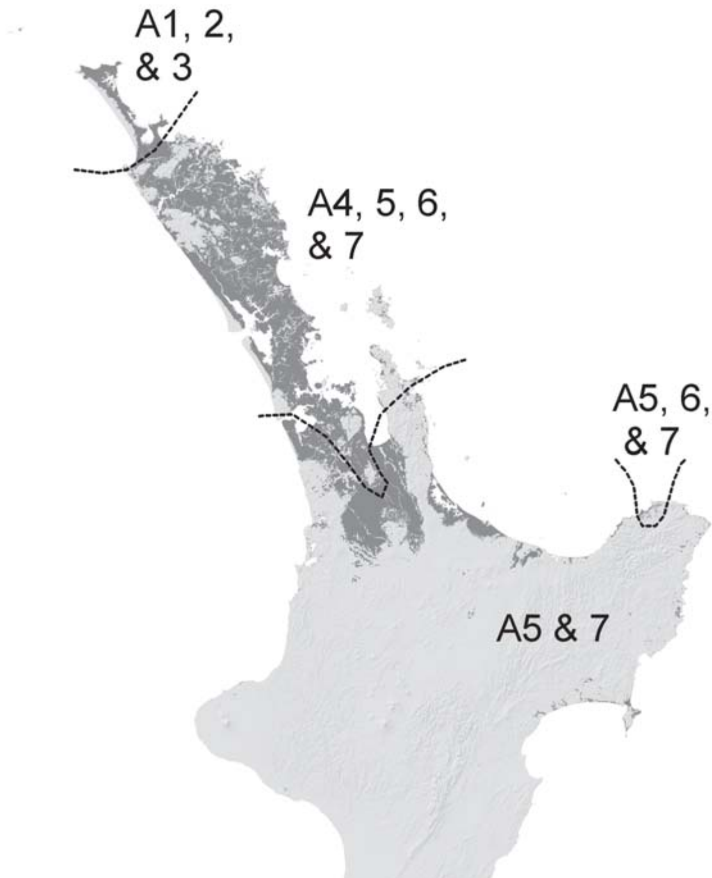
Results	Level I (20 Groups)	Level II (100 Groups)	Level III (200 Groups)	Level IV (500 Groups)
Northland	6	15	22	43
Auckland	7	19	31	64
Waikato	14	35	59	129
Bay of Plenty	9	22	37	83
Gisborne	11	27	46	101
Hawkes Bay	12	33	63	138
Taranaki	10	28	44	77
Manawatu-Wanganui	12	26	40	94
Wellington	8	13	21	61
Tasman	17	35	51	90
Nelson City	10	17	20	27
Marlborough	16	43	65	119
West Coast	17	38	57	110
Canterbury	16	48	85	173
Otago	14	48	86	169
Southland	13	37	64	128

Parallel to these changes, is a general trend of increased numbers of environments occurring in each region with progression from Level I to Level IV (Table 4.2), although these increases are not uniform. Rather, they reflect the degree of environmental variability at different spatial scales within each region. For example, Northland and Auckland, which have six and seven Level I environments respectively, differ much more in their number of Level IV environments, the Auckland Region having nearly 50% more variability at this finer scale than Northland. The greatest numbers of Level IV environments occur in Canterbury and Otago, reflecting their environmental variability, which extends from warm, dry lowlands with wide variation in topography and soils to montane environments along the Southern Alps with very cold, wet climates.

Environment Descriptions

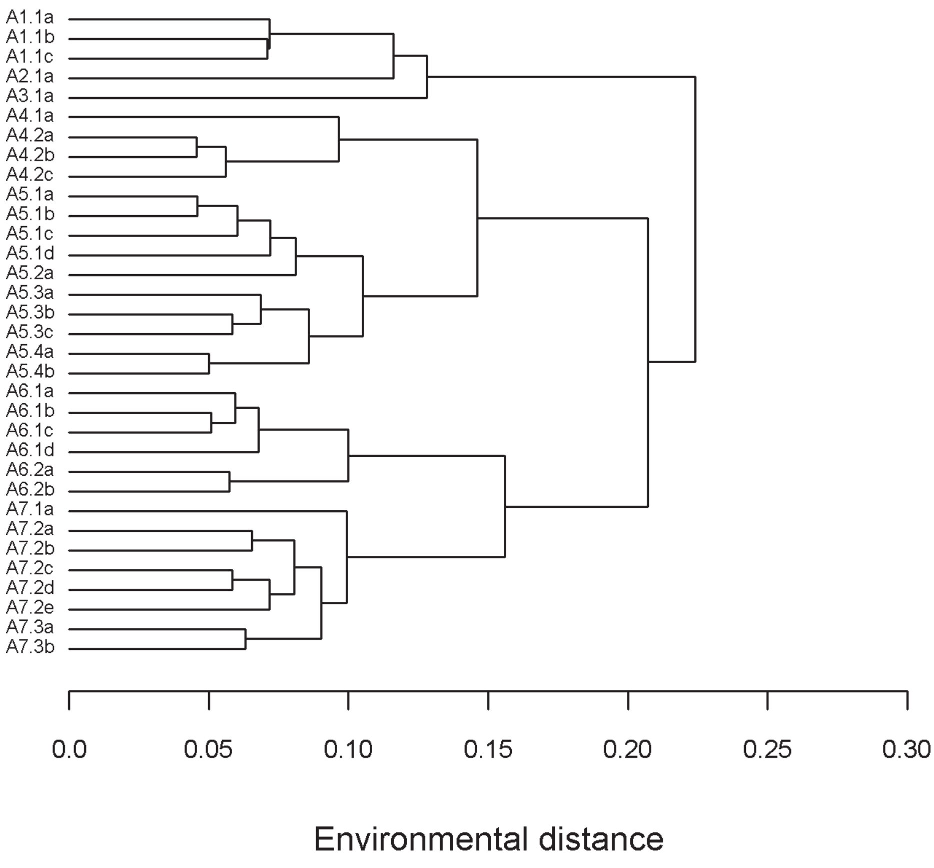
Descriptions of the LENZ environments form the rest of this chapter. These are grouped by Level I environment, a description of which provides a general introduction to each group of environments at the more detailed classification levels. A dendrogram is also provided for each group of environments, along with a table showing the average environmental conditions for the respective Level II environments. This is followed by more detailed descriptions for the Level II and III environments in which standard descriptive terms (Appendix I) are used to provide consistent descriptions. For example, variation in mean annual temperature is described as ‘very cold’ (< 5 ºC), ‘cold’ (5–7.5 ºC), ‘cool’ (7.5–10 ºC), ‘mild’ (10–12.5 ºC), ‘warm’ (12.5–15 ºC) and ‘very warm’ (>15 ºC). A list of all the standard descriptors can be found in the appendix. Where no subdivision of a Level II environment occurs at Level III, its attributes, which will be identical to those of its Level II counterpart, are listed in tabular form for completeness. Descriptions of the Level IV environments are more limited, focusing on differences between each environment and its parent Level III environment using comparative descriptors.

A - Northern Lowlands



Environment A encompasses the extensive lowlands of the northern North Island with the majority occurring in Northland, Auckland and Waikato. Smaller areas are scattered around the Bay of Plenty coast from northern Coromandel to East Cape, with occasional occurrences along the east coast south to about the Mohaka River mouth in Hawke's Bay. Several tiny areas occur on the south Taranaki coast near Waverley. Climatically, Environment A is warm, with very high annual and winter solar radiation. Minimum winter temperatures are also high, with frosts occurring only infrequently from Auckland north. Although annual water deficits are low, the low monthly water balance ratio makes this environment susceptible to drought in years with lower than average rainfall. October vapour pressure deficits are moderate. Landforms are generally flat to gently rolling, with parent materials that include deeply weathered sandstone and greywacke, older volcanic tephra, alluvium from various sources, peat and older basaltic rocks. Most soils are poorly to moderately drained and of low natural fertility, reflecting the intense weathering caused by the warm, moist climate.

DENDROGRAM OF A



Environment	A1	A2	A3	A4	A5	A6	A7
Area (ha)	50,390	31,187	816	9650	386,152	894,743	486,404
Altitude (m)	56	26	20	9	34	93	55
Mean annual temperature (ºC)	15.7	15.8	15.8	15.3	14.3	14.7	14.2
Mean minimum temperature of the coldest month (ºC)	8.4	8.5	8.4	6.9	4.9	6.3	5.1
Mean annual solar radiation (MJ/m^2/day)	15.3	15.3	15.3	15.1	14.9	15.0	14.9
Mean winter solar radiation (MJ/m^2/day)	6.9	6.8	7.1	6.4	5.9	6.2	5.9
October vapour pressure deficit (kPa)	0.4	0.4	0.3	0.4	0.4	0.4	0.4
Monthly water balance ratio (ratio)	2.0	2.0	1.9	2.5	2.5	2.7	2.6
Mean annual water deficit (mm)	102.6	106.7	121.3	58.9	51.0	40.3	43.5
Slope (º)	5.5	1.2	1.8	1.4	0.6	6.2	1.7
Drainage (1=very poor to 5=good)	4.1	1.1	3.0	1.9	1.6	3.1	4.6
Acid soluble phosphorus (1=v. low to 5=v. high)	1.8	1.1	2.0	2.0	1.6	1.2	1.9
Exchangeable calcium (1=low to 5=v. high)	1.0	1.6	3.0	3.0	2.1	1.1	1.5
Particle size (1=clay/silt to 5=boulders–massive)	3.4	1.5	2.0	1.0	1.3	2.0	1.9
Induration (1=non-indurated to 5=v. strongly ind.)	3.8	2.4	1.0	1.0	1.6	3.2	2.4
Soil Age (1=raw/recent, 2=older)	2.0	2.0	1.0	2.0	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	2.0	1.0	1.0	1.0

Environment A1

Environment A1 consists of the hills that extend from the Three Kings Islands to North Cape and south to Ahipara at the base of Ninety Mile Beach, with smaller areas on northern Great Barrier Island. The climate of Environment A1 is very warm, with very high solar radiation, very low monthly water balance ratios and moderate annual water deficits. Soil parent materials are predominantly basalt and older sand deposits with some sandstone, rhyolite and greywacke. A small area of ultramafic rocks occur on the tip of North Cape. Soils are imperfectly drained and of low natural fertility.

Level III & IV Descriptions

Level III	A1.1 – No Subdivision at Level III
Area	50,400 ha
Elevation	55 m
Location	North Cape, Three Kings Islands
Climate	Very warm temperatures, very high solar radiation, moderate annual water deficits
Landform	Undulating hills
Soils	Imperfectly drained soils of low fertility from basaltic and rhyolite
Level IV	a. strongly rolling hills, well-drained, moderate fertility b. as for A1.1 c. gently undulating hills, fine-textured soils

Environment A2

This environment is restricted in extent, occurring only on sites with little slope and at low elevation in the far north, often in close proximity to Environment A1. As with the previous environment, A2's climate is typified by very warm temperatures, very high solar radiation and moderate annual water deficits. Sand and peat are the dominant soils, with some estuarine alluvium. Soils are very poorly-drained and of very low natural fertility.

Level III & IV Descriptions

Level III	A2.1 – No Subdivision at Level III
Area	31,230 ha
Elevation	25 m
Location	North Cape
Climate	Very warm temperatures, very high solar radiation, moderate annual water deficits
Landform	Gently undulating hills
Soils	Very poor drainage and very low fertility from peat, sand and some estuarine alluvium
Level IV	a. – no subdivision at Level IV – same as A2.1

Environment A3

This environment is one of the smallest in the level II classification consisting of small areas of gently sloping imperfectly drained soils formed from andesitic alluvium on the tip of the North Cape. The climate of the environment is very similar to that of A1 and A2, with very warm temperatures, very high solar radiation and moderate annual water deficits. Soils are imperfectly drained and of moderate fertility.

Level III & IV Descriptions

Level III	A3.1 – No Subdivision at Level III
Area	822 ha
Elevation	20 m
Location	North Cape
Climate	Very warm temperatures, very high solar radiation, moderate annual water deficits
Landform	Gently undulating hills
Soils	Recent, imperfectly drained soils of moderate fertility from andesitic alluvium
Level IV	a. – no subdivision at Level IV – same as A3.1

Environment A4

Environment A4 occurs as small pockets scattered throughout the northern North Island in protected coastal estuaries, harbours and inlets mostly in Northland but also extending as far south as Marokopa and the Tauranga Harbour. Very warm temperatures, very high solar radiation and low annual water deficits typify the climate of Environment A4. Estuarine alluvium is the sole parent material and the calcium-rich saline soils are poorly-drained and of moderate fertility.

Level III & IV Descriptions

Level III	A4.1	A4.2
Area	8972 ha	768 ha
Elevation	10 m	10m
Location	Northland	Tauranga Harbour, Marokopa
Climate	Very warm temperatures, very high solar radiation, low annual water deficits	Very warm temperatures, very high solar radiation, low annual water deficits
Landform	Gently undulating hills	Gently undulating hills
Soils	Poorly-drained saline soils of moderate fertility from estuarine alluvium	Very poorly-drained saline soils of moderate fertility from estuarine alluvium
Level IV	a. – no subdivision at Level IV – same as A4.1	a. as for A4.2 b. cooler temperatures, higher annual water deficits c. lower solar radiation, much lower vapour pressure deficits

Environment A5

Environment A5 is widespread, consisting of flat sites at low elevation, with the most extensive areas occurring around Kaitaia and Dargaville, on the Hauraki Plains, in the Hamilton basin and on the coastal plains of the Bay of Plenty from Te Puke to Whakatane. Small patches also occur from East Cape to northern Hawke's Bay. Climatic conditions are generally cooler than in the preceding Level II environments, with only moderate rainfall deficits. Alluvium from a variety of sources, including estuarine sediments and rhyolitic and andesitic ash are dominant, along with peat and some older sands. Soils are typically poorly-drained and of low to moderate natural fertility.

Level III & IV Descriptions

Level III	A5.1	A5.2	A5.3	A5.4
Area	107,224 ha	17,920 ha	248,620 ha	12,396 ha
Elevation	40 m	70 m	30 m	50 m
Location	Scattered around Northland	West coast of Northland	Central Waikato, Hauraki Plains, East Cape	Northern Hawke's Bay
Climate	Very warm temperatures, very high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, low annual water deficits
Landform	Very gently undulating hills	Gently undulating hills	Flat terraces	Gently undulating hills
Soils	Poorly-drained peat soils of low fertility with some alluvium	Very poorly-drained soils of low fertility from sand and basaltic alluvium	Poorly-drained peat soils of low fertility	Poorly-drained soils of low fertility from rhyolitic tephra and some alluvium
Level IV	a. warmer temperature b. moderate fertility c. as for A5.1 d. lower winter temperatures, higher vapour pressure deficits, lower annual water deficits	a. – no subdivision at Level IV – same as A5.2	a. very low fertility b. as for A5.3 c. higher solar radiation, higher vapour pressure deficits, lower annual water deficits	a. moderate fertility b. undulating hills

Environment A6

Environment A6 has the highest mean elevation of the Level II environments in A, consisting of rolling hills in Northland, Auckland and northern Waikato. The largest of the A environments (nearly 50% of A's total area), it has warm temperatures, very high solar radiation and low annual water deficits. Sandstone is the most widespread soil parent material closely followed by greywacke – both are deeply weathered. Soils are imperfectly drained and are of low natural fertility.

Level III & IV Descriptions

Level III	A6.1	A6.2
Area	831,040 ha	63,088 ha
Elevation	90 m	110 m
Location	North of Auckland, Waiheke Island	South of Auckland City to Bombay Hills
Climate	Warm temperatures, very high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, low annual water deficits
Landform	Undulating hills	Undulating hills
Soils	Imperfectly drained soils of very low fertility from sandstone, mudstone and some greywacke	Imperfectly drained soils of very low fertility from greywacke with some argillite
Level IV	a. easy rolling hills, imperfect drainage b. as for A6.1 c. easy rolling hills d. high fertility, coarse parent material	a. easy rolling hills b. recent soils

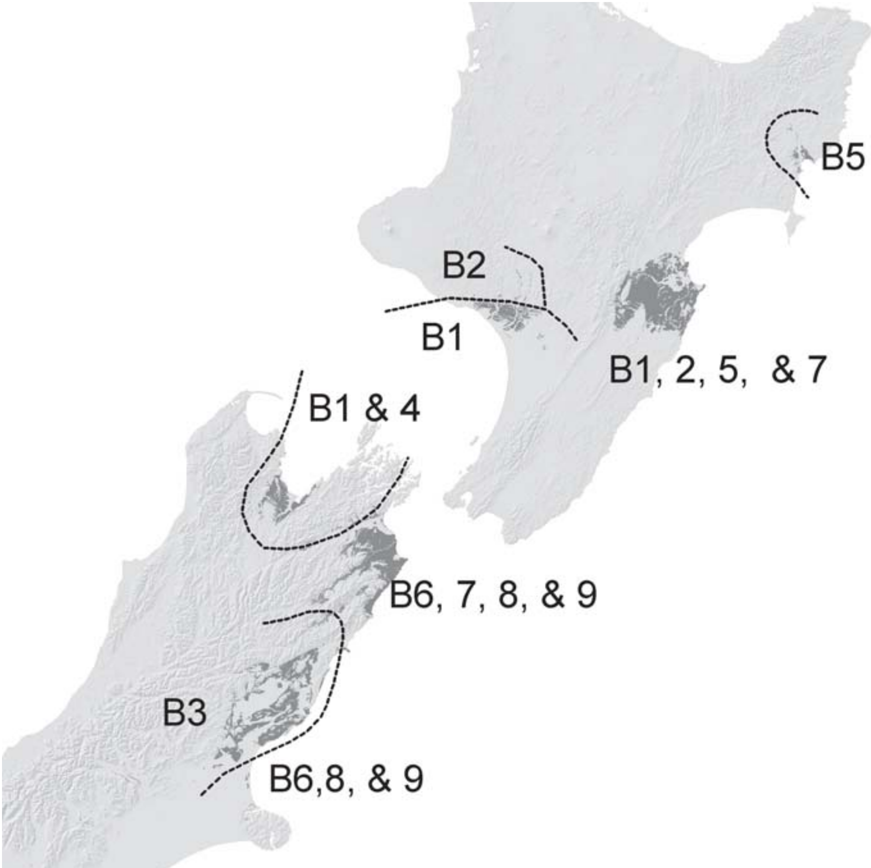
Environment A7

Environment A7 is the southernmost of the Level II environments within A, occurring on gently sloping land at low to mid-elevation in Auckland, Waikato and the Bay of Plenty with smaller areas in Northland and around Mahia Peninsula. Climatic conditions are warm with high solar radiation and low annual water deficits. Rhyolitic alluvium and tephra are the dominant soil parent materials with smaller areas of younger basaltic rock, wind-blown sand and loess. Soils are well-drained but of moderately low natural fertility.

Level III & IV Descriptions

Level III	A7.1	A7.2	A7.3
Area	61,924 ha	380,108 ha	44,396 ha
Elevation	110 m	45 m	70 m
Location	Northland, Auckland City, Rangitoto Island	Lower slopes of the Waitakere Ranges, south of Auckland, Hamilton, Tauranga	Ninety Mile Beach, Awhitu Peninsula, Mahia Peninsula
Climate	Warm temperatures, very high solar radiation, low annual water deficits	Warm temperatures in summer, moderate in winter, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, low annual water deficits
Landform	Very gently undulating hills	Very gently undulating hills	Undulating hills
Soils	Well-drained soils of high fertility from basalt	Imperfectly drained soils of low fertility from rhyolitic tephra and alluvium, some peat and greywacke	Well-drained soils of very low fertility from sand, rhyolitic tephra, some mudstone
Level IV	a. – no subdivision at Level IV – same as A7.1	a. much higher winter temperatures b. as for A7.2 c. lower winter temperatures, well-drained d. lower annual water deficits, well-drained e. higher annual water deficits, well-drained, moderate fertility	a. as for A7.3 b. higher winter temperatures

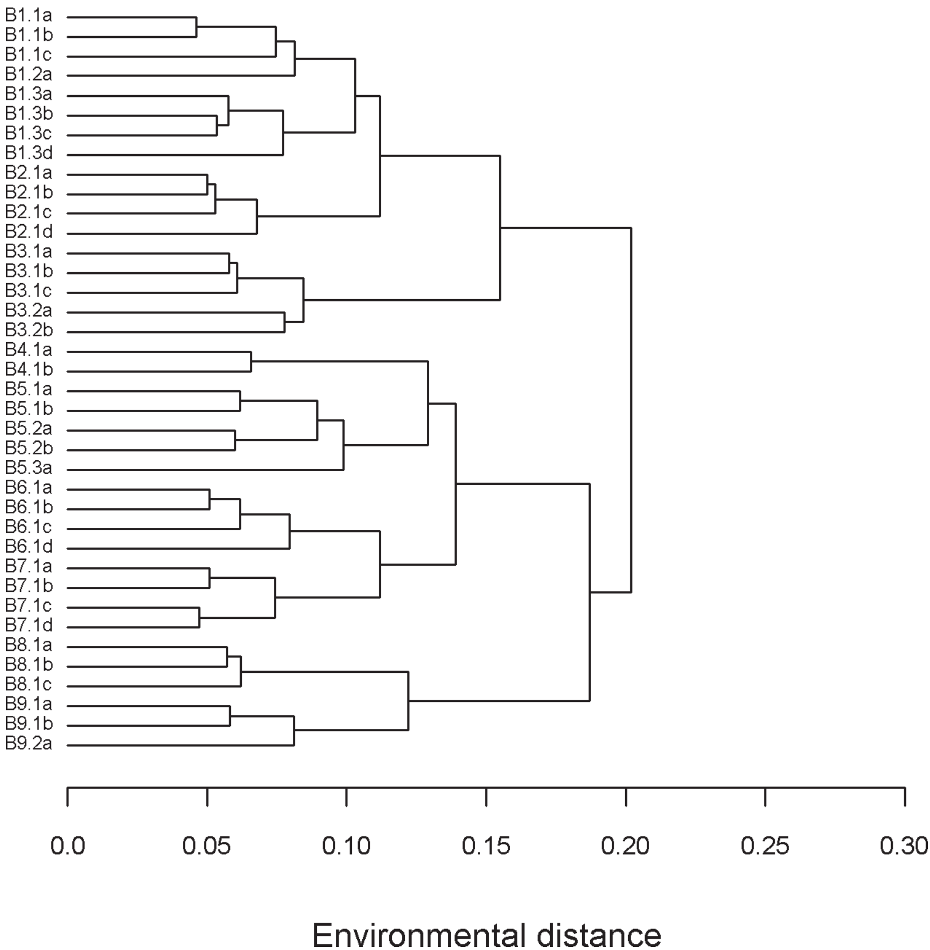
B - Central Dry Lowlands



Environment B consists of dry hill-country and older alluvial soils in central New Zealand, mostly at low elevations. It is most extensive in the east, extending from Gisborne and Hawke's Bay in the north to Marlborough and North Canterbury in the south, with smaller patches in Tasman Bay and on rolling hill-country immediately inland from Wanganui.

The climate of Environment B is dry and mild with high solar radiation, reflecting its protection from prevailing winds by mountain ranges to the west. Annual water deficits are moderate on average but may be severe in years with below-average rainfall. Vapour pressure deficits are high. The portion of Environment B located inland from Wanganui is partially protected from rain-bearing winds to the southwest and northwest by the volcanic cones of Taranaki and to a smaller extent the mountains of north-west Nelson. The terrain is generally flat to moderately sloping, with soils of low to moderate natural fertility formed on loess, alluvium, greywacke, sandstone, mudstone or limestone.

DENDROGRAM OF B



Environment	B1	B2	B3	B4	B5	B6	B7	B8	B9
Area (ha)	190,850	70,156	189,309	2715	50,198	29,343	54,544	87,207	18,791
Altitude (m)	165	313	300	66	67	111	129	350	89
Mean annual temperature (°C)	12.3	11.8	10.7	12.2	13.3	12.2	12.7	11.2	12.4
Mean minimum temperature of the coldest month (°C)	2.5	2.0	0.0	1.8	3.1	2.0	3.1	1.2	2.4
Mean annual solar radiation ($MJ/m^2/day$)	14.7	14.5	14.3	15.2	14.6	14.9	14.8	14.9	14.9
Mean winter solar radiation ($MJ/m^2/day$)	5.0	5.1	4.5	4.8	5.4	5.0	5.4	5.3	5.2
October vapour pressure deficit (kPa)	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
Monthly water balance ratio (ratio)	2.4	2.4	2.1	2.4	1.8	1.5	1.7	1.6	1.4
Mean annual water deficit (mm)	90.6	61.8	120.1	94.3	168.4	247.6	181.3	197.9	261.4
Slope (°)	6.9	4.0	9.0	1.2	1.5	3.9	5.5	13.8	2.1
Drainage (1=very poor to 5=good)	3.8	3.7	4.1	1.6	3.1	2.9	3.1	5.0	4.9
Acid soluble phosphorus (1=v. low to 5=v. high)	1.7	2.0	3.1	2.7	2.0	3.3	2.1	3.0	4.2
Exchangeable calcium (1=low to 5=v. high)	1.8	2.0	2.0	2.0	2.2	2.0	2.1	1.3	2.0
Particle size (1=clay/silt to 5=boulders–massive)	4.4	1.1	4.0	1.9	1.1	1.2	5.0	4.1	3.0
Induration (1=non-indurated to 5=v. strongly ind.)	3.6	1.1	3.7	1.9	1.2	2.1	3.9	3.6	3.4
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.8
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Environment B1

One of the most widespread Level II environments in B, B1 is extensive on undulating low hills in the Tasman, Wanganui and Hawke's Bay regions, with smaller areas on the north bank of the Wairau River in Marlborough. The climate within this environment is warm, with high solar radiation, moderate vapour pressure deficits and low annual water deficits. Parent materials vary with location and include sandstone (Wanganui), sandstone, mudstone, argillite and limestone (Hawke's Bay), deep, dissected beds of coarse gravels (Nelson) and greywacke (Marlborough). Soils are imperfectly drained and of low natural fertility.

Level III & IV Descriptions

Level III	B1.1	B1.2	B1.3
Area	63,432 ha	14,788 ha	112,664 ha
Elevation	200 m	75 m	160 m
Location	Nelson & Hawke's Bay	Motueka	Hawke's Bay, Wanganui
Climate	Mild temperatures, moderate solar radiation, low annual water deficits and low monthly water balance ratios	Mild temperatures, high solar radiation, moderately annual water deficits	Warm temperatures, high solar radiation, low annual water deficits and very low monthly water balance ratios
Landform	Strongly undulating plains and hills	Undulating plains	Undulating hills
Soils	Well-drained soils of low fertility from coarse greywacke gravels and Tertiary rocks	Soils of imperfect drainage and very low fertility from gravels	Soils of imperfect drainage and low fertility from sandstone and mudstone
Level IV	a. Tasman District, well-drained gravels b. Hawke's Bay, higher vapour pressure deficits, sandstone, limestone and greywacke, very low fertility c. Marlborough, much cooler winter temperatures, soils of imperfect drainage on greywacke, moderate fertility	a. – no subdivision at Level IV – same as B1.2	a. Wanganui – dissected sandstone hills, very low fertility b. southern Hawke's Bay, much colder winter temperature but high solar radiation, calcareous mudstone, with some argillite c. southern Hawke's Bay, higher monthly water balance ratios, cool, moist climate, calcareous mudstone, moderate fertility d. southern Hawke's Bay, limestone, very high fertility

Environment B2

This environment occurs on inland areas of the southern Hawke's Bay plains on gently sloping alluvial surfaces. The climate is mild, with high solar radiation and low annual water deficits. Soils are imperfectly drained and have low natural fertility mainly due to the parent material consisting of ryolitic tephra, loess and mixed alluvium.

Level III & IV Descriptions

Level III	B2.1 – No Subdivision at Level III
Area	70,188 ha
Elevation	310 m
Location	Southern Hawke's Bay
Climate	Mild temperatures, high solar radiation, low annual water deficits and very low monthly water balance ratios
Landform	Gently undulating plains
Soils	Imperfectly drained soils of low fertility from a mixture of rhyolitic tephra, loess and mixed alluvium
Level IV	a. higher vapour pressure deficits, mixed alluvium and loess parent materials, imperfect drainage with very low fertility b. lower annual water deficits, finer alluvial parent materials, imperfect drainage c. cooler, lower annual water deficits, rolling slope, rhyolitic ash, imperfect drainage and moderate fertility d. lower annual water deficits, well-drained soils of loess and very high fertility

Environment B3

While extensive in area, this sub-unit is largely confined to North Canterbury, with only small areas found in inland valleys of southern Marlborough. The climate is mild, with high solar radiation and moderate annual water deficits. This environment occupies easy rolling land, and parent materials are mostly younger sandstone, mudstone and limestone, with some older greywacke, some of which is overlain by loess. Soils are of moderate natural fertility and are imperfectly to moderately well-drained.

Level III & IV Descriptions

Level III	B3.1	B3.2
Area	103,112 ha	86,040 ha
Elevation	260 m	345 m
Location	North Canterbury – coastal to inland	North Canterbury – mainly inland
Climate	Mild temperatures, high solar radiation, high vapour pressure deficits and moderate annual water deficits	Mild temperatures, high solar radiation, high vapour pressure deficits and moderate annual water deficits
Landform	Easy rolling hills	Easy rolling hills
Soils	Imperfectly drained, moderately fertile soils from predominantly calcareous mudstone with some greywacke gravels	Well-drained and moderately fertile soils from greywacke rock and gravels with some limestone and Tertiary sandstone
Level IV	a. lower annual water deficits, mudstone parent material, with some coastal gravels, imperfect drainage b. much lower annual water deficits, mudstone parent materials with soils of imperfect drainage c. loess parent materials	a. cooler temperatures in winter, much lower annual water deficits with greywacke and basalt on undulating hills, high fertility b. higher annual water deficits, greywacke and limestone on strongly rolling hills

Environment B4

The least extensive of the level II B environments, B4 occupies small areas of flat alluvium and peat in the middle reaches of the Motueka River on the coast near Nelson and along the Wairau River to its mouth. The climate is mild with very high solar radiation, low annual water deficits and high vapour pressure deficits. Its most distinctive feature is its poorly to very poorly-drained soils.

Level III & IV Descriptions

Level III	B4.1 – No Subdivision at Level III
Area	2644 ha
Elevation	65 m
Location	Nelson – Motueka River
Climate	Mild temperatures, very high solar radiation, low annual water deficits and high vapour pressure deficits
Landform	Very gently undulating plains
Soils	Poorly-drained soils of moderate fertility formed from alluvium from sedimentary, granite and gabbroic rocks
Level IV	a. poor drainage with moderate acid soluble phosphorus. Particle size and induration are moderate b. very poor drainage, fine-textured soils of very low fertility formed from peat and very fine greywacke alluvium

Environment B5

This environment is the most northern of the level II B environments, occurring on gently undulating sites surrounding Gisborne and in the Hawke's Bay region. The climate of this environment is warm, with high solar radiation and moderate annual water deficits. Soils of poor to imperfect drainage and low natural fertility are formed from fine alluvium, loess, peat and estuarine sediments.

Level III & IV Descriptions

Level III	B5.1	B5.2	B5.3
Area	16,768 ha	30,424 ha	3132 ha
Elevation	15 m	100 m	30 m
Location	Gisborne, Hawke's Bay	Hawke's Bay	Gisborne
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, very low monthly water balance ratios and moderate annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, very low monthly water balance ratios and moderate annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, very low monthly water balance ratios and moderate annual water deficits
Landform	Gently undulating plains	Gently undulating plains	Gently undulating plains
Soils	Poorly-drained soils of moderate fertility from mixed alluvium	Imperfectly drained soils of low fertility from loess with small deposits of peat, argillite and sandstone	Imperfectly drained soils of low fertility from sand and rhyolitic tephra
Level IV	a. lower annual water deficits, poor drainage, high fertility b. higher annual water deficits, poor drainage, low fertility	a. well-drained soils b. imperfect drainage	a. – no subdivision at Level IV – same as B5.3

Environment B6

This environment is the first of four level II ‘B’ environments that dominate the Marlborough lowlands. It occurs in the lower reaches of the Wairau Valley, occupying sites with a mild climate, high solar radiation, high vapour pressure deficits and high annual water deficits. Soils of imperfect drainage and moderate natural fertility formed from greywacke alluvium and loess.

Level III & IV Descriptions

Level III	B6.1 – No Subdivision at Level III
Area	29,408 ha
Elevation	110 m
Location	Wairau Valley – Blenheim
Climate	Mild temperatures, high annual water deficits, high vapour pressure deficits
Landform	Undulating plains
Soils	Soils of imperfect drainage and moderate fertility formed from greywacke alluvium and loess, imperfect drainage
Level IV	a. warmer temperatures in winter, lower vapour pressure deficits, imperfect drainage b. lower annual water deficits, imperfect drainage c. warmer temperatures in winter, higher annual water deficits, imperfect drainage, gently undulating landform d. poor drainage, flat terraces, high fertility

Environment B7

This environment occurs on low elevation hill-country both in Hawke's Bay and southeast from the Awatere River and around Cape Campbell. The climate is typified by warm temperatures, high solar radiation, moderate annual water deficits and high vapour pressure deficits. Soils of imperfect drainage and low fertility are formed from sandstone and mudstone (Hawke's Bay) and calcareous mudstones (Marlborough).

Level III & IV Descriptions

Level III	B7.1 – No Subdivision at Level III
Area	54,548 ha
Elevation	130 m
Location	Southern Hawke's Bay / East of the Awatere River to Cape Campbell
Climate	Warm temperatures, high solar radiation, moderate annual water deficits, high vapour pressure deficits
Landform	Undulating plains
Soils	Imperfectly drained soils of low fertility from, sometimes calcareous, sandstone and mudstone
Level IV	a. much higher annual water deficits, imperfect drainage, high fertility b. higher annual water deficits, much higher vapour pressure deficits, imperfect drainage, high fertility, easy rolling hills c. much lower annual water deficits, imperfect drainage, very low fertility d. imperfect drainage, strongly undulating hills

Environment B8

Environment B8 is the most extensive of the Marlborough B environments, extending from the low coastal hills that separate the Wairau and Awatere valleys, inland to the upper Awatere and the lower reaches of the Clarence River. The climate is mild with high solar radiation, high vapour pressure deficits and moderate annual water deficits. Soils are well-drained and of moderate natural fertility and are formed from greywacke loess and older gravels.

Level III & IV Descriptions

Level III	B8.1 – No Subdivision at Level III
Area	87,068 ha
Elevation	350 m
Location	Coastal hills around the Wairau, Awatere and Clarence Rivers, Marlborough
Climate	Mild temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits
Landform	Strongly rolling hills
Soils	Well-drained soils of moderate fertility from greywacke loess and colluvium, sandstones
Level IV	a. much cooler winter temperatures, steep hills b. warmer temperatures, much lower vapour pressure deficits c. warmer winter temperatures, higher vapour pressure deficits

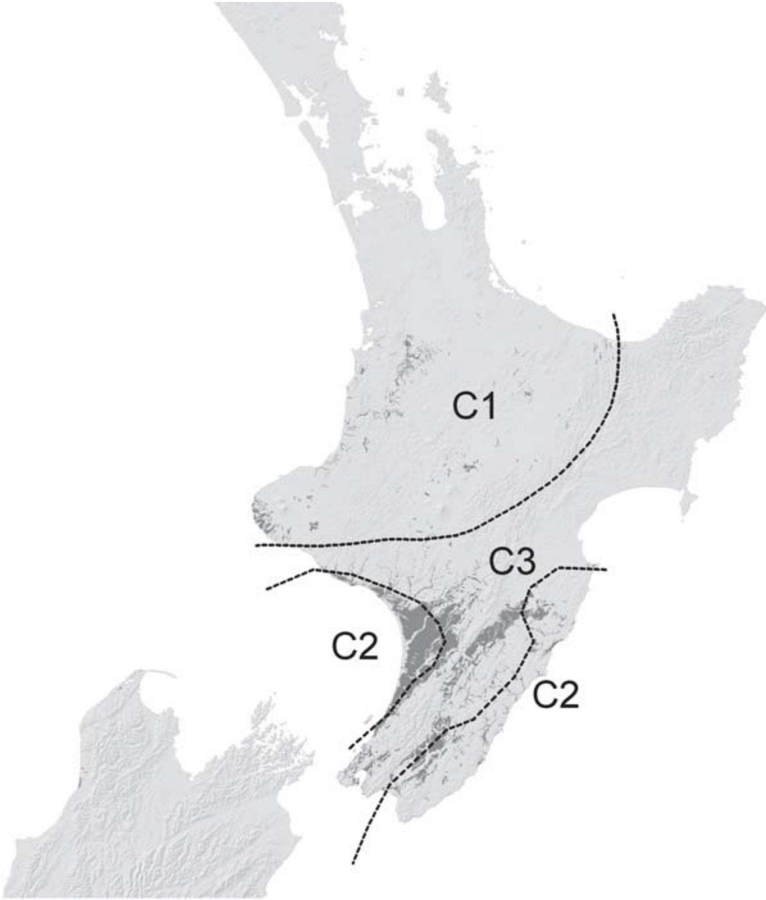
Environment B9

This environment mostly occurs on alluvial terraces of varying ages adjacent to rivers and streams in the northeastern South Island from the Wairau River south to Kaikoura. Temperatures within the environments are mild with high solar radiation, high vapour pressure deficits and high annual water deficits. Well-drained soils of high natural fertility are formed from alluvial gravels, sands and greywacke rock.

Level III & IV Descriptions

Level III	B9.1	B9.2
Area	15,528 ha	3176 ha
Elevation	75 m	150 m
Location	Valleys of the Wairau, Awatere and Clarence Rivers, Marlborough	Valleys of the Wairau, Awatere and Clarence Rivers, Marlborough
Climate	Mild temperatures, very high solar radiation, high vapour pressure deficits, high annual water deficits	Mild temperatures, very high solar radiation, very high vapour pressure deficits, high annual water deficits
Landform	Very gently undulating plains	Undulating plains
Soils	Well-drained soils of high fertility from greywacke alluvium with some loess	Imperfectly drained soils of high fertility from greywacke alluvium
Level IV	a. flat plains, strongly indurated b. higher vapour pressure deficits	a. – no subdivision at Level IV – same as B9.2

C - Western and Southern North Island Lowlands



°Environment C consists predominantly of low-lying areas of gently sloping alluvium, occurring almost entirely in the lower half of the North Island. A few small outliers occur in western Nelson and northern Buller. It is most extensive on the alluvial plains of Manawatu, Wairarapa and Wellington with smaller areas scattered through Taranaki, southern Waikato and in the Bay of Plenty lowlands.

The climate of Environment C is mild, with high solar radiation. Although the monthly water balance ratio is low, the even spread of rainfall through the year results in low average annual rainfall deficits but with occasional more intense droughts in years with below-average rainfall. Vapour pressure deficits are generally moderate but are higher in the east. Fine-textured alluvium from a variety of sources is the predominant soil parent material but with a predominance of andesitic alluvium in Taranaki, water-sorted tephra in Waikato and Bay of Plenty and loess in southern Hawke's Bay, Wairarapa and inland Manawatu. Soils generally have poor or impeded drainage and moderate natural fertility.

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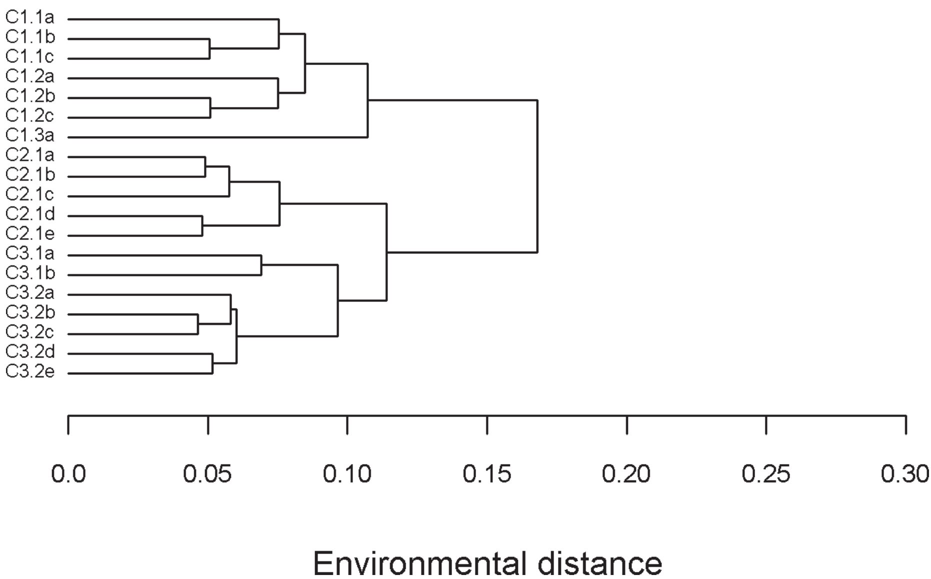


Environment	C1	C2	C3
Area (ha)	84,259	259,201	295,730
Altitude (m)	166	198	71
Mean annual temperature (°C)	12.8	12.0	12.7
Mean minimum temperature of the coldest month (°C)	3.6	3.1	3.7
Mean annual solar radiation ($MJ/m^2/day$)	14.5	14.0	14.2
Mean winter solar radiation ($MJ/m^2/day$)	5.2	4.6	4.7
October vapour pressure deficit (kPa)	0.3	0.3	0.4
Monthly water balance ratio (ratio)	3.4	2.9	2.2
Mean annual water deficit (mm)	12.7	40.5	106.5
Slope (°)	1.6	2.9	0.8
Drainage (1=very poor to 5=good)	1.8	3.8	2.9
Acid soluble phosphorus (1=v. low to 5=v. high)	2.3	2.0	2.2
Exchangeable calcium (1=low to 5=v. high)	2.0	2.0	2.0
Particle size (1=clay/silt to 5=boulders–massive)	1.3	1.0	1.3
Induration (1=non-indurated to 5=v. strongly ind.)	1.6	1.0	1.8
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0

Environment C1

Environment C1 occurs mostly as scattered small units of poorly-drained land along rivers and streams in southern Waikato, lahar deposits in Taranaki and coastal wetlands in western Nelson. The climate is warm, with high solar radiation and slight annual water deficits. Fine-textured alluvium is the predominant soil parent material and soils are poorly to very poorly-drained and of low natural fertility.

Level III & IV Descriptions

Level III	C1.1	C1.2	C1.3
Area	15,272 ha	50,660 ha	18,540 ha
Elevation	370 m	130 m	100 m
Location	Western Nelson, Taranaki	Southern Waikato, Taranaki	Taranaki
Climate	Mild temperatures, high solar radiation, slight annual water deficits	Warm temperatures, high solar radiation, slight annual water deficits	Warm temperatures, high solar radiation, slight annual water deficits
Landform	Very gently undulating plains	Gently undulating plains	Flat plains
Soils	Poorly-drained peat soils of low fertility	Poorly-drained peat soils of low fertility with some alluvium	Poorly-drained soils of high fertility from Mt Taranaki lahar deposits
Level IV	a. warmer temperatures, very poor drainage b. much cooler temperatures, very poor drainage c. cooler temperatures	a. as for C1.2 b. much cooler temperatures, very poor drainage, very low fertility c. much cooler temperatures, undulating plains, very poor drainage	a. – no subdivision at Level IV – same as C1.3

Environment C2

Environment C2 occupies gently undulating inland plains in Manawatu, southern Hawke's Bay and northern Wairarapa with smaller areas in Wellington. The climate is mild, with high solar radiation, moderate vapour pressure deficits and low annual water deficits. Loess is the predominant parent material, along with extensive areas of fine alluvium. Soils are of imperfect drainage and low natural fertility.

Level III & IV Descriptions

Level III	C2.1 – No Subdivision at Level III
Area	259,512 ha
Elevation	200 m
Location	Inland Manawatu, southern Hawke's Bay, northern Wairarapa and parts of Wellington
Climate	Mild temperatures, high solar radiation, moderate vapour pressure deficits and low annual water deficits
Landform	Gently undulating plains
Soils	Imperfectly drained soils of low fertility from loess with some fine alluvium
Level IV	a. higher annual water deficits, poorly-drained b. poorly-drained c. cooler temperatures, lower annual water deficits d. very gently undulating, well-drained e. as for C2.1

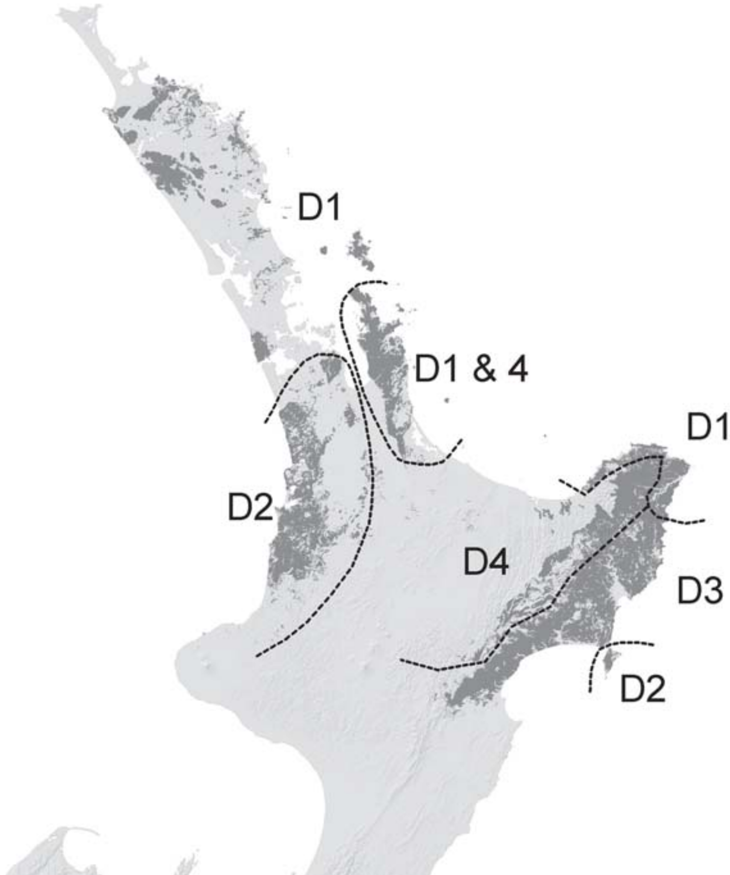
Environment C3

This environment includes the dry, flat, low-lying plains of Manawatu, southern Hawke's Bay and Wairarapa. Warm temperatures, high solar radiation, moderate vapour pressure deficits and moderate annual water deficits typify the climate. While loess is the most widespread soil parent material, alluvium and old dune sands are also common. Slopes are very gentle, and soils are generally imperfectly drained.

Level III & IV Descriptions

Level III	C3.1	C3.2
Area	72,060 ha	223,384 ha
Elevation	85 m	65 m
Location	Manawatu, southern Hawke's Bay, central Wairarapa	Manawatu, southern Hawke's Bay, central Wairarapa
Climate	Warm temperatures, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, moderate annual water deficits
Landform	Flat plains	Flat plains
Soils	Well-drained, low fertility soils of loess with some alluvium	Imperfectly drained soils of low fertility from loess with some dune sand and tephra
Level IV	a. warmer winter temperatures, imperfectly drained b. as for C3.1	a. as for C3.2 b. lower annual water deficits c. moderate fertility, strongly indurated d. gently undulating plains e. cooler winter temperatures, much higher annual water deficits

°D - Northern Hill Country



Environment D encompasses hill country of low to moderate elevation in the central and northern regions of the North Island. It occurs only sporadically at higher elevation in Northland and Auckland but is more extensive on the Coromandel Peninsula, in the west from Port Waikato south to about Mokau and in the east from the eastern Bay of Plenty to central Hawke's Bay.

Environment D has a warm climate, with high annual and winter solar radiation, low monthly water balance ratios and slight annual rainfall deficits. However, year-to-year variation in rainfall results in occasional dry years, particularly on the East Coast. Vapour pressure deficits are intermediate, although higher in the east. The terrain of Environment D is hilly with moderate to steep slopes. Soil parent materials are variable, with older volcanic rocks and greywacke widespread in the north, including on the Coromandel Peninsula while mixtures of greywacke and Tertiary rocks with some rhyolitic tephra predominate in the east. Soils are generally moderately drained and of low to moderate natural fertility.

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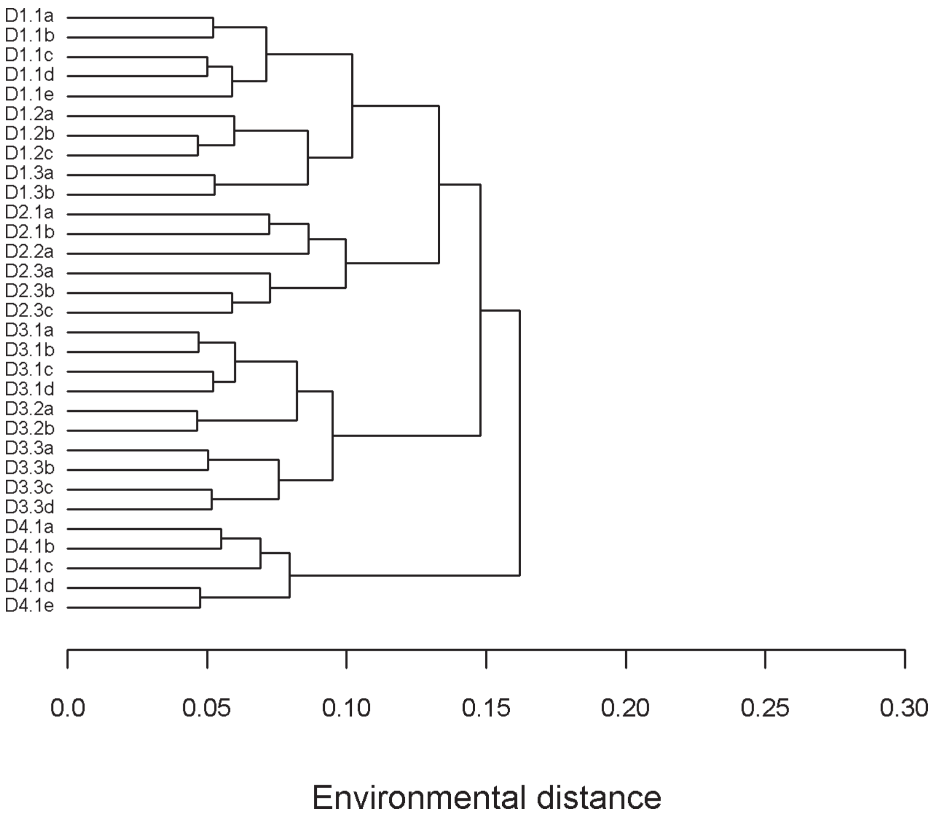


Environment	D1	D2	D3	D4
Area (ha)	662,318	447,457	687,723	306,070
Altitude (m)	217	187	263	669
Mean annual temperature (ºC)	13.8	13.1	12.8	10.7
Mean minimum temperature of the coldest month (ºC)	5.6	4.3	3.8	2.6
Mean annual solar radiation (MJ/m^2/day)	15.0	14.5	14.8	14.8
Mean winter solar radiation (MJ/m^2/day)	6.3	5.5	5.8	5.9
October vapour pressure deficit (kPa)	0.4	0.3	0.5	0.3
Monthly water balance ratio (ratio)	3.4	3.6	2.9	4.9
Mean annual water deficit (mm)	14.5	13.8	34.0	0.3
Slope (º)	12.3	9.4	11.2	18.9
Drainage (1=very poor to 5=good)	4.3	4.0	4.3	4.3
Acid soluble phosphorus (1=v. low to 5=v. high)	2.7	1.9	2.1	1.3
Exchangeable calcium (1=low to 5=v. high)	1.4	1.6	2.4	1.2
Particle size (1=clay/silt to 5=boulders–massive)	4.6	3.7	4.2	4.3
Induration (1=non-indurated to 5=v. strongly ind.)	3.9	3.4	3.4	3.9
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0

Environment D1

Environment D1 consists of hills in Northland, Auckland, Coromandel and the eastern Bay of Plenty. The climate is warm with very high solar radiation and slight annual water deficits. Predominant soil parent materials are deeply weathered older basalts (Northland), andesites and rhyolites with greywacke, argillite and sandstone locally important. Soils are generally imperfectly drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	D1.1	D1.2	D1.3
Area	412,240 ha	154,564 ha	95,428 ha
Elevation	220 m	235 m	190 m
Location	Northland, Coromandel Peninsula, Great Barrier Island, East Cape, Waitakere Ranges	Northland, Coromandel Peninsula	East Cape
Climate	Warm temperatures, very high solar radiation, low monthly water balance ratios, slight annual water deficits	Warm temperatures, very high solar radiation, low monthly water balance ratios, slight annual water deficits	Warm temperatures, very high solar radiation, high vapour pressure deficits, slight annual water deficits
Landform	Strongly rolling hills	Easy rolling hills	Rolling hills
Soils	Well-drained soils of moderate fertility from andesite or basalt	Imperfectly drained soils of moderate fertility from andesite or basalt	Imperfectly drained soils of low fertility from mudstone, greywacke and argillite
Level IV	a. warmer temperatures b. much warmer temperatures, higher annual water deficits, low fertility c. cooler temperatures, low fertility d. low fertility e. steep hills, very low fertility	a. much cooler temperatures, lower vapour pressure deficits b. warmer temperatures c. cooler temperatures, rolling hills, low fertility	a. undulating hills, very fine-textured soils from tephra and Tertiary rocks a. strongly rolling hills, very low fertility

Environment D2

This environment includes the Hunua Ranges, extensive areas of western Waikato hill-country and the Mahia Peninsula in Hawke's Bay. This environment has more gently sloping terrain and occurs at lower elevations than the other environments in D. This combined with the generally high westerly exposure results in warm temperatures with high solar radiation and slight annual water deficits. Greywacke is the most extensive soil parent material but Tertiary mudstones and rhyolitic ash are also common. Soils are moderately well-drained and of low natural fertility.

Level III & IV Descriptions

Level III	D2.1	D2.2	D2.3
Area	223,004 ha	10,944 ha	213,428 ha
Elevation	145 m	155 m	235 m
Location	Hunua Ranges, Auckland region	Western Waikato	Mahia Peninsula, Hawke's Bay
Climate	Warm temperatures, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, slight annual water deficits
Landform	Easy rolling hills	Strongly rolling hills	Easy rolling hills
Soils	Imperfectly drained soils of low fertility from calcareous mudstone or greywacke with argillite	Imperfectly drained soils of moderate fertility from mudstone	Imperfectly drained soils of low fertility from tephra, mudstone or greywacke
Level IV	a. strongly rolling hills, very low fertility b. moderate fertility	a. – no subdivision at Level IV – same as D2.2	a. as for D2.3 b. cooler temperatures, steep hills, very low fertility c. poorly-drained, very low fertility

Environment D3

Environment D3 is extensive in the eastern hills from about East Cape south to central Hawke's Bay. The climate is warm with high solar radiation and low annual water deficits. Soft calcareous mudstones and sandstones are the most widespread parent materials with harder sandstones forming local massifs. Rhyolitic ash is widespread in the west. Soils are generally well-drained and of low natural fertility.

Level III & IV Descriptions

Level III	D3.1	D3.2	D3.3
Area	256,888 ha	195,812 ha	235,116 ha
Elevation	185 m	395 m	235 m
Location	Gisborne region, northern Hawke's Bay	Gisborne region	Northern Hawke's Bay
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, low annual water deficits	Mild temperatures, high solar radiation, high vapour pressure deficits, slight annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, low annual water deficits
Landform	Rolling hills	Strongly rolling hills	Easy rolling hills
Soils	Imperfectly drained soils of moderate fertility from sometimes calcareous sandstone and mudstone	Imperfectly drained soils of moderate fertility from sometimes calcareous sandstone and mudstone	Well-drained soils of low fertility from rhyolitic tephra, sandstone and mudstone
Level IV	a. high fertility b. as for D3.1 c. higher annual water deficits, lower drainage, high fertility d. much higher annual water deficits	a. as for D3.2 b. warmer winter temperatures, steep hills, low fertility	a. strongly weathered, very fine-textured soils b. weathered, very fine-textured soils c. very coarse-textured soils d. warmer summer and winter temperatures, higher annual water deficits, low fertility, coarse-textured soils

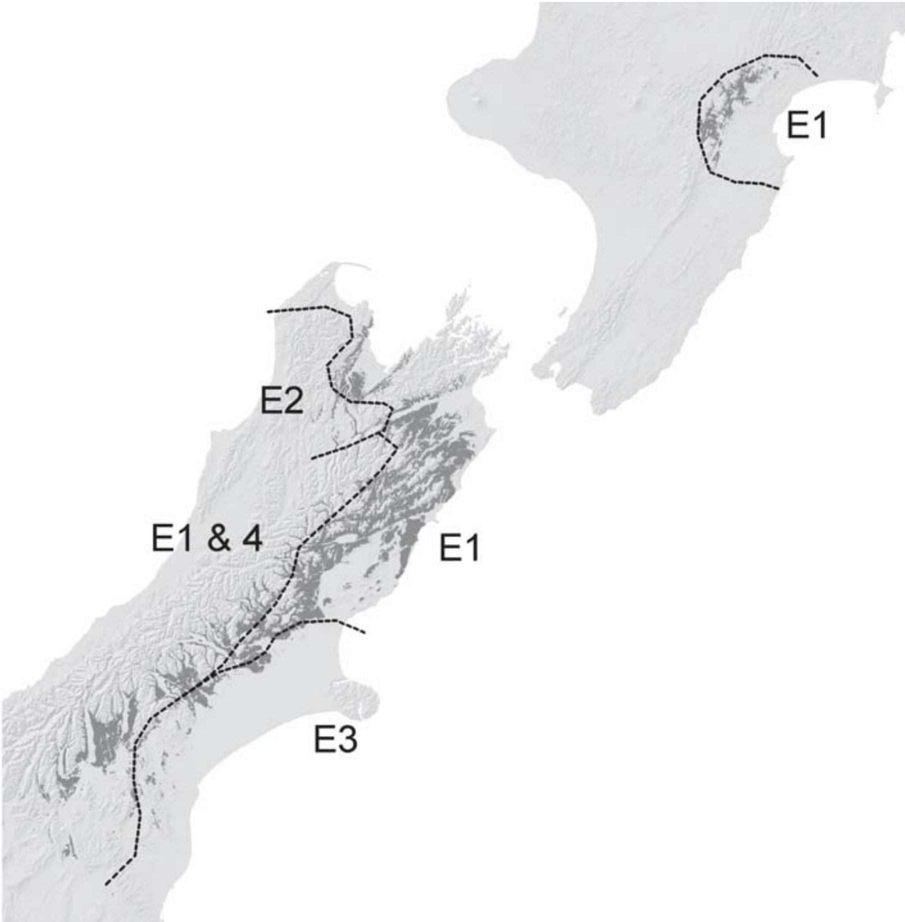
Environment D4

Environment D4 encompasses an extensive area of steep hills and mountains from the East Cape through the Urewera National Park, following the Raukumara and Huiarau Ranges, south though the North Island to the Maungaharuru Range. The climate is mild with high solar radiation, no annual water deficits and intermediate monthly water balance ratios. Greywacke with some argillite is the predominant parent material. Soils are generally well-drained and of very low natural fertility.

Level III & IV Descriptions

Level III	D4.1 – No Subdivision at Level III
Area	305,924 ha
Elevation	670 m
Location	Raukumara Range – East Cape and the Huiarau Range– Urewera National Park
Climate	Mild temperatures, high solar radiation, moderate vapour pressure deficits, no annual water deficits
Landform	Steep mountains and hills
Soils	Imperfectly drained soils of very low fertility from greywacke with some argillite, including small areas of mudstone in the Urewera National Park
Level IV	a. much warmer temperatures in both summer and winter, higher vapour pressure deficits b. as for D4.1 c. much lower temperatures, lower vapour pressure deficits, much higher monthly water balance ratios, no annual water deficits, very steep mountains d. much lower temperatures, no annual water deficits, low fertility e. low fertility

E - Central Dry Foothills



Environment E consists of dry foothills and basin floors at mid-elevations in the eastern parts of both main islands, with the largest areas occurring in the South Island. It is most extensive in inland parts of Canterbury and Marlborough, with smaller areas in Tasman Bay. In the North Island it occurs only in inland Hawke's Bay. Environment E has a cool climate with high annual solar radiation and low average annual water deficit but high October vapour pressure deficits. The latter reflects its protection from prevailing westerly winds by mountain ranges - the Southern Alps, Kaikoura Ranges, and the mountains of northwest Nelson in the South Island, and the Tongariro volcanoes and Kaimanawa and Kaweka Ranges in the North Island. Slopes are generally rolling to moderate. Sedimentary rocks are the predominant soil parent material, with greywacke the most widespread followed by schist and softer Tertiary rocks. Gravels and/or loess from greywacke are widespread in Canterbury and Nelson, and andesitic tephra occurs in Hawke's Bay. Soils are generally well drained and of moderate natural fertility.

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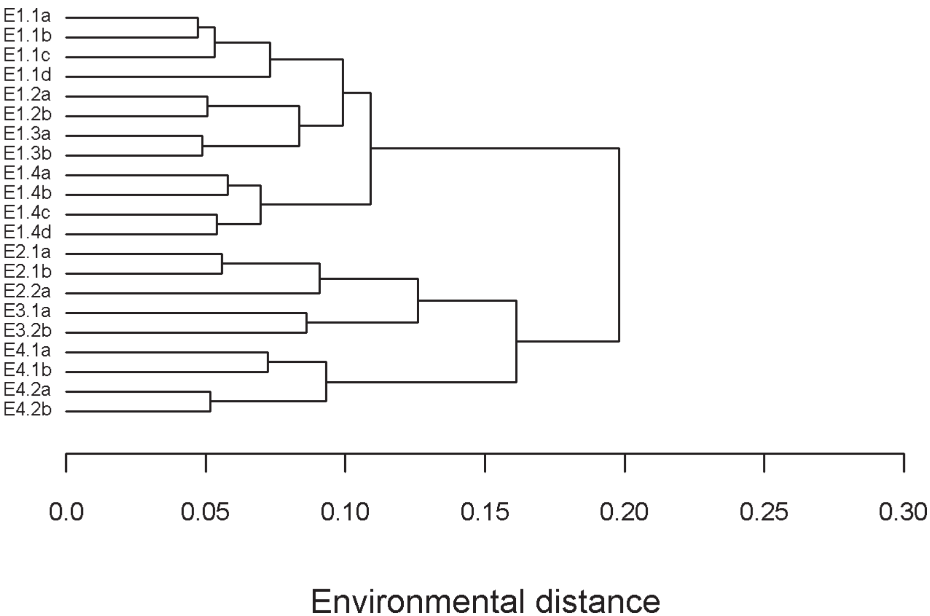


Environment	E1	E2	E3	E4
Area (ha)	921,770	16,456	68,455	320,616
Altitude (m)	638	539	466	746
Mean annual temperature (ºC)	9.3	9.5	9.6	8.4
Mean minimum temperature of the coldest month (ºC)	-0.9	-1.4	-0.9	-2.2
Mean annual solar radiation (MJ/m^2/day)	14.5	14.7	13.6	14.1
Mean winter solar radiation (MJ/m^2/day)	4.9	4.5	4.5	4.6
October vapour pressure deficit (kPa)	0.5	0.3	0.4	0.4
Monthly water balance ratio (ratio)	2.8	3.9	2.4	2.7
Mean annual water deficit (mm)	42.2	6.0	19.8	64.2
Slope (º)	19.1	7.4	6.4	6.5
Drainage (1=very poor to 5=good)	5.0	2.2	3.5	5.0
Acid soluble phosphorus (1=v. low to 5=v. high)	2.7	2.6	3.1	3.9
Exchangeable calcium (1=low to 5=v. high)	1.2	1.5	2.0	1.1
Particle size (1=clay/silt to 5=boulders–massive)	3.9	3.7	1.4	3.0
Induration (1=non-indurated to 5=v. strongly ind.)	3.8	2.1	2.3	2.1
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0

Environment E1

Environment E1 has a large geographic range occurring from inland Hawke's Bay to Nelson, Marlborough and Canterbury. The climate is cool with high solar radiation, high vapour pressure deficits and low annual water deficits. Slopes are higher than in the other Level II environments in E, reflecting the dominance of dissected hill landforms mostly with sedimentary rock parent materials but with small amounts of rhyolitic, basaltic and andesitic rock and/or ash, granite, and marble. Steep, dissected beds of coarse gravel (Moutere Gravels) are extensive in Nelson. Soils are well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	E1.1	E1.2	E1.3	E1.4
Area	202,168 ha	93,068 ha	64,816 ha	562,572 ha
Elevation	435 m	620 m	295 m	755 m
Location	Hawke's Bay, Golden Bay, Blenheim plains	Hills south of Blenheim	Coastal hills north and south of Kaikoura	Inland hills from Marlborough south to mid-Canterbury
Climate	Mild temperatures, very high solar radiation, low annual water deficits	Cool temperatures, high solar radiation, moderate annual water deficits	Mild temperatures, warm solar radiation, high vapour pressure deficits, low annual water deficits	Cool temperatures, high solar radiation, low annual water deficits
Landform	Strongly rolling foothills	Steep foothills	Steep foothills	Steep foothills
Soils	Well-drained, low fertility soils from Moutere / Pleistocene gravels	Well-drained, moderate fertility soils from greywacke	Well-drained, moderate fertility soils from greywacke	Well-drained, moderate fertility soils from greywacke
Level IV	a. lower vapour pressure deficits, very low fertility b. warmer temperatures c. higher annual water deficits, moderate fertility d. steep foothills	a. as for E1.2 b. warmer winter temperatures, coarse-textured soils	a. lower annual water deficits, very steep foothills b. higher annual water deficits	a. very high solar radiation b. much colder winter temperatures, much higher annual water deficits c. as for E1.4 d. higher temperatures, higher annual water deficits

Environment E2

The environment is of limited extent occurring as scattered pockets (approximately 16,000 ha in total) in the upper parts of the Motueka catchment. As a consequence of its exposure to moist westerly winds, the climate is cool with high solar radiation and slight annual water deficits. Soils are poorly-drained and are formed from Tertiary mudstones and sandstones, greywacke and coarse gravels with moderate natural fertility.

Level III & IV Descriptions

Level III	E2.1	E2.2
Area	12,540 ha	3876 ha
Elevation	150 m	730 m
Location	Upper parts of the Motueka catchment	Upper parts of the Motueka catchment
Climate	Cool temperature, high solar radiation, slight annual water deficits	Cool temperature, high solar radiation, no annual water deficits
Landform	Easy rolling hills	Undulating hills
Soils	Imperfectly drained soils of moderate fertility from loess with some greywacke alluvium, mudstones and sandstones	Poorly-drained soils of low fertility from alluvium from sedimentary rocks
Level IV	a. finer texture soils a. rolling hills	a. – no subdivision at Level IV – same as E2.2

Environment E3

Environment E3 occurs on gently sloping sites along the inland foothills bordering the Canterbury Plains. Climatically this environment has cool temperatures, moderate solar radiation, very low monthly water balance ratios and slight annual water deficits. Loess is the predominant soil parent material, with smaller areas of gravel formed from greywacke and quartz. Soils are moderately fertile but are imperfectly drained.

Level III & IV Descriptions

Level III	E3.1	E3.2
Area	30,100 ha	32,232 ha
Elevation	570 m	380 m
Location	Northern and Mid-Canterbury	Mid-and Southern Canterbury
Climate	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, slight annual water deficits	Mild temperatures, moderate solar radiation, high vapour pressure deficits, low annual water deficits
Landform	Easy rolling foothills	Undulating foothills
Soils	Imperfectly drained soils of moderate fertility from loess from greywacke and schist	Imperfectly drained soils of moderate fertility from loess from greywacke and schist
Level IV	a. – no subdivision at Level IV – same as E3.1	a. same as E3.2 b. lower elevation foothills, warmer temperatures

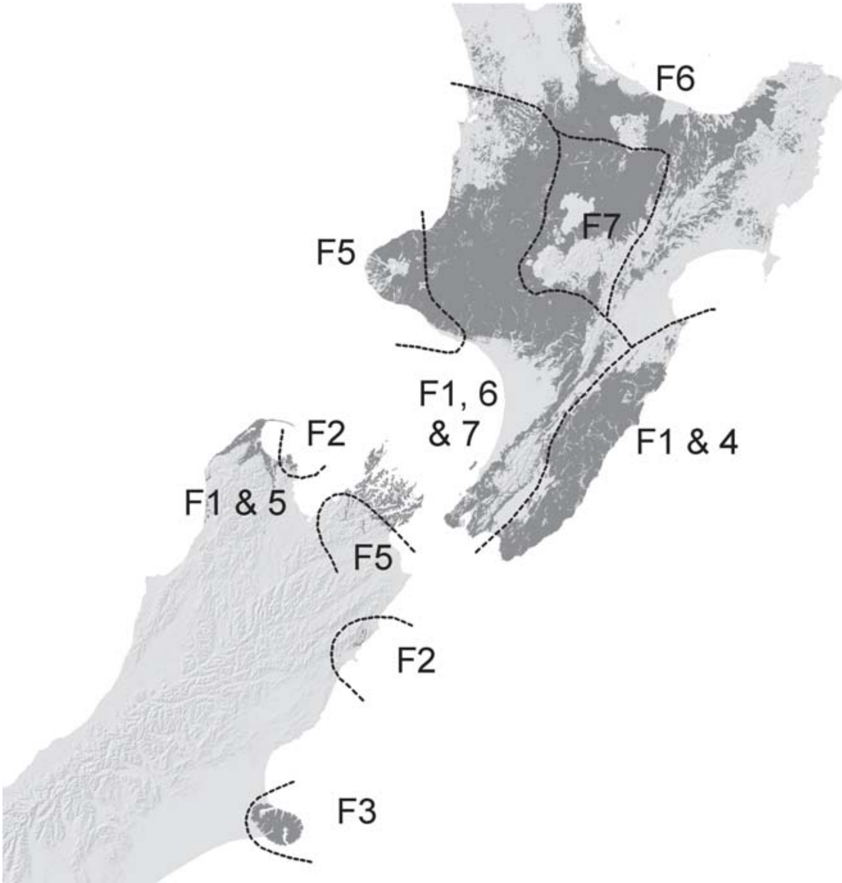
Environment E4

This environment is quite widespread, occurring in inland valleys throughout Canterbury. The climate is generally cool with high solar radiation, moderate vapour pressure deficits and low annual water deficits. Parent materials for Environment E4 consist of greywacke alluvium with some loess, colluvium and till. Soils are generally well-drained and have high natural fertility.

Level III & IV Descriptions

Level III	E4.1	E4.2
Area	151,320 ha	169,336 ha
Elevation	700 m	785 m
Location	Central South Island, east of the Southern Alps	Central South Island, east of the Southern Alps, closer to the coast
Climate	Cool temperatures, high solar radiation, high vapour pressure deficits, very low monthly water balance ratios, moderate annual water deficits	Cool temperatures, high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Gently undulating foothills	Easy rolling foothills
Soils	Well-drained, high fertility soils from greywacke alluvium with some loess, colluvium and till	Well-drained, high fertility soils from greywacke alluvium with some loess, colluvium and till
Level IV	a. much higher annual water deficits b. as for E4.1	a. as for E4.2 b. higher temperatures, lower monthly water balance ratios, higher annual water deficits

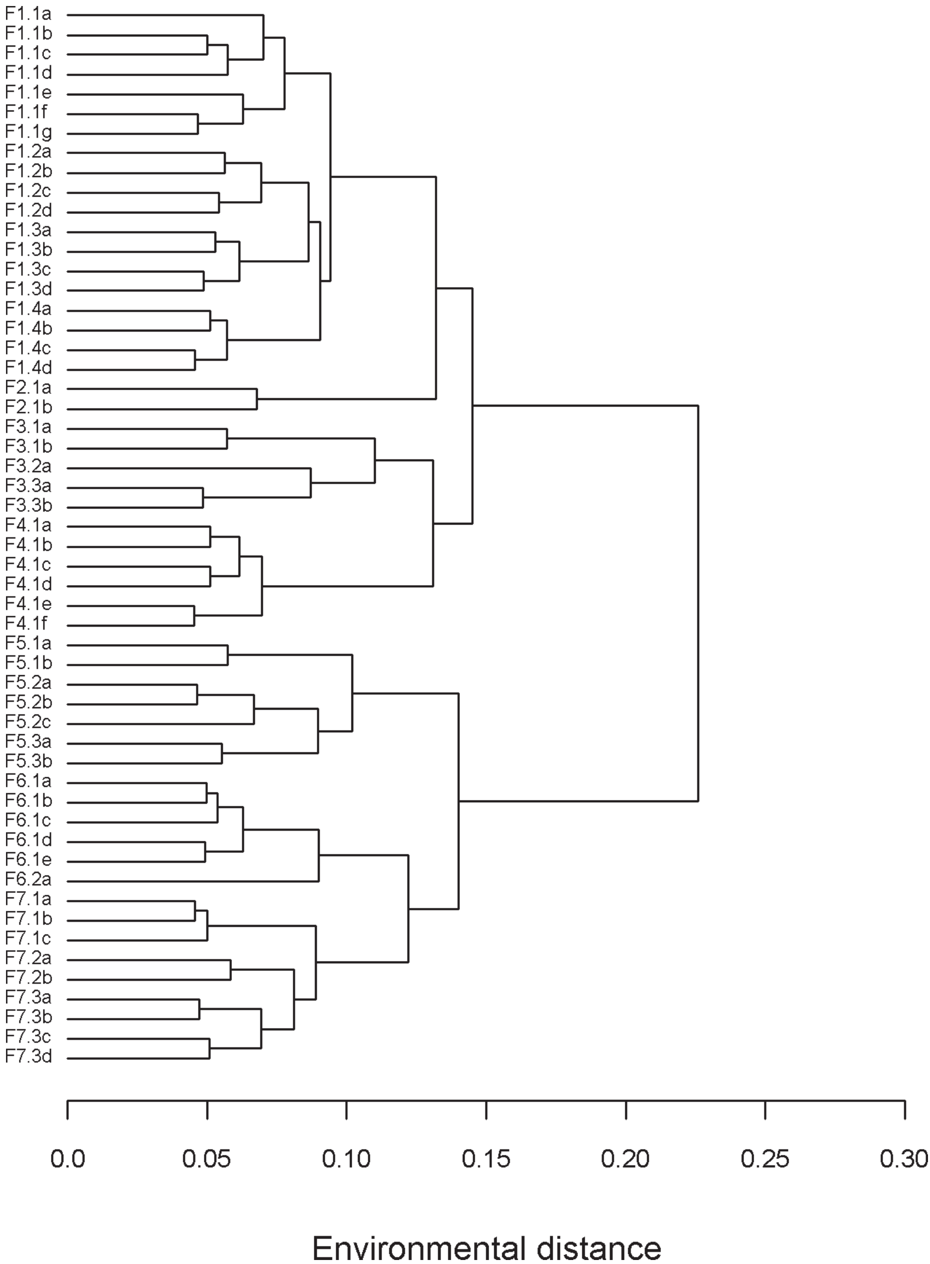
F - Central Hill Country and Volcanic Plateau



°Environment F extends across large areas of low to mid-elevation hill country in central and southern North Island, extending along the western flanks of the Raukumara Range in the northeast to Taranaki in the west and to Wellington and Wairarapa in the south. In the South Island it occurs on the northern coastal hills of northwest Nelson, in the Marlborough Sounds, around Kaikoura and on Banks Peninsula.

The climate of Environment F is mild, with high levels of annual solar radiation and moderate winter solar radiation. Although it has a low monthly water balance ratio, the even spread of rainfall throughout the year means that rainfall deficits are slight on average but with droughts in years with below-average rainfall, particularly in the east. A diverse range of soil parent materials include older Mesozoic greywacke and granite, younger Tertiary sandstones and mudstones, and a range of volcanic tephra, mostly rhyolitic in the central North Island but with more fertile andesitic tephra around the Tongariro volcanoes and Taranaki. Loess dominates on Banks Peninsula but with some protruding basaltic rock. Soils are generally well-drained and many are of low natural fertility.

DENDROGRAM OF F



Environment	F1	F2	F3	F4	F5	F6	F7
Area (ha)	1,826,616	13,393	96,130	386,468	302,141	1,196,632	1,431,198
Altitude (m)	312	216	272	176	168	355	507
Mean annual temperature (ºC)	11.5	11.7	11.0	12.2	12.5	12.1	10.9
Mean minimum temperature of the coldest month (ºC)	2.7	2.3	3.2	3.5	4.4	2.6	1.5
Mean annual solar radiation (MJ/m^2/day)	14.2	15.0	13.7	14.0	14.7	14.8	14.4
Mean winter solar radiation (MJ/m^2/day)	4.8	4.7	4.5	4.7	5.0	5.7	5.1
October vapour pressure deficit (kPa)	0.3	0.4	0.4	0.4	0.3	0.3	0.3
Monthly water balance ratio (ratio)	3.6	3.8	2.8	2.8	4.0	3.7	3.5
Mean annual water deficit (mm)	20.6	3.2	104.0	93.3	16.3	5.2	6.8
Slope (º)	13.6	13.0	16.6	7.9	2.2	10.6	5.7
Drainage (1=very poor to 5=good)	4.6	3.0	4.1	4.3	4.9	5.0	4.9
Acid soluble phosphorus (1=v. low to 5=v. high)	1.5	1.7	3.5	2.4	4.6	2.0	1.8
Exchangeable calcium (1=low to 5=v. high)	1.3	1.9	2.0	2.0	1.9	1.9	1.3
Particle size (1=clay/silt to 5=boulders–massive)	4.7	4.9	2.1	4.8	1.3	1.1	1.6
Induration (1=non-indurated to 5=v. strongly ind.)	3.8	3.9	2.6	3.2	2.2	2.1	2.5
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Environment F1

Environment F1 is the largest and most geographically diverse of the Level II environments. It is most extensive in the North Island where it includes old volcanic cones of southern Waikato, extensive dissected Tertiary hills of inland Taranaki and northern Manawatu, and low to mid-elevation hills in Wellington and Wairarapa. Smaller areas in the northern South Island include dissected low elevation hills in the Marlborough Sounds and in Golden Bay. The climate is mild with high solar radiation and slight annual water deficits. Predominant parent materials include Tertiary sandstones, mudstones and argillites with some volcanic material in the north and greywacke in Wellington and Wairarapa. Soils are well-drained and of low natural fertility.

Level III & IV Descriptions

Level III	F1.1	F1.2	F1.3	F1.4
Area	845,824 ha	296,024 ha	394,452 ha	290,292 ha
Elevation	325 m	200 m	370 m	305 m
Location	Northern Taranaki and south Waikato volcanic cones	Coastal Wairarapa and Marlborough Sounds	Southern Taranaki and Manawatu	Wellington and Wairarapa
Climate	Mild temperatures, high solar radiation, moderate vapour pressure deficits, slight annual water deficits	Mild temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits	Mild temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits	Mild temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits
Landform	Strongly rolling hills	Steep hills	Strongly rolling hills	Strongly rolling hills
Soils	Well-drained, low fertility soils from mudstone and sandstone	Well-drained, low fertility soils from greywacke and argillite	Well-drained, low fertility soils from mudstone and sandstone	Imperfectly drained soils of very low fertility from mudstone sandstone, greywacke and argillite

Level III	F1.1	F1.2	F1.3	F1.4
Level IV	a. higher monthly water balance ratios, no annual water deficits b. much warmer temperatures, steep hills c. moderate fertility, moderate induration d. steep hills, very low fertility e. much higher vapour pressure deficits, easy rolling hills f. higher annual water deficits, easy rolling hills g. much cooler temperatures, very high fertility	a. lower annual water deficits b. moderate fertility c. higher annual water deficits, very low fertility d. strongly rolling hills, very low fertility	a. steep hills, imperfectly drained b. warmer temperatures, steep hills, very low fertility c. very low fertility d. cooler temperatures, higher annual water deficits.	a. easy rolling hills b. much warmer winter temperatures c. lower annual water deficits, steep hills d. low fertility

Environment F2

Environment F2 consists of a very small pocket of low elevation hill-country in the Abel Tasman National Park. The climate is mild but receives very high amounts of solar radiation and has almost no annual water deficits. Soils generally have imperfect drainage and are formed predominantly on granite but with some calcareous mudstone and marble.

Level III & IV Descriptions

Level III	F2.1 – No Subdivision at Level III
Area	13,308 ha
Elevation	215 m
Location	Abel Tasman National Park
Climate	Mild temperatures, very high solar radiation, negligible annual water deficits
Landform	Strongly rolling hills
Soils	Imperfectly drained soils of low fertility from granite and mudstone
Level IV	a. lower vapour pressure deficits, very low fertility b. much higher vapour pressure deficits, high fertility

Environment F3

Environment F3 is located on Banks Peninsula and has a mild climate with moderate solar radiation and moderate annual water deficits. It encompasses the eroded remnants of old basaltic volcanoes whose steep slopes are now largely mantled with loess. Soils have moderate to high natural fertility, particularly where loess deposits are thin enough to expose the underlying basalt.

Level III & IV Descriptions

Level III	F3.1	F3.2	F3.3
Area	54,900 ha	10,936 ha	30,256 ha
Elevation	185 m	200 m	455 m
Location	Banks Peninsula	Banks Peninsula	Banks Peninsula
Climate	Mild temperatures, moderate solar radiation, moderate vapour pressure deficits, moderate annual water deficits	Mild temperatures, moderate solar radiation, moderate vapour pressure deficits, moderate annual water deficits	Mild temperatures, moderate solar radiation, moderate vapour pressure deficits, low annual water deficits
Landform	Strongly rolling hills	Strongly rolling hills	Steep hills
Soils	Imperfectly drained soils of moderate fertility from loess derived from greywacke and schist	Well-drained, very high fertility soils from weathered basalt	Well-drained, high fertility soils from a combination of loess derived from greywacke and schist and weathered basalt
Level IV	a. higher annual water deficits b. much lower annual water deficits, steep hills	a. – no subdivision at Level IV – same as F3.2	a. very high fertility, well-drained, coarse-textured soils b. moderate fertility, well-drained, fine-textured soils

Environment F4

This environment consists of the southeastern coastal hills of Hawke's Bay, Wairarapa, and Wellington. The climate is mild with high solar radiation, moderate vapour pressure deficits and low annual water deficits. Soils are generally moderately to well-drained and are formed from easily weathered Tertiary mudstones with some argillite, limestone and sandstone with small amounts of older greywacke.

Level III & IV Descriptions

Level III	F4.1 – No Subdivision at Level III
Area	386,468 ha
Elevation	175 m
Location	Hawke's Bay, Wairapa, and Wellington
Climate	Mild temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits
Landform	Easy rolling hills
Soils	Imperfectly drained soils of low fertility from mudstone, sandstone and argillite
Level IV	a. moderate fertility b. warmer temperatures, higher annual water deficits, well-drained, moderate fertility c. lower annual water deficits, rolling hills, moderate fertility d. rolling hills, moderate fertility e. very low fertility f. higher annual water deficits, rolling hills, imperfect drainage

Environment F5

Environment F5 encompasses the rolling lower slopes of the Taranaki ringplain with smaller areas at low elevation in Golden Bay and the inner Marlborough Sounds. This environment has a warm climate with high solar radiation. The annual water deficit is slight, mainly because of exposure to rain-bearing westerly winds. Soils are generally well-drained and of high natural fertility and are formed from either andesitic ash and lahar deposits (Taranaki) or alluvium from granite and sedimentary rocks (northern South Island).

Level III & IV Descriptions

Level III	F5.1	F5.2	F5.3
Area	30,928 ha	250,028 ha	21,064 ha
Elevation	50 m	160 m	470 m
Location	Golden Bay, Marlborough Sounds	Taranaki plains	Lower slopes of Mt Taranaki
Climate	Mild temperatures, high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Warm temperatures high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Mild temperatures high solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits
Landform	Gently undulating plains	Gently undulating ringplain	Undulating low slopes of the Mt Taranaki ringplain
Soils	Imperfectly drained soils of moderate fertility from sedimentary alluvium	Well-drained, very high fertility soils from Taranaki andesitic tephra	Well-drained, very high fertility soils from Taranaki andesitic tephra
Level IV	a. imperfect drainage b. well-drained	a. higher monthly water balance ratios b. warmer temperatures c. lower monthly water balance ratios, higher annual water deficits	a. lower winter temperatures, imperfect drainage b. well-drained

Environment F6

This environment extends from the Waikato across southeastern parts of the Coromandel Peninsula through coastal Bay of Plenty and down through the Urewera ranges to inland Gisborne and Hawke's Bay. The climate is generally mild with high solar radiation and slight annual water deficits. Soils are mostly formed from older rhyolitic ash and are well-drained but of low natural fertility.

Level III & IV Descriptions

Level III	F6.1	F6.2
Area	879,336 ha	317,624 ha
Elevation	315 m	470 m
Location	Waikato, southeastern Coromandel Peninsula, coastal Bay of Plenty, inland Gisborne and Hawke's Bay	Urewera ranges, small vein running southern end of the Coromandel Peninsula, western side of East Cape
Climate	Mild temperatures, high solar radiation, low monthly water balance ratios, slight annual water deficits	Mild temperatures, high solar radiation, no annual water deficits
Landform	Undulating hills	Steep mountains
Soils	Well-drained, low fertility soils from mid-age rhyolitic tephra	Well-drained, low fertility soils from mid age rhyolitic tephra
Level IV	a. warmer temperatures b. cooler temperatures c. cooler temperatures d. warmer temperatures, higher annual water deficits f. cooler temperatures, lower vapour pressure deficits	a. – no subdivision at Level IV – same as F6.2

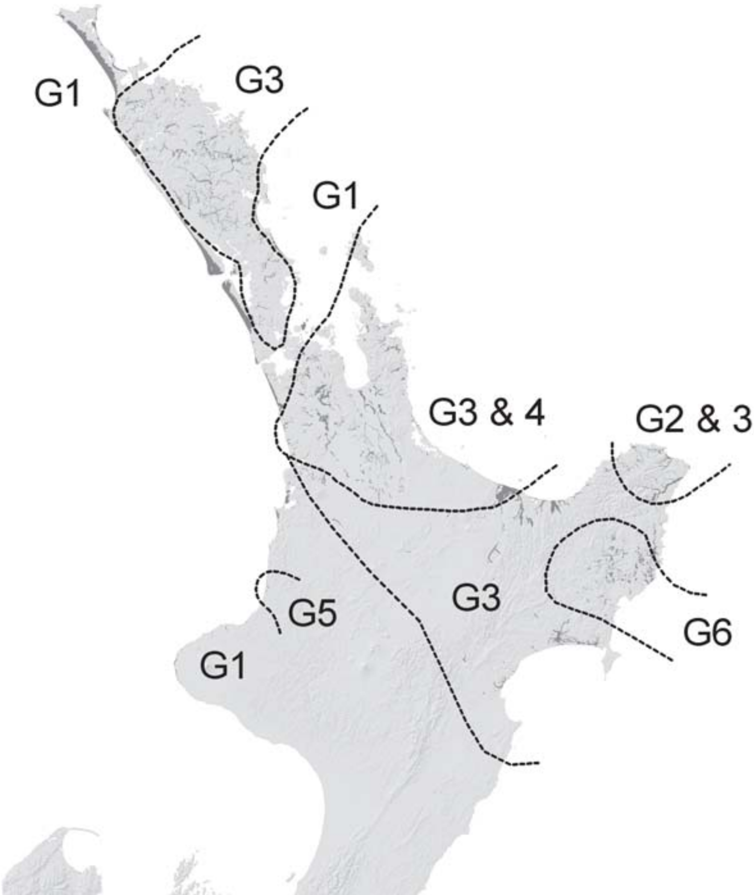
Environment F7

Environment F7 encompasses undulating landforms of the central volcanic plateau and has the highest mean elevation (~500 m average) of all the F-group environments. The climate is mild with winter minimum temperatures often lowered by severe inversion frosts. Solar radiation is high. The distinctive, well-drained but relatively infertile soils are formed from rhyolitic ash, much of it deposited in a major eruption approximately 1800 years ago. More fertile soils formed from andesitic ash from the Tongariro volcanoes occur in the south.

Level III & IV Descriptions

Level III	F7.1	F7.2	F7.3
Area	546,480 ha	599,512 ha	284,768 ha
Elevation	520 m	390 m	730 m
Location	Northeastern volcanic plateau, surrounding Lake Taupo	Northwestern volcanic plateau	Southern volcanic plateau
Climate	Mild temperatures, high solar radiation, slight annual water deficits	Mild temperatures, high solar radiation, slight annual water deficits	Mild temperatures, high solar radiation, slight annual water deficits
Landform	Undulating volcanic plateau	Easy rolling volcanic plateau	Undulating volcanic plateau
Soils	Well-drained, very low fertility soils from rhyolitic flow tephra	Well-drained, low fertility soils from rhyolitic and andesitic tephra some of which is water sorted	Well-drained, low fertility soils from andesitic tephra
Level IV	a. warmer temperatures b. as for F7.1 c. lower temperatures, flat volcanic plateau	a. strongly rolling volcanic plateau, moderate fertility b. cooler temperatures, undulating volcanic plateau	a. cooler temperatures b. cooler temperatures, higher vapour pressure deficits c. warmer temperatures, easy rolling volcanic plateau, imperfect drainage d. higher annual water deficits, rolling volcanic plateau

G - Northern Recent Soils



°Environment G consists of recent soils in the lowlands of the northern two-thirds of the North Island and is dominated by two contrasting landforms. The first consists of narrow alluvial floodplains along rivers and larger streams distributed throughout Northland, Auckland, Waikato, Bay of Plenty and Gisborne, and extending into northern Hawke's Bay in the east and to coastal Taranaki in the west. The second includes coastal sand dunes that are most extensive along the west coast of the northern North Island. Environment G also includes smaller areas of land in which soils are formed from erosion debris from greywacke and argillite, soft Tertiary rocks, estuarine alluvium and peat. Environment G has a warm climate with very high annual and winter solar radiation, reflecting its northern location. Average water deficits are low and vapour pressure deficits are moderate, but the low monthly water balance ratio results in droughts in years with below-average rainfall, particularly in the east. The terrain is generally flat to gently sloping. Soils are typically well-drained but of low to moderate fertility.

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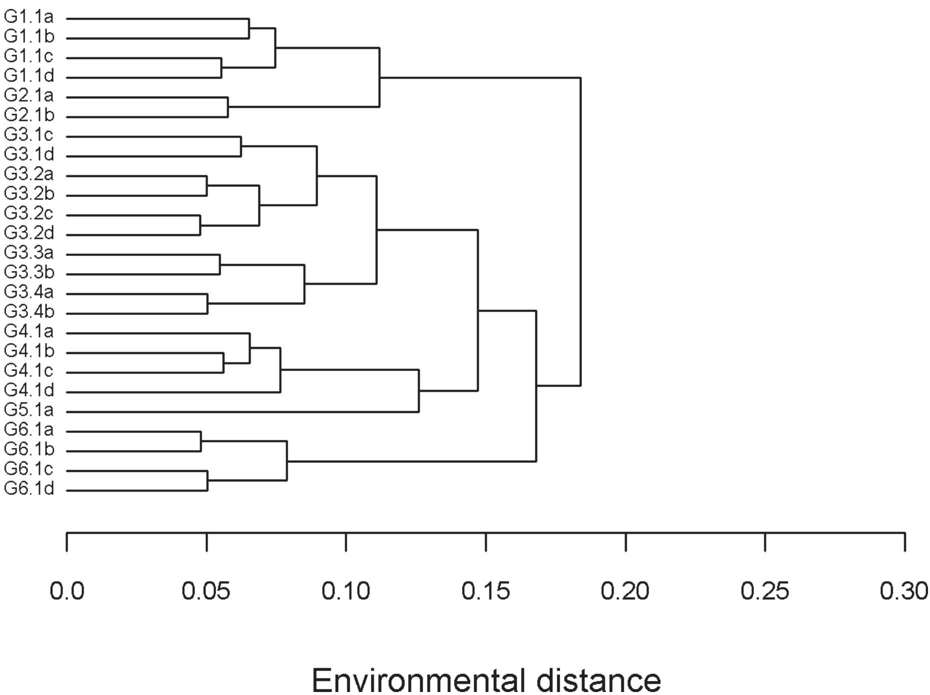


Environment	G1	G2	G3	G4	G5	G6
Area (ha)	105,092	8363	151,604	57,129	353	21,535
Altitude (m)	49	91	47	24	16	1840
Mean annual temperature (°C)	15.0	14.2	14.5	14.2	13.9	13.2
Mean minimum temperature of the coldest month (°C)	7.2	5.2	5.2	4.5	5.8	3.9
Mean annual solar radiation (MJ/m^2/day)	15.1	15.1	14.9	14.9	14.4	14.8
Mean winter solar radiation (MJ/m^2/day)	6.4	6.3	6.0	5.8	5.2	5.9
October vapour pressure deficit (kPa)	0.4	0.5	0.4	0.4	0.3	0.5
Monthly water balance ratio (ratio)	2.2	3.9	2.8	2.6	3.3	2.6
Mean annual water deficit (mm)	85.4	6.9	37.7	45.9	10.3	57.4
Slope (°)	2.5	4.3	1.7	0.6	2.3	8.2
Drainage (1=very poor to 5=good)	5.0	5.0	4.1	1.8	1.0	3.4
Acid soluble phosphorus (1=v. low to 5=v. high)	1.0	1.0	2.0	2.0	2.0	2.4
Exchangeable calcium (1=low to 5=v. high)	1.0	1.0	2.2	2.1	3.0	2.5
Particle size (1=clay/silt to 5=boulders–massive)	2.0	3.7	1.2	1.2	1.0	3.2
Induration (1=non-indurated to 5=v. strongly ind.)	4.0	4.0	1.2	1.0	1.0	2.4
Soil Age (1=raw/recent, 2=older)	1.0	1.0	1.0	1.0	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	2.0	1.0

Environment G1

Environment G1 consists of coastal sands occurring from Cape Egmont to North Cape along the North Island's west coast and from Auckland City north in the east. It is most extensive about the Kaipara Peninsulas and along Ninety Mile Beach. Climatic conditions are very warm, with very high levels of solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and low annual water deficits. Dunes sands are by far the most extensive soil parent material, but small areas of argillite and greywacke with recent soils also occur on Motutapu Island in the Hauraki Gulf. Soils are well-drained but of low natural fertility.

Level III & IV Descriptions

Level III	G1.1 – No Subdivision at Level III
Area	105,224 ha
Elevation	50 m
Location	West coast of northern North Island, some islands in the Hauraki Gulf
Climate	Very warm temperatures, very high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, low annual water deficits
Landform	Gently undulating coastal dunes
Soils	Recent, well-drained soils of very low fertility from dune sands
Level IV	a. warmer temperatures, higher annual water deficits, North Cape b. higher annual water deficits, easy rolling coastal dunes, west coast south of Ninety Mile beach c. cooler winter temperatures, Hauraki Gulf islands d. much cooler temperatures, much lower annual water deficits, Port Waikato south to Cape Egmont

Environment G2

Environment G2 occurs predominantly along the coastal rivers and streams at the northern end of the Raukamara Range, but a small area also occurs to the west of Tauranga Harbour. The climate is warm, with very high levels of solar radiation, high vapour pressure deficits (reflecting the more eastern location) and slight annual water deficits. Soil parent materials in the east consist of coarse erosion debris from greywacke and argillite while dune sands predominate on the Tauranga coast. The natural soil fertility is low and drainage is moderate.

Level III & IV Descriptions

Level III	G2.1 – No Subdivision at Level III
Area	8308 ha
Elevation	95 m
Location	East Cape, Tauranga
Climate	Warm temperatures, very high levels of solar radiation, high vapour pressure deficits, slight annual water deficits
Landform	Undulating coastal and river plains
Soils	Recent, well-drained soils of very low fertility from greywacke, argillite and sand
Level IV	a. lower temperatures, easy rolling floodplains b. as for G2.1

Environment G3

Environment G3 is widely distributed along gently sloping flood-plains of rivers and larger streams throughout the northern half of the North Island, occurring in Northland, Waikato, the Bay of Plenty, the more coastal parts of Gisborne, and northern and central Hawke's Bay. The climate is warm with high solar radiation, high vapour pressure deficits and low annual water deficits. Soil parent materials are mostly fine-textured alluvium with some rhyolitic ash, dune sand and loess. Drainage is moderate and the natural soil fertility is moderate to low.

Level III & IV Descriptions

Level III	G3.1	G3.2	G3.3	G3.4
Area	71,080 ha	34,332 ha	38,952 ha	7348 ha
Elevation	50 m	45 m	45 m	50 m
Location	Northland	Port Waikato area, coastal East Cape	Bay of Plenty, Whakatane, Waikato	Northern Hawke's Bay
Climate	Very warm temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, low annual water deficits	Warm temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, low annual water deficits
Landform	Very gently undulating flood plains	Gently undulating flood plains	Very gently undulating flood plains	Gently undulating flood plains
Soils	Recent, imperfectly drained soils of low fertility from mixed alluvium	Recent, imperfectly drained soils of low fertility from mixed alluvium	Recent, well-drained soils of low fertility from mixed alluvium	Recent, well-drained soils of low fertility from mixed alluvium
Level IV	a. well-drained soils, moderate fertility b. as for G3.1	a. much warmer temperatures, lower annual water deficits b. higher vapour pressure deficits c. imperfect drainage d. high fertility	a. as for G3.3 b. moderately indurated	a. higher annual water deficits, very low fertility, well indurated b. as for G3.4

Environment G4

Environment G4 is much less extensive than the previous environment, occurring on flat terrain from Auckland and northern Coromandel to the Bay of Plenty. The climate is warm, with high levels of solar radiation, moderate vapour pressure deficits and low annual water deficits. Alluvium from a variety of sources is the dominant parent material with some peat and estuarine alluvium. Soils are poorly-drained and of moderate to low natural fertility.

Level III & IV Descriptions

Level III	G4.1 – No Subdivision at Level III
Area	57,048 ha
Elevation	25 m
Location	Auckland, Coromandel, Bay of Plenty
Climate	Warm temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits
Landform	Very gently undulating flood plains
Soils	Recent, poorly-drained soils of low fertility from mixed alluvium
Level IV	a. much warmer winter temperatures, lower annual water deficits b. much cooler winter temperatures c. as for G4.1 d. saline soils

Environment G5

Environment G5 is of very limited extent, consisting of three coastal wetlands on the north Taranaki coast at Mokau and Waitoetoe. The climate is warm, with high solar radiation, low vapour pressure deficits and slight annual water deficits. These wetlands have very poorly-drained, saline soils formed from fine estuarine alluvium.

Level III & IV Descriptions

Level III	G5.1 – No Subdivision at Level III
Area	348 ha
Elevation	15 m
Location	North Taranaki
Climate	Warm temperatures, high solar radiation, low vapour pressure deficits, slight annual water deficits
Landform	Very gently undulating wetlands
Soils	Recent, very poorly-drained, saline soils of moderate fertility from estuarine alluvium
Level IV	a. – no subdivision at Level IV – same as G5.1

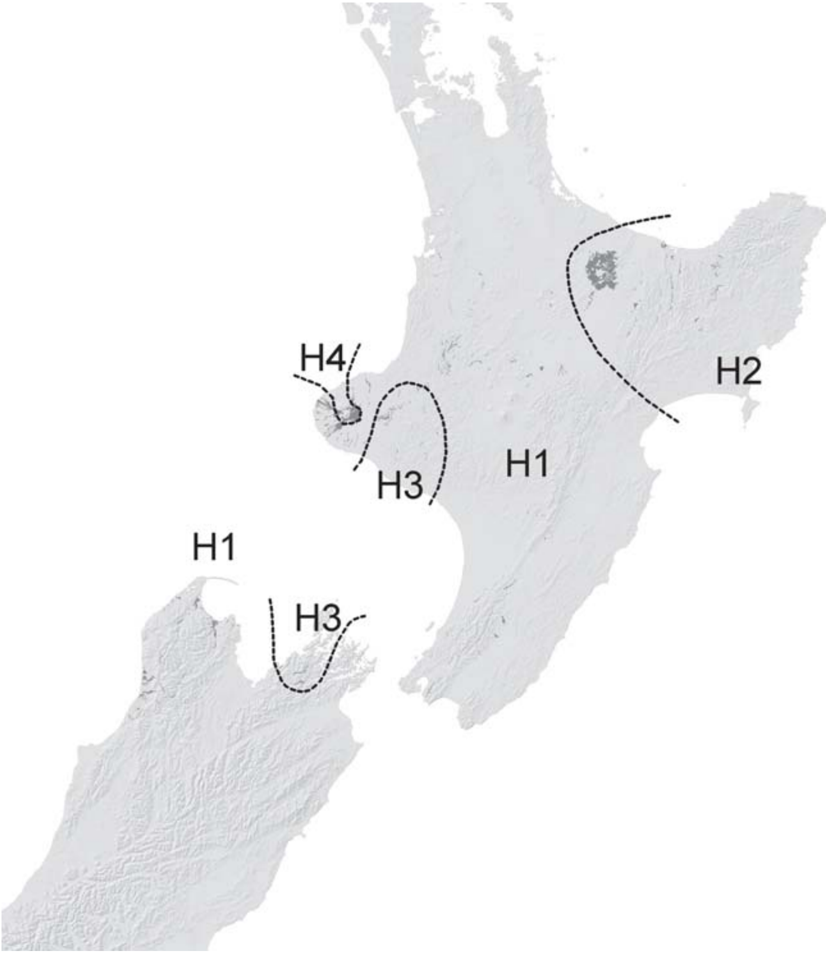
Environment G6

Environment G6 occurs on gently sloping but highly erodable hills in the Gisborne District. Climatically this environment is warm, with high solar radiation, high vapour pressure deficits and slight annual water deficits. Parent materials are mainly calcareous mudstone and sandstone with some argillite. Soils are recent, imperfectly drained and of moderate natural fertility

Level III & IV Descriptions

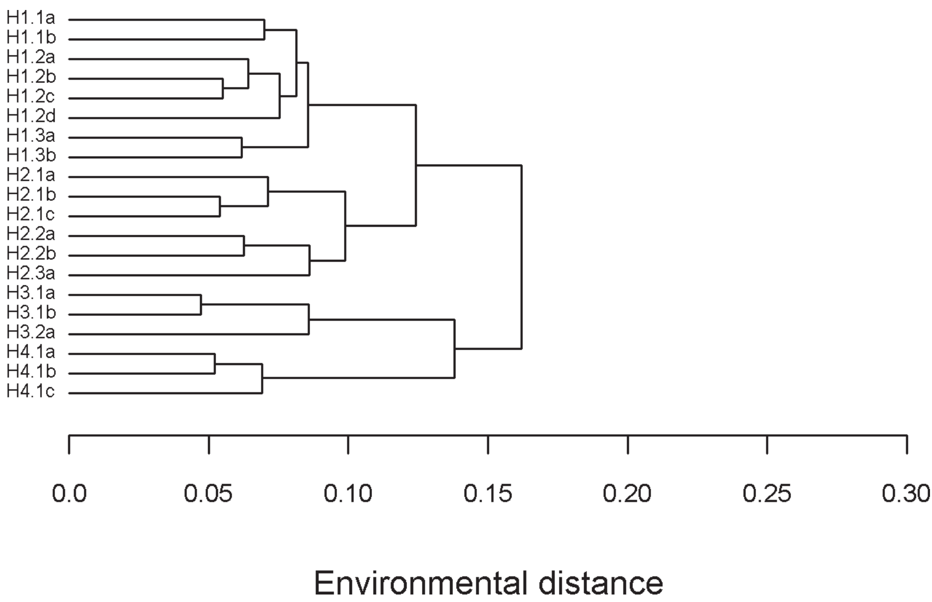
Level III	G6.1 – No Subdivision at Level III
Area	21,560 ha
Elevation	190 m
Location	East Cape
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, slight annual water deficits
Landform	Easy rolling hills
Soils	Recent, imperfectly drained soils of moderate fertility from calcareous mudstone, sandstone and some argillite
Level IV	a. low fertility b. lower annual water deficits, high fertility c. higher annual water deficits, high fertility d. much higher annual water deficits, low fertility

H - Central Sandy Recent Soils



Environment H consists of scattered areas of recent soils formed generally on sandy parent materials in the central and southern North Island and the northern South Island. The two largest areas occur on the Taranaki ring-plain and in the zone affected by the Tarawera eruption of 1886. Environment H has a mild climate with high solar radiation, moderate vapour pressure deficits and slight annual water deficits. The majority of the parent materials are sandy but come from a variety of sources, including Rotomahana mud and basaltic lapilli from the Tarawera eruption, rhyolitic and andesitic tephra, weakly indurated sandstone and alluvium from granite, greywacke and softer Tertiary rocks. Soils are mostly moderately to well drained but small areas have impeded or poor drainage. Soil fertility varies widely depending on the soil parent material, with highest fertility occurring on andesitic tephra in contrast to the low fertility on alluvial deposits of rhyolitic tephra.

DENDROGRAM OF H



Environment	H1	H2	H3	H4
Area (ha)	53,723	61,278	8370	13,912
Altitude (m)	171	431	129	669
Mean annual temperature (°C)	12.3	11.5	12.2	9.6
Mean minimum temperature of the coldest month (°C)	3.4	1.4	2.6	2.0
Mean annual solar radiation (MJ/m^2/day)	14.5	15.0	14.7	14.6
Mean winter solar radiation (MJ/m^2/day)	4.9	5.6	4.7	5.0
October vapour pressure deficit (kPa)	0.3	0.3	0.3	0.2
Monthly water balance ratio (ratio)	4.5	3.6	4.4	8.7
Mean annual water deficit (mm)	4.8	4.5	1.3	0.0
Slope (°)	3.1	6.9	3.4	5.1
Drainage (1=very poor to 5=good)	4.8	4.8	2.4	3.4
Acid soluble phosphorus (1=v. low to 5=v. high)	1.7	2.8	2.9	4.3
Exchangeable calcium (1=low to 5=v. high)	1.8	1.5	2.5	2.2
Particle size (1=clay/silt to 5=boulders–massive)	1.7	2.1	2.4	1.2
Induration (1=non-indurated to 5=v. strongly ind.)	1.3	2.7	2.1	1.8
Soil Age (1=raw/recent, 2=older)	1.0	1.0	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0

Environment H1

Environment H1 occurs widely at low to moderate elevations throughout the central and southern North Island and along the north coast of the northern South Island. The climate is mild with high solar radiation, moderate vapour pressure deficits and slight annual water deficits. It includes lower elevation, well-drained soils of low natural fertility formed from water sorted pumice (Taupo basin), greywacke alluvium (southern North Island), andesitic ash (Taranaki) and granite (South Island).

Level III & IV Descriptions

Level III	H1.1	H1.2	H1.3
Area	17,036 ha	20,288 ha	16,436 ha
Elevation	92 m	220 m	200 m
Location	North-west South Island	Taupo, Wairarapa	Taranaki
Climate	Mild temperatures, high solar radiation, slight annual water deficits	Mild temperatures, high solar radiation, slight annual water deficits	Warm temperatures, high solar radiation, slight annual water deficits
Landform	Gently undulating hills	Undulating hills	Very gently undulating hills
Soils	Recent, well-drained soils of very low fertility from granite and alluvium from granite	Recent, well-drained soils of low fertility from mixed alluvium	Recent, well-drained soils of moderate fertility from andesitic alluvium
Level IV	a. as for H1.1 b. lower temperatures, higher monthly water balance ratios, nil annual water deficits	a. much lower winter temperatures b. as for H1.2 c. higher temperatures, easy rolling land d. much higher winter temperatures, strongly indurated parent materials	a. as for H1.3 b. lower temperatures, higher monthly water balance ratios

Environment H2

Environment H2 is concentrated primarily in central and eastern Bay of Plenty with small areas in inland parts of Gisborne and northern Hawke's Bay. Climatically this environment is varied, with mild temperatures, very high solar radiation and slight annual water deficits. Dominant soil parent materials are Tarawera lapilli, rhyolitic ash, and alluvium from greywacke, but it also includes a small area of weakly indurated sandstone just east of Whakatane. Soils are well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	H2.1	H2.2	H2.3
Area	11,956 ha	48,388 ha	980 ha
Elevation	380 m	440 m	670 m
Location	Rotorua District	Rotorua District	Urewera National Park
Climate	Mild temperatures, high solar radiation, slight annual water deficits	Mild temperatures, very high solar radiation, slight annual water deficits	Mild temperatures, high solar radiation, slight annual water deficits
Landform	Gently undulating hills	Easy rolling hills	Steep hills
Soils	Recent, imperfectly drained soils of low fertility from Rotomahana mud and mixed alluvium	Recent, well-drained soils of moderate fertility from Tarawera lapilli and rhyolitic tephra	Recent, imperfectly drained soils of moderate fertility from calcareous sandstone and a small amount of rhyolitic tephra
Level IV	a. warmer temperatures, imperfect drainage b. much warmer winter temperatures c. moderate fertility	a. rolling hills, low fertility b. high fertility, strongly indurated	a. – no subdivision at Level IV – same as H2.3

Environment H3

Environment H3 occurs in three locations: eastern Taranaki primarily along the Mangehu River; northwestern Marlborough along the Pelorus and Whangamoa Rivers; and northern Buller on the lower flood-plain of the Karamea River. The climate is mild, with high solar radiation and slight annual water deficits. Soil parent materials are andesitic alluvium (Taranaki), greywacke gravels (Marlborough) and mixed alluvium. Soils mostly have poor or imperfect drainage and are moderately fertile.

Level III & IV Descriptions

Level III	H3.1	H3.2
Area	5216 ha	3124 ha
Elevation	175 m	60 m
Location	Taranaki	Marlborough and Buller
Climate	Mild temperatures, high solar radiation, high vapour pressure deficits, slight annual water deficits	Mild temperatures, very high solar radiation, high vapour pressure deficits, slight annual water deficits
Landform	Gently undulating flood plains	Undulating flood plains
Soils	Recent, poorly-drained soils of high fertility from andesitic alluvium	Recent, imperfectly drained soils of high fertility from greywacke gravels with some loess
Level IV	a. warmer winter temperatures, high fertility b. as for H3.1	a. – no subdivision at Level IV – same as H3.2

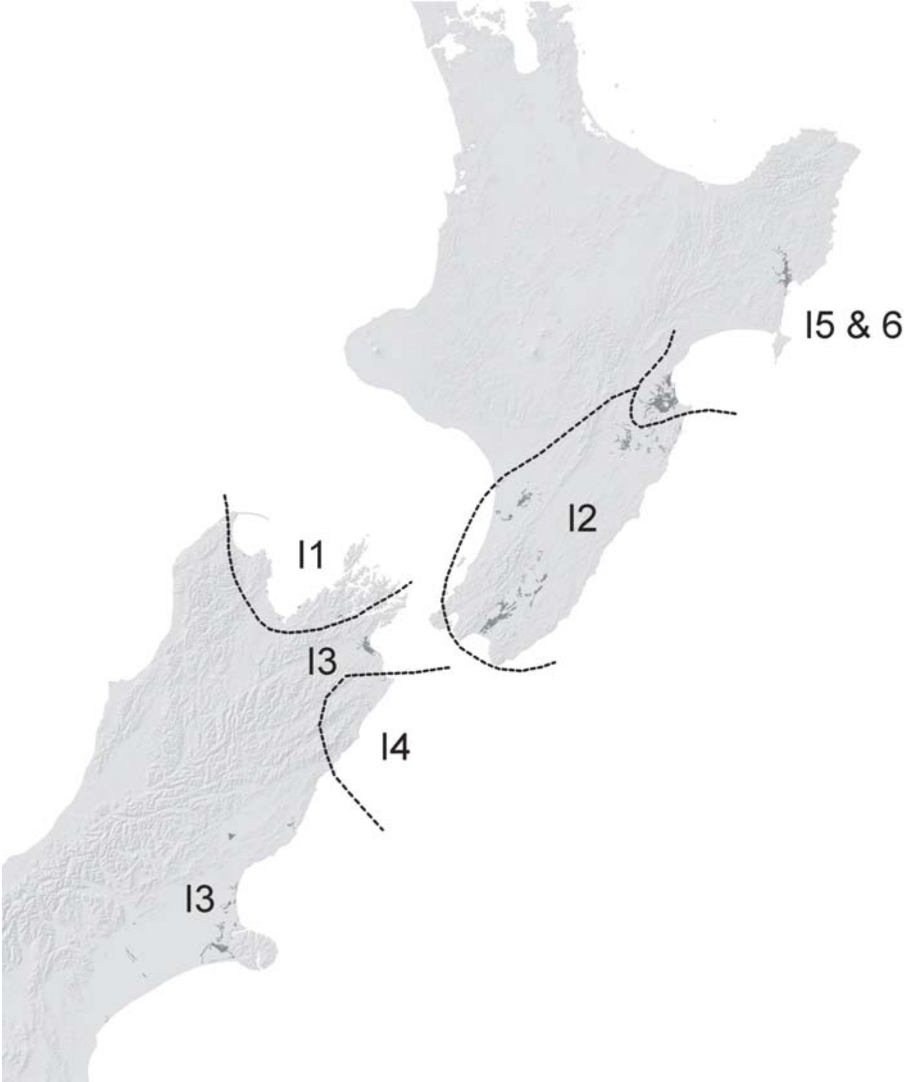
Environment H4

Environment H4 occurs on upper parts of the Taranaki ring-plain and consequently is one of the higher elevation environments in H. The climate is cool, with high solar radiation, low vapour pressure deficits, high monthly water balance ratios and nil annual water deficits. Soils, formed from fine-textured andesitic tephra and alluvium, have high natural fertility but imperfect drainage.

Level III & IV Descriptions

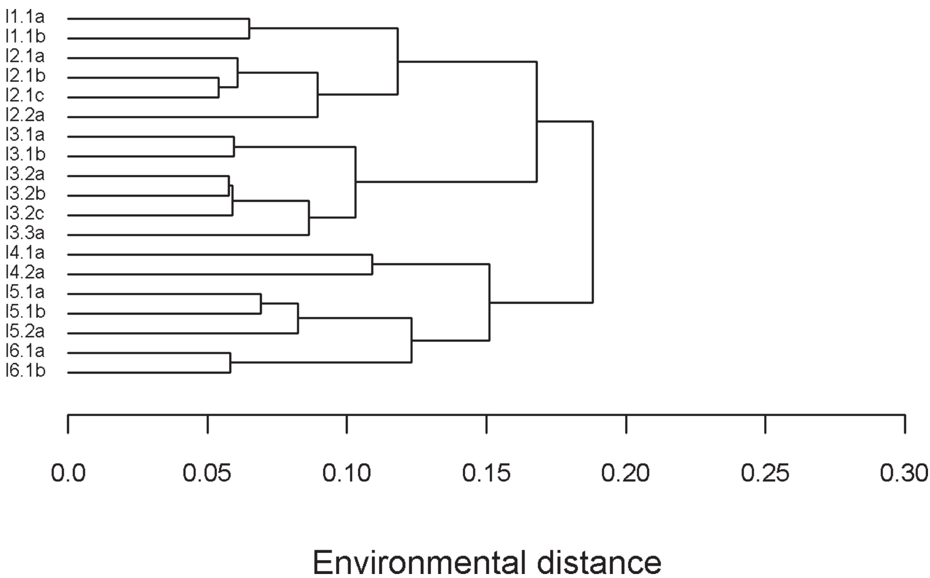
Level III¨	H4.1 – No Subdivision at Level III
Area¨	13,872 ha
Elevation¨	670 m
Location¨	Mt Taranaki
Climate¨	Cool temperatures, high solar radiation, low vapour pressure deficits, high monthly water balance ratios, nil annual water deficits
Landform¨	Undulating ring plain
Soils¨	Recent, imperfectly drained soils of high fertility from andesitic tephra and alluvium
Level IV¨	a. warmer temperatures, very high fertility b. moderate fertility c. much lower temperatures, higher monthly water balance ratios, easy rolling ring plain, very high fertility

I - Central Poorly Drained Recent Soils



°Environment I consists of scattered pockets of poorly drained recent soils that occur mostly on coastal plains and river valleys in eastern New Zealand from Gisborne to mid-Canterbury. The climate is typified by warm temperatures, high annual solar radiation, moderate annual water deficits and high vapour pressure deficits. The terrain is generally flat and soils are very poorly to imperfectly drained. Recent alluvium from a variety of sources is the dominant soil parent material with some loess. Soil fertility is moderate, with some saline soils, particularly on coastal sites.

DENDROGRAM OF I



Environment	I1	I2	I3	I4	I5	I6
Area (ha)	1776	48,891	27,991	427	39,194	4363
Altitude (m)	10	70	35	62	24	6
Mean annual temperature (°C)	12.5	12.6	11.9	12.5	13.6	13.8
Mean minimum temperature of the coldest month (°C)	2.8	3.4	1.6	3.6	3.3	4.0
Mean annual solar radiation ($MJ/m^2/day$)	15.1	14.1	14.2	14.8	14.7	14.8
Mean winter solar radiation ($MJ/m^2/day$)	4.7	4.6	4.4	5.2	5.4	5.5
October vapour pressure deficit (kPa)	0.4	0.4	0.5	0.6	0.5	0.5
Monthly water balance ratio (ratio)	3.5	2.4	1.7	1.5	1.7	1.7
Mean annual water deficit (mm)	34.1	106.9	221.3	225.1	183.1	181.8
Slope (°)	0.8	0.6	0.2	2.9	0.3	0.4
Drainage (1=very poor to 5=good)	2.0	2.0	2.5	2.0	3.8	1.2
Acid soluble phosphorus (1=v. low to 5=v. high)	4.0	2.0	4.0	4.0	2.3	2.0
Exchangeable calcium (1=low to 5=v. high)	2.0	2.1	2.0	2.0	2.3	3.0
Particle size (1=clay/silt to 5=boulders–massive)	1.0	1.0	1.0	1.0	1.1	1.0
Induration (1=non-indurated to 5=v. strongly ind.)	1.0	1.0	1.5	2.0	1.0	1.0
Soil Age (1=raw/recent, 2=older)	1.0	1.0	1.0	1.1	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	2.0	1.1	1.5	1.0	1.0	1.9

Environment I1

Environment I1 consists of several small areas of poorly-drained coastal alluvium in the northern South Island, occurring from the base of Farewell Spit to the inner Marlborough Sounds. It is distinguished by its combination of mild temperatures, very high solar radiation, low annual water deficits and saline soils that are of high natural fertility.

Level III & IV Descriptions

Level III¨	I1.1 – No Subdivision at Level III
Area¨	1760 ha
Elevation¨	10 m
Location¨	Marlborough Sounds, Farewell Spit
Climate¨	Mild temperatures, very high solar radiation, low monthly water balance ratios, low annual water deficits
Landform¨	Very gently undulating plains
Soils¨	Poorly-drained soils of high fertility from saline coastal alluvium
Level IV¨	a. lower annual water deficits b. lower monthly water balance ratios, much higher annual water deficits, flat plains

Environment I2

Environment I2 is the largest of the Level II environments in I, accounting for 40% of the total area. It occurs in three distinct locations in the North Island: southern Hawke's Bay, Manawatu and Wairarapa. The climate is typified by warm temperatures, high solar radiation and moderate annual water deficits. Fine-textured, recent alluvium from a variety of sources is the dominant soil parent material along with some loess. Soils are poorly-drained and of low natural fertility.

Level III & IV Descriptions

Level III	I2.1	I2.2
Area	46,404 ha	2712 ha
Elevation	75 m	10 m
Location	Southern Wairarapa, southern Hawke's Bay, Palmerston North area	Palmerston North area, southern Wairarapa
Climate	Warm temperatures, high solar radiation, moderate annual water deficits	Warm temperatures, high solar radiation, moderate annual water deficits
Landform	Flat plains	Flat plains
Soils	Poorly-drained recent soils of low fertility from fine alluvium	Poorly-drained saline soils of moderate fertility from estuarine alluvium
Level IV	a. much cooler winter temperatures b. as for I2.1 c. higher monthly water balance ratios, much lower annual water deficits, gently undulating plains	a. – no subdivision at Level IV – same as I2.2

Environment I3

Environment I3 occurs in the east of the South Island from coastal Marlborough to Canterbury. Climatic conditions are mild with high solar radiation, high vapour pressure deficits and high annual water deficits. Parent materials are predominantly saline alluvium or fine greywacke alluvium with some loess. Soils are imperfectly drained and of high natural fertility. Saline soils around Lake Ellesmere and the Wairau River mouth.

Level III & IV Descriptions

Level III	I3.1	I3.2	I3.3
Area	7412 ha	10,436 ha	10,188 ha
Elevation	5 m	85 m	5 m
Location	Marlborough	Mid Canterbury	Lake Ellesmere
Climate	Warm temperatures, very high solar radiation, high vapour pressure deficits, high annual water deficits	Mild temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits	Mild temperatures, moderate solar radiation, high vapour pressure deficits, high annual water deficits
Landform	Flat plains	Flat plains	Flat plains
Soils	Recent, poorly-drained, saline soils of high fertility from saline and mixed alluvium	Imperfectly drained recent soils of high fertility from fine greywacke alluvium	Imperfectly drained, recent saline soils of high fertility from saline alluvium
Level IV	a. non-saline soils b. saline soils	a. lower winter temperatures, higher vapour pressure deficits b. higher winter temperatures, higher annual water deficits c. lower temperatures, much lower annual water deficits	a. – no subdivision at Level IV – same as I3.3

Environment I4

Environment I4 comprises several very small, gently sloping units in southern Marlborough and coastal north Canterbury. Climatically Environment I4 has mild temperatures, high solar radiation, very high vapour pressure deficits and high annual water deficits. Soils are formed from fine greywacke alluvium with some loess and are poorly-drained but of high natural fertility.

Level III & IV Descriptions

Level III	I4.1	I4.2
Area	384 ha	52 ha
Elevation	25 m	395 m
Location	North Canterbury coast	Middle reaches of the Awatere River
Climate	Warm temperatures, high solar radiation, very high vapour pressure deficits, high annual water deficits	Mild temperatures, very high solar radiation, high vapour pressure deficits, moderate annual water deficits
Landform	Gently undulating	Undulating plains
Soils	Poorly-drained soils of high fertility from fine greywacke alluvium	Very poorly-drained soils of very high fertility from fine greywacke alluvium
Level IV	a. – no subdivision at Level IV – same as I4.1	a. – no subdivision at Level IV – same as I4.2

Environment I5

Environment I5 is the second most extensive Level II unit in I, occurring in two North Island locations: along the flood plain of the Waipaoa River near Gisborne and around Hastings. The climate is warm with high solar radiation and moderate annual water deficits. Parent materials are mostly fine alluvium, some of it rhyolitic, with some loess. Soils are recent and are imperfectly drained but are of only moderate natural fertility.

Level III & IV Descriptions

Level III	I5.1	I5.2
Area	27,864 ha	11,260 ha
Elevation	25 m	25 m
Location	Gisborne, Napier/Hastings	Napier/Hastings
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, high annual water deficits
Landform	Flat flood plains	Flat flood plains
Soils	Imperfectly drained recent soils of low fertility from mixed alluvium	Imperfectly drained recent soils of low fertility from alluvium and loess
Level IV	a. warmer winter temperatures, low annual water deficits, high fertility b. well-drained	a. – no subdivision at Level IV – same as I5.2

Environment I6

Environment I6 is located mainly on the Napier/Hastings plains, with a small area also found on the Gisborne plains. The climate within this small environment is warm, with high solar radiation, high vapour pressure deficits and moderate annual water deficits. The predominant parent material across the whole environment is estuarine alluvium, and the resulting saline soils have very poor drainage and moderate fertility.

Level III & IV Descriptions

Level III	I6.1 – No Subdivision at Level III
Area	4328 ha
Elevation	5 m
Location	Napier/Hastings, Gisborne
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits
Landform	Flat flood plains
Soils	Recent, saline soils of poor drainage and moderate fertility from estuarine alluvium
Level IV	a. lower annual water deficits, non-saline soils b. saline soils

Environment I5

Environment I5 is the second most extensive Level II unit in I, occurring in two North Island locations: along the flood plain of the Waipaoa River near Gisborne and around Hastings. The climate is warm with high solar radiation and moderate annual water deficits. Parent materials are mostly fine alluvium, some of it rhyolitic, with some loess. Soils are recent and are imperfectly drained but are of only moderate natural fertility.

Level III & IV Descriptions

Level III	I5.1	I5.2
Area	27,864 ha	11,260 ha
Elevation	25 m	25 m
Location	Gisborne, Napier/Hastings	Napier/Hastings
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits	Warm temperatures, high solar radiation, high vapour pressure deficits, high annual water deficits
Landform	Flat flood plains	Flat flood plains
Soils	Imperfectly drained recent soils of low fertility from mixed alluvium	Imperfectly drained recent soils of low fertility from alluvium and loess
Level IV	a. warmer winter temperatures, low annual water deficits, high fertility b. well-drained	a. – no subdivision at Level IV – same as I5.2

Environment I6

Environment I6 is located mainly on the Napier/Hastings plains, with a small area also found on the Gisborne plains. The climate within this small environment is warm, with high solar radiation, high vapour pressure deficits and moderate annual water deficits. The predominant parent material across the whole environment is estuarine alluvium, and the resulting saline soils have very poor drainage and moderate fertility.

Level III & IV Descriptions

Level III	I6.1 – No Subdivision at Level III
Area	4328 ha
Elevation	5 m
Location	Napier/Hastings, Gisborne
Climate	Warm temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits
Landform	Flat flood plains
Soils	Recent, saline soils of poor drainage and moderate fertility from estuarine alluvium
Level IV	a. lower annual water deficits, non-saline soils b. saline soils

Environment	J1	J2	J3	J4
Area (ha)	53,966	116,722	15,278	111,241
Altitude (m)	119	136	82	78
Mean annual temperature (ºC)	12.0	11.3	12.2	12.7
Mean minimum temperature of the coldest month (ºC)	1.5	0.6	3.6	3.6
Mean annual solar radiation (MJ/m^2/day)	15.3	14.1	14.6	14.2
Mean winter solar radiation (MJ/m^2/day)	5.0	4.4	4.8	4.7
October vapour pressure deficit (kPa)	0.5	0.5	0.6	0.4
Monthly water balance ratio (ratio)	2.4	1.8	2.1	2.3
Mean annual water deficit (mm)	109.7	182.3	130.1	96.5
Slope (º)	1.8	0.6	2.1	0.9
Drainage (1=very poor to 5=good)	4.9	5.0	4.7	4.7
Acid soluble phosphorus (1=v. low to 5=v. high)	3.3	3.9	3.9	2.2
Exchangeable calcium (1=low to 5=v. high)	1.9	2.0	2.0	2.0
Particle size (1=clay/silt to 5=boulders–massive)	2.5	2.5	3.1	1.3
Induration (1=non-indurated to 5=v. strongly ind.)	2.9	3.5	3.9	1.9
Soil Age (1=raw/recent, 2=older)	1.3	1.0	1.5	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0

Environment J1

Environment J1 occurs along the middle and upper reaches of the Wairau River in Marlborough and along the Waimea and Motueka Rivers in Nelson. The climate within this environment is mild, with very high solar radiation, high vapour pressure deficits and moderate annual water deficits. Soils are formed mostly from greywacke gravels (Marlborough) or sandy alluvium from sedimentary rocks, granite and/or gabbro (Nelson). Soils are well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	J1.1	J1.2
Area	29,920 ha	23,980 ha
Elevation	85 m	165 m
Location	Waimea, Motueka Rivers, Nelson	Wairau River, Blenheim
Climate	Mild temperatures, very high solar radiation, high vapour pressure deficits, low annual water deficits	Mild temperatures, very high solar radiation, high vapour pressure deficits, moderate annual water deficits
Landform	Gently undulating flood plains	Very gently undulating flood plains
Soils	Well-drained soils of moderate fertility from sedimentary alluvium	Well-drained soils of high fertility from greywacke gravels with some loess
Level IV	a. cooler temperatures, lower annual water deficits b. as for J1.1 c. undulating flood plains, low fertility d. higher annual water deficits, imperfect drainage	a. older soils b. recent soils

Environment J2

Environment J2 occurs along the lower reaches of the Wairau River in Marlborough and the larger river and streams of Canterbury to the upper headwaters of the Waitaki River. The climate is mild, with high solar radiation, high vapour pressure deficits and moderate annual water deficits. Parent materials are mostly greywacke gravels but with some finer alluvium and loess. Soils are well-drained and have high natural fertility.

Level III & IV Descriptions

Level III	J2.1	J2.2
Area	77,760 ha	39,060 ha
Elevation	55 m	300 m
Location	Marlborough, around Christchurch	Inland mid Canterbury
Climate	Mild temperatures, high solar radiation, high vapour pressure deficits, high annual water deficits	Mild temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits
Landform	Flat flood plains	Very gently undulating flood plains
Soils	Recent, well-drained soils of high fertility from greywacke gravels and alluvium	Recent, well-drained soils of high fertility from greywacke gravels
Level IV	a. warmer temperatures, much higher solar radiation b. as for J2.1 c. cooler winter temperatures, higher vapour pressure deficits d. gently undulating flood plains, moderate fertility	a. much cooler temperatures, lower annual water deficits b. warmer temperatures c. undulating floodplains

Environment J3

Environment J3 is the most restricted in extent of the J environments, extending north from the lower reaches of the Conway River along the Kaikoura coast to the lower reaches of the Clarence River. Of the three South Island environments in J this is the warmest, having a mild climate with high solar radiation, very high vapour pressure deficits and moderate annual water deficits. Greywacke gravels are the dominant soil parent material but with small areas of adjacent greywacke. Soils are well-drained and have high natural fertility.

Level III & IV Descriptions

Level III	J3.1	J3.2
Area	7152 ha	8072 ha
Elevation	70 m	55 m
Location	Kaikoura region	Kaikoura region
Climate	Mild temperatures, high solar radiation, very high vapour pressure deficits, moderate annual water deficits	Mild temperatures, high solar radiation, very high vapour pressure deficits, moderate annual water deficits
Landform	Gently undulating plains	Very gently undulating floodplains
Soils	Well-drained soils of high fertility from greywacke gravels with some loess	Well-drained soils of high fertility from greywacke gravels with some loess
Level IV	a. – no subdivision at Level IV – same as J3.1	a. cooler winter temperatures, much lower annual water deficits, b. higher annual water deficits

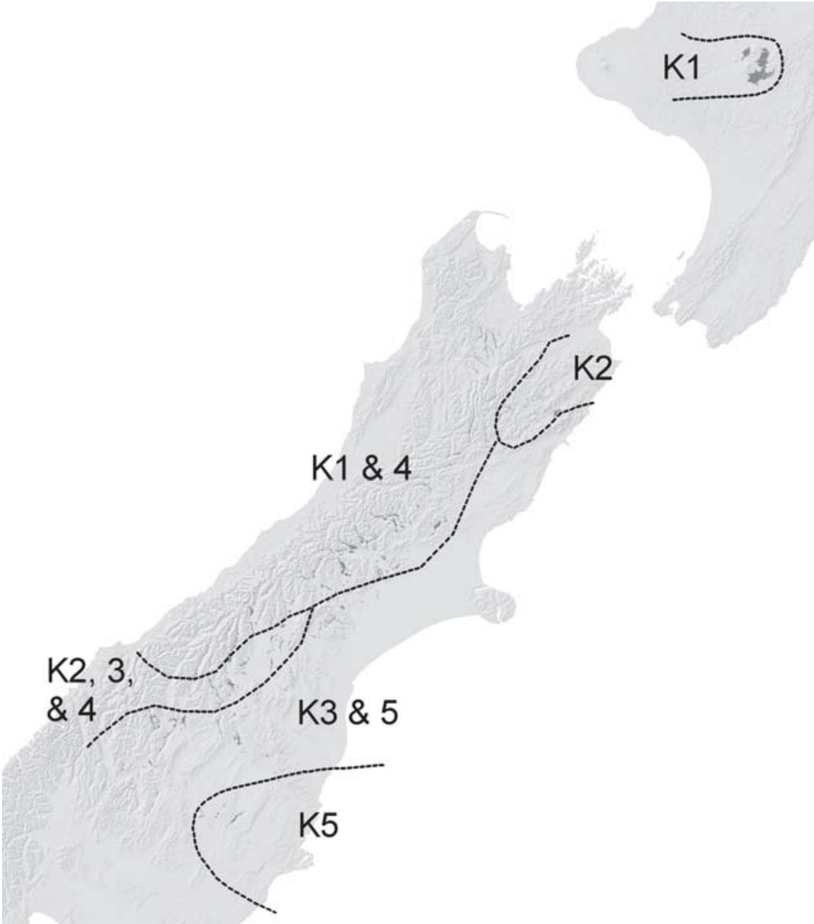
Environment J4

Environment J4 occurs in the lower North Island mainly forming narrow ribbons along the major rivers of southern Hawke's Bay, Manawatu and the Wairarapa. It also includes extensive coastal dunes in Manawatu and coastal terraces in southern Wellington and Wairarapa. The climate is typified by warm temperatures, high solar radiation, moderate vapour pressure deficits and low annual water deficits. Mixed alluvium and dune sands are the most widespread soil parent materials with some volcanic ash and loess. The well-drained soils are the least fertile of the J environments, with relatively low levels of available phosphorus.

Level III & IV Descriptions

Level III	J4.1	J4.2	J4.3
Area	70,424 ha	34,228 ha	6520 ha
Elevation	110 m	20 m	50 m
Location	River terraces along coastal Manawatu	Coastal Manawatu, Wanganui	Southern Wairarapa coastline
Climate	Warm temperatures, high solar radiation, low annual water deficits	Warm temperatures, high solar radiation, moderate annual water deficits	Warm temperatures, high solar radiation, moderate annual water deficits
Landform	Flat flood plains	Flat coastal sandplains	Undulating coastal floodplains
Soils	Recent, well-drained soils of low fertility from mixed alluvium	Recent, well-drained soils of moderate fertility from sand, with small pockets of Taupo tephra	Recent, well-drained soils of low fertility from mixed alluvium
Level IV	a. much cooler temperatures, lower annual water deficits, undulating flood plains b. undulating flood plains, imperfectly drained c. higher annual water deficits d. much lower annual water deficits	a. much warmer winter temperatures, lower annual water deficits, low fertility b. as for J4.2 c. very low fertility d. higher annual water deficits, imperfect drainage	a. warmer winter temperatures, easy rolling coastal plains, strongly indurated parent materials b. as for J4.3

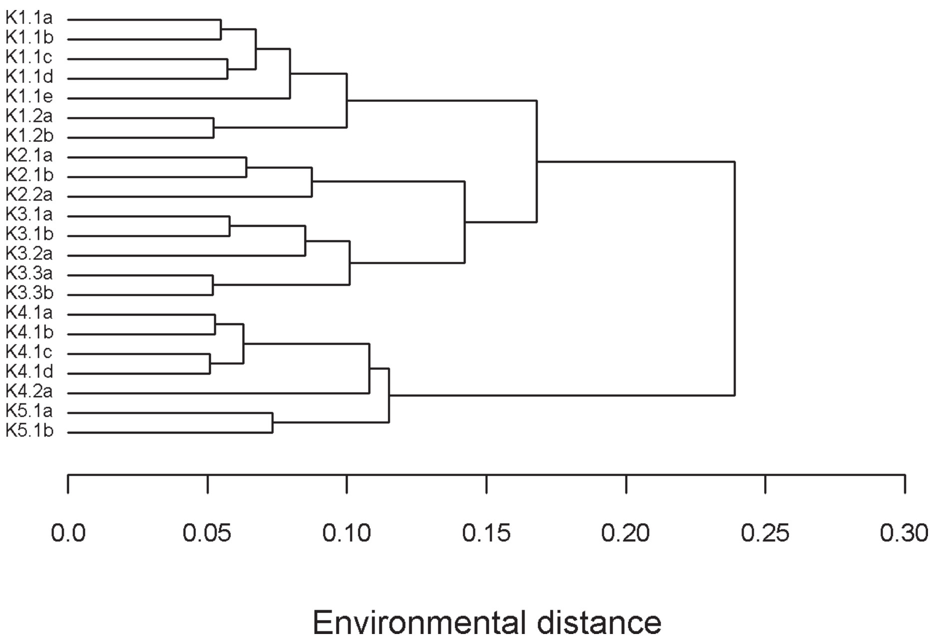
K - Central Upland Recent Soils



Environment K comprises areas of recent soils at moderate to high elevation in inland parts of both main islands where it generally occurs on flood plains along major river valleys. It is most extensive in inland parts of the eastern South Island. In the North Island it is restricted to high elevation sites on the ringplain surrounding the Tongariro volcanoes.

The climate of Environment K is cool but with high solar radiation. Although annual water deficits are low on average, more eastern sites in the South Island receive substantially less rainfall than those exposed to the west or located close to the Southern Alps. Vapour pressure deficits are moderate. Alluvium, mostly from greywacke but some from schist, is the main soil parent material with varying mixes of gravel and finer material. Andesitic tephra is the dominant parent material around the Tongariro volcanoes. Slopes are generally gentle, and most soils are well-drained. Natural soil fertility is moderately high.

DENDROGRAM OF K



Environment	K1	K2	K3	K4	K5
Area (ha)	98,044	11,395	32,481	16,612	4894
Altitude (m)	747	790	533	604	626
Mean annual temperature (ºC)	8.7	8.5	9.0	9.0	7.7
Mean minimum temperature of the coldest month (ºC)	-1.1	-2.4	-2.1	-1.9	-3.3
Mean annual solar radiation (MJ/m^2/day)	14.1	14.7	13.8	14.0	13.1
Mean winter solar radiation (MJ/m^2/day)	4.8	5.0	3.9	4.5	3.8
October vapour pressure deficit (kPa)	0.4	0.5	0.4	0.5	0.4
Monthly water balance ratio (ratio)	4.2	1.7	2.0	2.4	1.8
Mean annual water deficit (mm)	9.3	170.4	107.9	62.0	81.4
Slope (º)	4.3	8.4	4.5	1.2	1.4
Drainage (1=very poor to 5=good)	5.0	5.0	4.5	1.0	2.1
Acid soluble phosphorus (1=v. low to 5=v. high)	3.6	3.8	3.5	4.0	3.2
Exchangeable calcium (1=low to 5=v. high)	1.7	1.8	2.0	2.0	2.0
Particle size (1=clay/silt to 5=boulders–massive)	2.4	3.2	2.8	1.0	1.8
Induration (1=non-indurated to 5=v. strongly ind.)	3.5	4.0	2.9	2.0	1.2
Soil Age (1=raw/recent, 2=older)	1.0	1.0	1.0	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	1.0

Environment K1

Environment K1 comprises the greatest area (60%) and has the highest mean elevation of the Level II environments in K. It occurs along the upper headwaters of major rivers draining the eastern slopes of the Southern Alps, and on Mt Ruapehu. It is distinguished by its cool, wet climate with high solar radiation and slight annual water deficits. Well-drained soils are formed from greywacke gravels with andesitic tephra in the North Island and some loess in the South Island.

Level III & IV Descriptions

Level III	K1.1	K1.2
Area	65,260 ha	32,616 ha
Elevation	610 m	1020 m
Location	Southern Alps	Mt Ruapehu
Climate	Cool temperatures, high solar radiation, moderate vapour pressure deficits, slight annual water deficits	Cool temperatures, high solar radiation, low vapour pressure deficits, slight annual water deficits
Landform	Undulating floodplains	Undulating ringplain
Soils	Recent, well-drained soils of high fertility from greywacke gravels with some loess	Recent, well-drained soils of moderate fertility from andesitic tephra
Level IV	a. much higher monthly water balance ratios b. as for K1.1 c. much lower vapour pressure deficits d. much cooler temperatures e. much warmer temperatures, higher solar radiation	a. as for K1.2 b. very gently undulating ringplain, high fertility, strongly indurated parent materials

Environment K2

Environment K2 is much smaller in area and is restricted to high, intermontane valleys in inland parts of southern Marlborough and south Canterbury. This environment has a cool climate, with high solar radiation, high vapour pressure deficits and moderate annual water deficits. This environment has gently sloping soils formed from greywacke gravels and consequently the environment is well-drained and of high fertility.

Level III & IV Descriptions

Level III	K2.1	K2.2
Area	8804 ha	2520 ha
Elevation	845 m	625 m
Location	Southern Marlborough and south Canterbury	Southern Marlborough
Climate	Cool temperatures, high solar radiation, high vapour pressure deficits, very low monthly water balance ratios and moderate annual water deficits	Cool temperatures, high solar radiation, high vapour pressure deficits, very low monthly water balance ratios and moderate annual water deficits
Landform	Undulating hills	Steep hills
Soils	Recent, well-drained soils of high fertility from greywacke gravels with some loess	Recent, well-drained soils of moderate fertility from greywacke
Level IV	a. higher annual water deficits b. lower annual water deficits, easy rolling hills	a. – no subdivision at Level IV – same as K2.2

Environment K3

Environment K3 has the lowest mean elevations in K and consists of narrow ribbons of recent soils along rivers and streams in the eastern ranges of south Canterbury and northern and central Otago. Climatically this environment is cool, with moderate solar radiation, moderate vapour pressure deficits and moderate annual water deficits. Soils are mostly formed from sands and gravels derived from greywacke and schist with some loess. They are well-drained, with moderate natural fertility.

Level III & IV Descriptions

Level III	K3.1	K3.2	K3.3
Area	17,640 ha	3344 ha	11,516 ha
Elevation	605 m	765 m	365 m
Location	South Canterbury, Central Otago	Central Otago	Central Otago
Climate	Cool temperatures, moderate solar radiation, low annual water deficits	Cool temperatures, moderate solar radiation, low annual water deficits	Mild temperatures, high solar radiation, moderate annual water deficits
Landform	Undulating floodplains	Undulating floodplains	Gently undulating floodplains
Soils	Recent, well-drained, soils of high fertility from greywacke gravels with some loess	Recent, imperfectly drained soils of moderate fertility from fine schist alluvium	Recent, imperfectly drained soils of moderate fertility from schist alluvium and colluvium
Level IV	a. higher annual water deficits b. lower annual water deficits	a. – no subdivision at Level IV – same as K3.2	a. as for K3.3 b. cooler temperatures, easy rolling floodplains

Environment K4

Environment K4 is scattered through the intermontaine basins of inland Canterbury with minor occurrences in Otago. The climate is cool, with high solar radiation, high vapour pressure deficits and low annual water deficits. Environment K4 occurs predominantly on areas of fine greywacke alluvium with minimal slope, and the resulting soils are very poorly-drained although highly fertile.

Level III & IV Descriptions

Level III	K4.1	K4.2
Area	16,540 ha	80 ha
Elevation	600 m	985 m
Location	Mid to southern Canterbury	North Canterbury, inland from Kaikoura
Climate	Cool temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits	Cold temperatures, high solar radiation, high vapour pressure deficits, low annual water deficits
Landform	Gently undulating inland basins	Rolling inland basins
Soils	Recent, poorly-drained soils of high fertility from fine greywacke alluvium with some loess	Recent, imperfectly drained soils of high fertility from fine greywacke alluvium with some loess
Level IV	a. much cooler temperatures, lower annual water deficits b. warmer winter temperatures, lower annual water deficits c. much higher annual water deficits d. cooler winter temperatures	a. – no subdivision at Level IV – same as K4.2

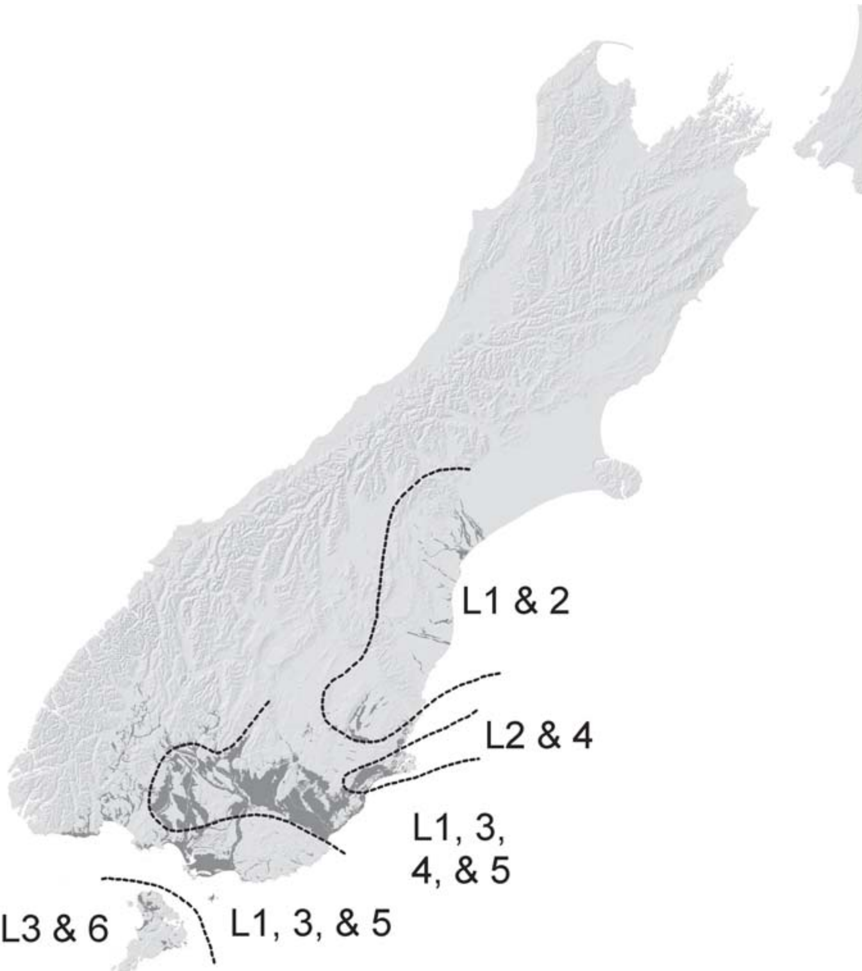
Environment K5

Environment K5 is the smallest Level II environment in K and occurs along river valleys in southern Canterbury and Central Otago. The climate is cool, with moderate solar radiation, moderate vapour pressure deficits and slight annual water deficits. Parent materials consist of either greywacke or schist alluvium with some loess. Soils are generally poorly-drained and have moderate natural fertility.

Level III & IV Descriptions

Level III¨	K5.1 – No Subdivision at Level III
Area¨	4836 ha
Elevation¨	625 m
Location¨	Southern Canterbury, Central Otago
Climate¨	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, slight annual water deficits
Landform¨	Gently undulating floodplains
Soils¨	Recent, poorly-drained soils of moderate fertility from a combination of greywacke or schist alluvium
Level IV¨	a. fine greywacke alluvium with loess, South Canterbury b. fine schist alluvium with loess, Central Otago

L - Southern Lowlands



the lowlands of Southland, with smaller areas in South Canterbury, coastal Otago and on Stewart Island. Environment L has a cool climate, with low solar radiation. There is a strong gradient in annual rainfall deficits, while low overall, vary from very low in the south and south-west to moderate in the northeast. Landforms are generally flat to gently sloping with a range of soil parent materials including extensive areas of fine-textured alluvium from schist and greywacke, loess, peat and dune sands. Soils vary widely in their drainage - some are of moderately high natural fertility.

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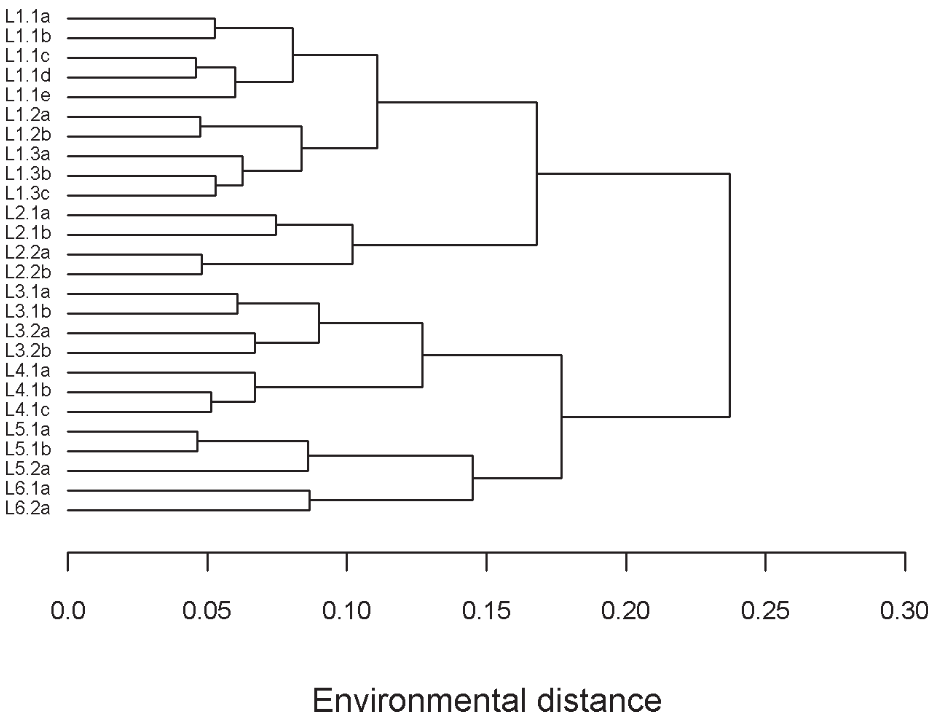


Environment	L1	L2	L3	L4	L5	L6
Area (ha)	207,672	9903	112,629	408,130	61,227	12,506
Altitude (m)	152	19	104	139	97	47
Mean annual temperature (ºC)	9.9	10.5	9.6	9.8	9.8	9.6
Mean minimum temperature of the coldest month (ºC)	0.1	0.5	1.2	0.4	0.6	2.4
Mean annual solar radiation (MJ/m^2/day)	12.7	12.6	12.3	12.4	12.5	11.8
Mean winter solar radiation (MJ/m^2/day)	3.5	3.7	3.1	3.3	3.2	2.8
October vapour pressure deficit (kPa)	0.4	0.4	0.3	0.4	0.4	0.2
Monthly water balance ratio (ratio)	2.4	1.7	3.6	2.4	3.2	5.2
Mean annual water deficit (mm)	68.1	114.4	10.4	54.3	24.5	0.0
Slope (º)	0.9	0.4	0.9	2.8	0.7	3.7
Drainage (1=very poor to 5=good)	5.0	2.7	1.3	2.8	3.0	3.3
Acid soluble phosphorus (1=v. low to 5=v. high)	3.6	3.5	1.5	3.1	3.2	1.6
Exchangeable calcium (1=low to 5=v. high)	2.2	1.9	1.6	2.0	2.8	1.0
Particle size (1=clay/silt to 5=boulders–massive)	1.9	1.5	1.9	1.3	1.8	2.4
Induration (1=non-indurated to 5=v. strongly ind.)	2.5	1.2	1.7	2.0	2.0	3.0
Soil Age (1=raw/recent, 2=older)	1.0	1.0	2.0	2.0	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.3	1.0	1.0	1.0	1.0

Environment L1

This environment occurs along the floodplains of the Rangitata and Waitaki Rivers in south Canterbury and throughout the Southland plains. The climate of L1 is cold, with low solar radiation, moderate vapour pressure deficits and low annual water deficits. Parent materials are alluvial sands and gravels predominantly derived from greywacke but also from schist, basic volcanic rocks and loess. The recent, well-drained soils are of high natural fertility.

Level III & IV Descriptions

Level III	L1.1	L1.2	L1.3
Area	142,380 ha	39,364 ha	25,808 ha
Elevation	150 m	85 m	270 m
Location	Southland	South Canterbury	Dunedin
Climate	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, low annual water deficits	Mild temperatures, moderate solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, moderate annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, moderate annual water deficits
Landform	Very gently undulating floodplains	Flat floodplains	Gently undulating floodplains
Soils	Recent, well-drained soils of high fertility from fine greywacke alluvium, alluvium from tuffaceous greywacke and dune sand	Recent, well-drained soils of high fertility from greywacke gravels with some loess	Recent, well-drained soils of moderate fertility from schist rock, colluvium and alluvium
Level IV	a. as for L1.1 b. much cooler winter temperatures, higher vapour pressure deficits, higher annual water deficits c. lower annual water deficits d. warmer winter temperatures, lower annual water deficits e. higher annual water deficits, moderate fertility	a. much lower annual water deficits b. higher annual water deficits	a. lower annual water deficits, imperfect drainage b. warmer temperatures c. higher annual water deficits, strongly indurated, moderately coarse-textured soils

Environment L2

Environment L2 consists of scattered pockets of low-lying, poorly-drained land, including coastal areas near Timaru and the Otago Peninsula, more inland sites in the lower Taieri Plains around Mosgiel and small scattered patches further south near Lake Waihola and around Balclutha. Environment L2 is mild, with low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios and moderate annual water deficits. Soils are highly fertile but imperfectly drained and are derived mostly from sandy alluvium from greywacke and schist. Saline soils occur near the coast.

Level III & IV Descriptions

Level III	L2.1	L2.2
Area	7,332 ha	2,512 ha
Elevation	20 m	10 m
Location	Coastal Otago, South Canterbury	Coastal Otago
Climate	Mild temperatures, low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, moderate annual water deficits	Mild temperatures, low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, moderate annual water deficits
Landform	Flat plains and terraces	Very gently undulating plains and terraces
Soils	Older, very poorly-drained soils of moderate fertility from fine schist and greywacke alluvium	Older, poorly-drained soils of high fertility from saline alluvium from mixed quartzo-feldspathic rocks
Level IV	a. higher annual water deficits, high fertility b. as for L2.1	a. very poorly-drained, saline soils of high fertility b. as for L2.2

Environment L3

Environment L3 includes high elevation wetlands on the Rock and Pillar Range, wetlands around Lake Te Anau, poorly-drained terraces in southwestern Fiordland and extensive wetlands around Invercargill and Balcutha and on Stewart Island. Climatically this environment is cool, with low solar radiation, low vapour pressure deficits and slight annual water deficits. Parent materials consist of extensive areas of alluvium from the Fiordland complex, tuffaceous greywacke, and loess from greywacke and schist. The combination of high rainfall and very poor drainage has resulted in extensive areas of peat. Soils are generally of low fertility.

Level III & IV Descriptions

Level III	L3.1	L3.2
Area	69,188 ha	46,544 ha
Elevation	125 m	70 m
Location	Central Otago and Southland particularly around Invercargill	South-western Southland, Invercargill, northern Stewart Island
Climate	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Flat floodplains	Very gently undulating floodplains
Soils	Recent, imperfectly drained soils of moderate fertility from alluvium from the Fiordland complex with extensive peat	Recent, poorly-drained soils of high fertility from Tertiary sandstones and alluvium from the Fiordland complex
Level IV	a. warmer winter temperatures b. much cooler temperatures	a. as for L3.2 b. much warmer temperatures, weakly indurated, fine-textured parent materials

Environment L4

Environment L4 is widely spread on the gently sloping Southland Plains (Awatua, Waimea, Tokomairiro) around Dunedin and on the Otago Peninsula. The climate is cool, with low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios and low annual water deficits. Most sites have little or no slope with imperfectly drained soils of clays and silt derived largely from greywacke, schist, basaltic alluvium and loess with some peat.

Level III & IV Descriptions

Level III¨	L4.1 – No Subdivision at Level III
Area¨	408,208 ha
Elevation¨	140 m
Location¨	Southland
Climate¨	Cool temperatures, low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, low annual water deficits
Landform¨	Gently undulating plains
Soils¨	Older, imperfectly drained soils of moderate fertility from greywacke loess and schist and loess from tuffaceous greywacke
Level IV¨	a. as for L4.1 b. flat plains c. higher annual water deficits

Environment L5

Environment L5 occurs on flat low elevation floodplains along rivers in Southland such as the Oreti and Upper Mataura. Climatically this environment is cool, with low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and low annual water deficits. Parent materials are predominantly fine schist and greywacke alluvium with some loess. Soils are recent and have imperfect drainage with high natural fertility

Level III & IV Descriptions

Level III	L5.1	L5.2
Area	59,036 ha	2296 ha
Elevation	100 m	65 m
Location	Southland	Southland
Climate	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, low annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Flat floodplains	Very gently undulating floodplains
Soils	Recent, imperfectly drained soils of high fertility from fine greywacke alluvium with some loess from tuffaceous greywacke	Recent, poorly-drained soils of high fertility from tuffaceous greywacke, mixed alluvium and small areas of saline alluvium
Level IV	a. higher annual water deficits b. as for L5.1	a. – no subdivision at Level IV – same as L5.2

Environment L6

Environment L6 consists of areas of gently sloping, recent soils on Stewart Island. The environment is differentiated from the other L environments by its maritime climate, which is cool with very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios and no annual water deficits. Parent materials are dune sands and alluvium and colluvium derived from granite, diorite, and rocks of the Fiordland complex. Soils are imperfectly drained and of low natural fertility

Level III & IV Descriptions

Level III	L6.1	L6.2
Area	9396 ha	3100 ha
Elevation	55 m	25 m
Location	Stewart Island	Stewart Island
Climate	Cold temperatures, very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits	Cold temperatures, very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits
Landform	Undulating floodplains	Very gently undulating floodplains
Soils	Recent, imperfectly drained soils of low fertility from dune sands and sandy alluvium	Recent, very poorly-drained soils of very low fertility from alluvium from the Fiordland complex
Level IV	a. – no subdivision at Level IV – same as L6.1	a. – no subdivision at Level IV – same as L6.2

Environment L5

Environment L5 occurs on flat low elevation floodplains along rivers in Southland such as the Oreti and Upper Mataura. Climatically this environment is cool, with low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and low annual water deficits. Parent materials are predominantly fine schist and greywacke alluvium with some loess. Soils are recent and have imperfect drainage with high natural fertility

Level III & IV Descriptions

Level III	L5.1	L5.2
Area	59,036 ha	2296 ha
Elevation	100 m	65 m
Location	Southland	Southland
Climate	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, low annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Flat floodplains	Very gently undulating floodplains
Soils	Recent, imperfectly drained soils of high fertility from fine greywacke alluvium with some loess from tuffaceous greywacke	Recent, poorly-drained soils of high fertility from tuffaceous greywacke, mixed alluvium and small areas of saline alluvium
Level IV	a. higher annual water deficits b. as for L5.1	a. – no subdivision at Level IV – same as L5.2

Environment L6

Environment L6 consists of areas of gently sloping, recent soils on Stewart Island. The environment is differentiated from the other L environments by its maritime climate, which is cool with very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios and no annual water deficits. Parent materials are dune sands and alluvium and colluvium derived from granite, diorite, and rocks of the Fiordland complex. Soils are imperfectly drained and of low natural fertility

Level III & IV Descriptions

Level III	L6.1	L6.2
Area	9396 ha	3100 ha
Elevation	55 m	25 m
Location	Stewart Island	Stewart Island
Climate	Cold temperatures, very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits	Cold temperatures, very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits
Landform	Undulating floodplains	Very gently undulating floodplains
Soils	Recent, imperfectly drained soils of low fertility from dune sands and sandy alluvium	Recent, very poorly-drained soils of very low fertility from alluvium from the Fiordland complex
Level IV	a. – no subdivision at Level IV – same as L6.1	a. – no subdivision at Level IV – same as L6.2

Environment	M1	M2	M3	M4
Area (ha)	92,992	77,784	452	57,510
Altitude (m)	49	229	704	256
Mean annual temperature (ºC)	11.2	10.5	7.8	9.0
Mean minimum temperature of the coldest month (ºC)	1.8	0.7	-1.5	1.0
Mean annual solar radiation (MJ/m²/day)	12.9	13.2	13.4	12.3
Mean winter solar radiation (MJ/m²/day)	3.9	3.9	3.6	3.2
October vapour pressure deficit (kPa)	0.3	0.3	0.3	0.2
Monthly water balance ratio (ratio)	9.5	7.5	4.8	11.0
Mean annual water deficit (mm)	0.0	0.4	2.0	0.0
Slope (º)	0.9	2.6	7.8	10.7
Drainage (1=very poor to 5=good)	2.6	4.8	1.5	5.0
Acid soluble phosphorus (1=v. low to 5=v. high)	4.0	3.7	3.5	1.0
Exchangeable calcium (1=low to 5=v. high)	1.0	1.4	2.0	1.0
Particle size (1=clay/silt to 5=boulders–massive)	2.0	3.0	1.5	3.0
Induration (1=non-indurated to 5=v. strongly ind.)	1.0	2.3	1.5	2.0
Soil Age (1=raw/recent, 2=older)	1.0	1.0	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0

Environment M1

Environment M1 is a very extensive unit along the west coast of the South Island occuring as far north as Westport. It generally occurs on river flats such as those adjacent to the Wanganui, Whataroa, Cook and Karangarua Rivers with smaller patches surrounding water bodies such as Lake Brunner. Further south it occurs on the floodplains of the Arawata and Cascade Rivers also extending into inland areas. The climate of this environment is mild, with low solar radiation, low vapour pressure deficits, high monthly water balance ratios and no annual water deficits. Parent materials consist of mixed alluvium from schist, greywacke and granite. Soils are imperfectly drained and of high natural fertility.

Level III & IV Descriptions

Level III¨	M1.1 – No Subdivision at Level III
Area¨	92,812 ha
Elevation¨	50 m
Location¨	West Coast of the South Island
Climate¨	Mild temperatures, low solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits
Landform¨	Very gently undulating floodplains
Soils¨	Recent, imperfectly drained soils of high fertility from mixed alluvium derived from schist, greywacke and granite alluvium
Level IV¨	a. as for M1.1 b. higher monthly water balance ratios, undulating plains c. warmer winter temperatures, higher solar radiation, higher vapour pressure deficits

Environment M2

This environment occurs north of Westport, around Murchison and down the west coast of the South Island. It generally occupies well-drained river terraces along the Grey and Cook Rivers and inland around the Haast River. Smaller areas occur east of the Southern Alps on the floodplains of the Makarora, Matukiuki, Dart and Eglinton Rivers. The most southern outlier occurs on the Oreti River in Southland. The climate is mild, with moderate solar radiation, high monthly water balance ratios and very slight annual water deficits. Parent materials are varied, consisting of greywacke gravels with some loess, schist alluvium and greywacke and granite alluvium. Soils are generally well-drained and of very low natural fertility.

Level III & IV Descriptions

Level III	M2.1	M2.2	M2.3
Area	46,624 ha	16,856 ha	14,388 ha
Elevation	90 m	360 m	545 m
Location	West Coast	Northern and southern West Coast	Southern and Inland West Coast, Otago and Southland
Climate	Mild temperatures, moderate solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Cool temperatures, moderate solar radiation, low vapour pressure deficits, moderate monthly water balance ratios, slight annual water deficits
Landform	Very gently undulating floodplains	Gently undulating floodplains	Easy rolling floodplains
Soils	Recent, well-drained soils of high fertility from greywacke and granite alluvium	Recent, imperfectly drained soils of moderate fertility from greywacke gravels with some loess, schist alluvium	Recent, well-drained soils of moderate fertility from greywacke gravels with some loess, schist alluvium
Level IV	a. – no subdivision at Level IV – same as M2.1	a. cooler winter temperatures, well-drained, high fertility b. as for M2.2	a. much higher monthly water balance ratios, imperfectly drained, moderate fertility b. undulating river terraces

Environment M3

Environment M3 is a small environment found in the mountain valleys of the Thomson and Eyre Mountains just south of Lake Wakatipu. Climatically this environment is cool, with moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and slight annual water deficits. Parent materials include fine schist alluvium, loess and fine greywacke alluvium. Soils are poorly-drained and of low natural fertility.

Level III & IV Descriptions

Level III	M3.1	M3.2
Area	48 ha	408 ha
Elevation	695 m	700 m
Location	Central Otago, Fiordland	Central Otago, Fiordland
Climate	Cool temperatures, moderate solar radiation, low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Easy rolling floodplains	Easy rolling floodplains
Soils	Recent, poorly-drained soils of high fertility from fine greywacke alluvium with some loess	Recent, poorly-drained soils of moderate fertility from fine schist and greywacke alluvium with some loess
Level IV	a. – no subdivision at Level IV – same as M3.1	a. – no subdivision at Level IV – same as M3.2

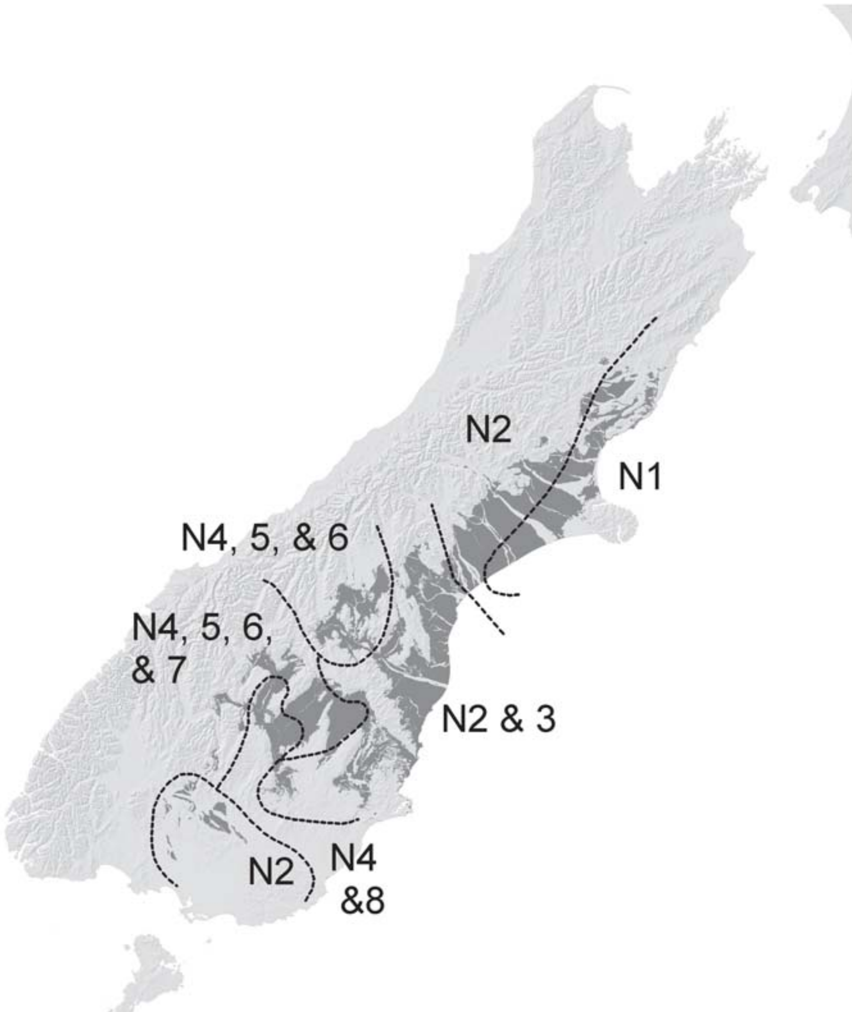
Environment M4

Environment M4 is located along valley floors in the Fiordland mountains extending from Awarua Bay north of Milford Sound to the far southwestern corner of the South Island (Long Point). The climate is cool, with low solar radiation, low vapour pressure deficits, very high monthly water balance ratios and no annual water deficits. Soils, which are well-drained and of very low natural fertility, are formed from alluvium from the Fiordland complex.

Level III & IV Descriptions

Level III¨	M4.1 – No Subdivision at Level III
Area¨	57,512 ha
Elevation¨	260 m
Location¨	Fiordland
Climate¨	Cool temperatures, low solar radiation, low vapour pressure deficits, very high monthly water balance ratios and no annual water deficits
Landform¨	Rolling u-shaped valley floors
Soils¨	Recent, well-drained soils of very low fertility from complex Fiordland alluvium
Level IV¨	a. higher monthly water balance ratios, steep lower slopes b. much cooler temperatures, much lower monthly water balance ratios c. much warmer temperatures, much higher monthly water balance ratios d. gently undulating u-shaped valley floors e. undulating u-shaped valley floors

N - Eastern South Island Plains



Environment N encompasses the extensive plains and inter-montane basin floors of Canterbury, Otago and Southland. In the north this includes both the Canterbury plains and the floor of the Waitaki Basin. In Otago, N extends from coastal areas north of Dunedin west to the Upper Taieri Plains and inland to the foot of the Southern Alps. Environment N has a cool climate with moderate solar radiation and moderate water and vapour pressure deficits. The terrain is generally flat to very gently sloping. Soils are mostly formed on alluvial sands and gravels derived from greywacke and schist, some of which are overlain with loess. They are generally moderately drained and of moderate natural fertility.

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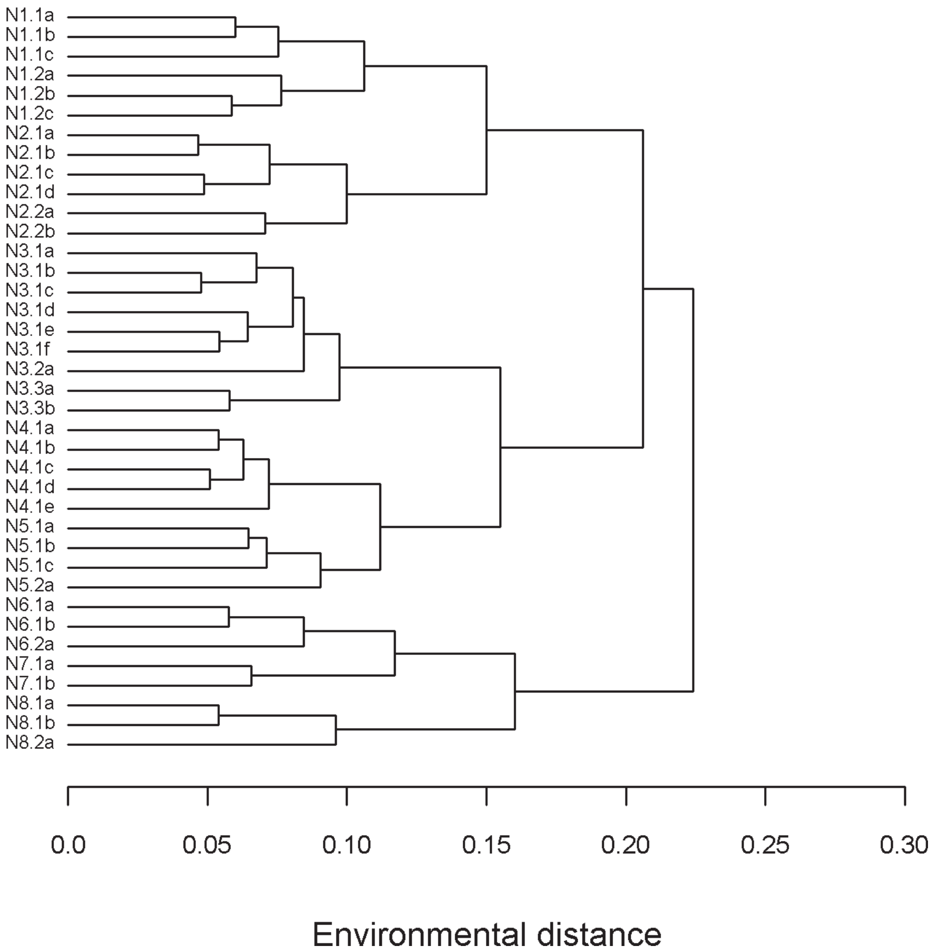


Environment	N1	N2	N3	N4	N5	N6	N7	N8
Area (ha)	404,783	487,825	605,148	243,015	166,341	94,933	12,376	39,141
Altitude (m)	97.3	214.8	293.7	492.2	422.0	489.4	411.5	243.4
Mean annual temperature (ºC)	11.3	10.5	9.5	8.8	9.1	9.1	9.2	10.2
Mean minimum temperature of the coldest month (ºC)	0.6	-0.1	-1.0	-3.2	-2.9	-3.1	-3.1	-2.4
Mean annual solar radiation (MJ/m^2/day)	14.0	13.6	13.0	13.6	13.6	13.8	13.6	13.9
Mean winter solar radiation (MJ/m^2/day)	4.4	4.3	4.0	3.7	3.8	4.1	3.9	3.6
October vapour pressure deficit (kPa)	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5
Monthly water balance ratio (ratio)	1.7	1.9	1.6	1.4	1.2	1.3	1.1	1.0
Mean annual water deficit (mm)	183.2	82.4	112.5	192.7	210.8	193.6	238.1	306.9
Slope (º)	0.7	0.3	4.2	11.2	1.6	0.8	0.2	2.3
Drainage (1=very poor to 5=good)	3.7	4.7	3.7	4.6	4.0	4.9	1.7	4.5
Acid soluble phosphorus (1=v. low to 5=v. high)	3.6	3.9	3.0	3.0	3.2	3.9	3.4	3.0
Exchangeable calcium (1=low to 5=v. high)	2.0	2.0	2.0	1.7	2.2	1.4	2.0	2.1
Particle size (1=clay/silt to 5=boulders–massive)	2.1	2.8	1.7	3.9	2.9	2.7	1.6	2.9
Induration (1=non-indurated to 5=v. strongly ind.)	2.9	3.7	2.3	3.8	2.5	2.3	1.4	2.1
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0	2.0	1.6	1.0	1.9
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.1

Environment N1

Most of Environment N1 is located on the Canterbury Plains extending from the Conway to the Rangitata River with some small areas occurring in Central Otago. The climate is mild, with high solar radiation, high vapour pressure deficits (mainly because of the föhn winds) and moderate annual water deficits. Parent materials are predominantly greywacke gravels with some loess and fine alluvium. Soils are imperfectly drained and of high natural fertility.

Level III & IV Descriptions

Level III	N1.1	N1.2
Area	227,196 ha	177,684 ha
Elevation	105 m	85 m
Location	Canterbury Plains	Canterbury Plains
Climate	Mild temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficits	Mild temperatures, high solar radiation, high vapour pressure deficits, moderate annual water deficit
Landform	Flat plains	Very gently undulating plains
Soils	Well-drained soils of high fertility from loess derived from greywacke and greywacke gravels	Fine-textured soils of imperfect drainage with high fertility from fine greywacke alluvium
Level IV	a. as for N1.1 b. cooler winter temperatures, higher vapour pressure deficits, moderate fertility c. higher vapour pressure deficits, higher annual water deficits	a. gently undulating plains, moderate fertility b. lower annual water deficits c. higher annual water deficits

Environment N2

Environment N2 occurs on the inland Canterbury Plains, around Hamner Springs and the Waitaki River mouth and in inland Southland. The climate is mild, with moderate levels of solar radiation, moderate vapour pressure deficits and low annual water deficits. Parent materials include greywacke gravels, loess and schist. Soils are well-drained and of high natural fertility.

Level III & IV Descriptions

Level III	N2.1	N2.2
Area	367,908 ha	119,944 ha
Elevation	250 m	110 m
Location	North of Timaru to Christchurch	South of Timaru, northern Southland
Climate	Mild temperatures, moderate solar radiation, high vapour pressure deficits, low annual water deficits	Mild temperatures, low solar radiation, moderate vapour pressure deficits, moderate annual water deficits
Landform	Flat plains	Flat plains
Soils	Well-drained soils of high fertility from greywacke gravels with some loess	Imperfectly drained soils of high fertility from greywacke gravels with some loess
Level IV	a. higher annual water deficits b. warmer winter temperatures, moderate fertility, weak induration, fine-textured soils c. much lower annual water deficits d. cooler winter temperatures, lower annual water deficits	a. higher annual water deficits b. much lower annual water deficits

Environment N3

Environment N3 occurs in south Canterbury, the eastern Otago plains and around the upper Taieiri River. The climate is cool with moderate solar radiation, moderate vapour pressure deficits and low annual water deficits. Parent materials include greywacke alluvium with some loess, schist and Tertiary mudstones and sandstones. Soils are imperfectly drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	N3.1	N3.2	N3.3
Area	463,824 ha	16,944 ha	124,660 ha
Elevation	300 m	535 m	245 m
Location	Timaru, Oamaru, Otago	Inland Otago	Lower Waitaki, Oamaru, coastal Otago south of Moeraki
Climate	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, moderate annual water deficits	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, moderate annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, moderate annual water deficits
Landform	Undulating plains	Undulating plains	Undulating plains
Soils	Imperfectly drained soils of moderate fertility from greywacke alluvium with some loess	Imperfectly drained soils of moderate fertility from Tertiary mudstones and sandstone with gravels	Well-drained soils of moderate fertility from loess derived from schist and greywacke, and schist
Level IV	a. lower annual water deficits b. much warmer temperatures, higher annual water deficits c. much warmer temperatures, higher annual water deficits d. much cooler temperatures e. much cooler temperatures, lower annual water deficits, undulating plains f. cooler temperatures	a. – no subdivision at Level IV – same as N3.2	a. as for N3.3 b. cooler winter temperatures, higher annual water deficits

Environment N4

Environment N4 occurs around Alexandra, along the Raggedy Range and around the lower slopes of the Dunstan and the Garvie Mountains. It is also extensive in the middle reaches of the Waitaki River. Climatically this environment is cool with moderate solar radiation, moderate vapour pressure deficits and moderate annual water deficits. Parent materials consist of schist (around Alexandra) and greywacke (around Lake Waitaki). Soils are well-drained and of moderate natural fertility

Level III & IV Descriptions

Level III¨	N4.1 – No Subdivision at Level III
Area¨	242,952 ha
Elevation¨	495 m
Location¨	Central Otago, Alexandra, Lake Waitaki
Climate¨	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, moderate annual water deficits
Landform¨	Rolling lower hillslopes and basin floors
Soils¨	Well-drained soils of moderate fertility from schist and greywacke
Level IV¨	a. warmer winter temperatures, undulating plains b. much cooler temperatures, undulating plains c. lower annual water deficits, steep hills d. warmer winter temperatures, steep hills e. warmer temperatures, much higher annual water deficits

Environment N5

Environment N5 is located on the plains near Ranfurly and Wanaka and north east of Alexandra. Scattered occurrences are found in the middle reaches of the Waitaki River. The climate is cool with moderate solar radiation, moderate vapour pressure deficits and high annual water deficits. Parent materials consist of colluvium and loess from greywacke and schist, and small pockets of calcareous mudstone. Soils are imperfectly drained and of moderate fertility. This environment includes small areas of saline soils.

Level III & IV Descriptions

Level III	N5.1	N5.2
Area	141,436 ha	25,112 ha
Elevation	425 m	415 m
Location	Around Ranfurly and Wanaka, also occurs around the Shotover River and around Queenstown's suburbs	Ranfurly and north east of Alexandra
Climate	Cool temperatures, moderate solar radiation, high vapour pressure deficits, high annual water deficits	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, high annual water deficits
Landform	Very gently undulating plains	Very gently undulating plains
Soils	Imperfectly drained soils of moderate fertility from a mixture of colluvium and loess from greywacke and schist	Imperfectly drained, saline soils of high fertility from calcareous mudstone
Level IV	a. as for N5.1 b. cooler winter temperatures, imperfect drainage c. warmer temperatures	a. – no subdivision at Level IV – same as N5.2

Environment N6

Environment N6 consists of extensive glacial outwash material in the Waitaki Basin and alluvium exending downstream to Lake Benmore. Smaller areas occur in Central Otago. Climatically this environment is cool, with moderate solar radiation, high vapour pressure deficits and moderate annual water deficits. Parent materials consist of till, alluvium and loess derived from both greywacke and schist. Soils are well-drained and of high natural fertility

Level III & IV Descriptions

Level III	N6.1	N6.2
Area	75,952 ha	18,972 ha
Elevation	500 m	445 m
Location	Plains between Twizel and Lake Tekapo	Omarama, Nevis Crossing, throughout Central Otago
Climate	Cool temperatures, moderate levels of solar radiation, high vapour pressure deficits, moderate annual water deficits	Cool temperatures, moderate levels of solar radiation, high vapour pressure deficits, high annual water deficits
Landform	Gently undulating plains	Gently undulating plains
Soils	Well-drained soils of high fertility from greywacke gravels, loess and colluvium	Recent, imperfectly drained soils of high fertility from fine schist and greywacke alluvium
Level IV	a. recent soils b. older soils	a. – no subdivision at Level IV – same as N6.2

Environment N7

Environment N7 consists of small areas of wetlands in the Upper Waitaki Plains and eastern parts of Central Otago. Climatically this environment is cool, with moderate solar radiation, high vapour pressure deficits and high annual water deficits. Parent materials consist of fine schist and greywacke alluvium with some small areas of loess. Soils are generally poorly-drained and of moderate natural fertility

Level III & IV Descriptions

Level III¨	N7.1 – No Subdivision at Level III
Area¨	12,272 ha
Elevation¨	410 m
Location¨	Central Otago
Climate¨	Cool temperatures, moderate solar radiation, high vapour pressure deficits, high annual water deficits
Landform¨	Flat plains
Soils¨	Recent, poorly-drained soils of moderate fertility from fine schist and greywacke alluvium with some loess
Level IV¨	a. high fertility b. as for N7.1

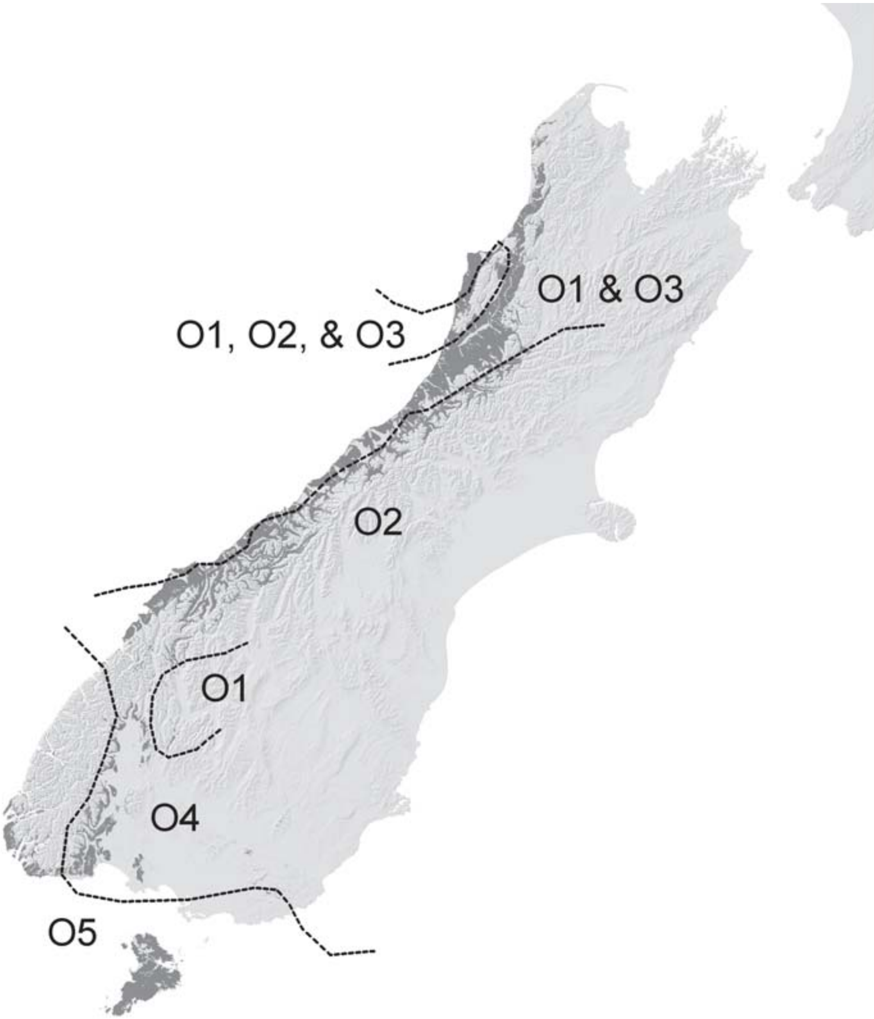
Environment N8

Environment N8 occurs on the Clutha plains surrounding Alexandra and from Cromwell to Luggate. The climate of this environment is dry, with mild temperatures, moderate solar radiation, high vapour pressure deficits and very high annual water deficits. Parent materials are varied consisting of schist alluvium, greywacke, and alluvium from Tertiary rocks. Soils are well-drained and have moderate natural fertility – some are saline.

Level III & IV Descriptions

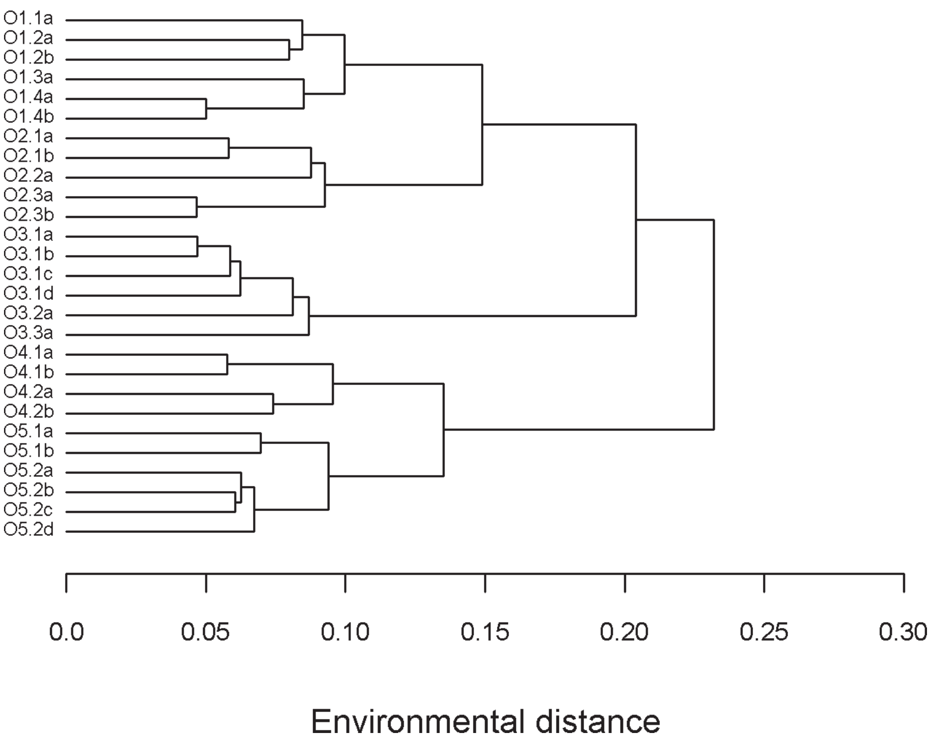
Level III	N8.1	N8.2
Area	34,888 ha	4384 ha
Elevation	245 m	230 m
Location	Mostly adjacent to the Clutha River from Luggate through to Alexandra	Clutha River valley around Alexandra and from Cromwell through to Luggate
Climate	Mild temperatures, moderate solar radiation, high vapour pressure deficits, very high annual water deficits	Mild temperatures, moderate solar radiation, high vapour pressure deficits, very high annual water deficits
Landform	Gently undulating floodplains	Gently undulating floodplains
Soils	Older, well-drained soils of moderate fertility from schist alluvium and colluvium, saline alluvium and greywacke gravels with some loess	Recent, imperfectly drained soils of moderate fertility from fine schist alluvium and colluvium with some loess
Level IV	a. saline soils b. as for N8.1	a. – no subdivision at Level IV – same as N8.2

O - Western South Island Foothills and Stewart Island



Environment O is most extensive at low to middle elevations in Westland, western Southland and on Stewart Island. The climate of Environment O reflects its generally high exposure to westerly winds and is typified by cool temperatures, low solar radiation, high monthly water balance ratios and low vapour pressure deficits. Landforms are diverse, consisting of older outwash materials of glacial origin, low rolling hill-country and the lower slopes of larger mountain ranges. A wide range of parent material includes granite, greywacke, schist, diorite, gabbro, alluvium from a variety of sources, Tertiary sandstone, mudstone, limestone, dune sands and peat. Soils range from very poorly to well drained and are of moderate to low natural fertility.

DENDROGRAM OF O



Environment	O1	O2	O3	O4	O5
Area (ha)	505,444	472,661	89,082	143,939	211,422
Altitude (m)	131	232	118	205	147
Mean annual temperature (°C)	10.9	9.3	11.1	8.0	8.8
Mean minimum temperature of the coldest month (°C)	1.3	0.3	1.9	0.0	2.0
Mean annual solar radiation (MJ/m^2/day)	13.2	12.8	13.1	12.4	11.8
Mean winter solar radiation (MJ/m^2/day)	4.0	3.8	4.0	3.1	2.8
October vapour pressure deficit (kPa)	0.3	0.2	0.3	0.3	0.2
Monthly water balance ratio (ratio)	7.9	13.3	8.3	5.5	7.1
Mean annual water deficit (mm)	0.0	0.0	0.0	0.1	0.0
Slope (°)	6.6	23.3	2.1	16.9	9.1
Drainage (1=very poor to 5=good)	4.8	4.5	1.7	3.9	2.6
Acid soluble phosphorus (1=v. low to 5=v. high)	2.6	2.8	2.7	1.9	1.5
Exchangeable calcium (1=low to 5=v. high)	1.2	1.6	1.2	1.8	1.2
Particle size (1=clay/silt to 5=boulders–massive)	3.4	3.6	2.7	3.2	4.5
Induration (1=non-indurated to 5=v. strongly ind.)	2.3	3.4	1.9	3.4	4.4
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	1.0

Environment O1

Environment O1 is a found along the entire West Coast, with smaller areas on inland sites around Haast. This environment has a wet climate with mild temperatures, moderate solar radiation and high monthly water balance ratios. Parent materials are dominated by mixed alluvium and gravels, with smaller amounts of Tertiary mudstones and sandstones, weathered granite, and limestone. Soils are well-drained and generally of moderate natural fertility.

Level III & IV Descriptions

Level III	O1.1	O1.2	O1.3	O1.4
Area	104,744 ha	33,716 ha	20,988 ha	346,308 ha
Elevation	220 m	230 m	15 m	180 m
Location	Northern West Coast, North of Westport	Around Punakaiki and Greymouth	West Coast coastline	West Coast plains, around Greymouth but stretching to Haast
Climate	Mild temperatures, moderate solar radiation, low vapour pressure deficits, moderate monthly water balance ratios, no annual water deficits	Mild temperatures, moderate solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits	Mild temperatures, moderate solar radiation, low vapour pressure deficits, moderate monthly water balance ratios, no annual water deficits	Mild temperatures, moderate solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits
Landform	Rolling hills	Rolling hills	Flat coastal plains	Undulating plains
Soils	Well-drained soils of moderate fertility from Tertiary mudstones and sandstones	Imperfectly drained soils of very high fertility from limestone, siltstone and mudstone	Imperfectly drained soils of moderate fertility from parent material of dune sand with small pockets of greywacke	Well-drained soils of moderate fertility from greywacke and granite alluvium
Level IV	a. – no subdivision at Level IV – same as O1.1	a. warmer winter temperatures, high fertility b. steep hills, very high fertility	a. – no subdivision at Level IV – same as O1.3	a. gently undulating plains

Environment O2

Environment O2 occupies the coastal terraces and hill-country and intermontane valleys of the West Coast. Climatically this environment, like O1, is wet with cool temperatures, low solar radiation, low vapour pressure deficits and extremely high monthly water balance ratios. Dominant parent materials are alluvium derived from granite and greywacke, schist. Soils are generally well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	O2.1	O2.2	O2.3
Area	161,044 ha	17,380 ha	294,456 ha
Elevation	270 m	390 m	575 m
Location	West of the Alpine Fault	South Westland	Predominatly east of the Alpine Fault
Climate	Mild temperatures, low solar radiation, low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits	Cool temperatures, low solar radiation, very low vapour pressure deficits, extremely high monthly water balance ratios, no annual water deficits	Cool temperatures, low solar radiation, low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits
Landform	Steep hills	Easy rolling hills	Very steep mountainous terrain
Soils	Well-drained soils of moderate fertility from Tertiary mudstones and sandstones and greywacke and granite alluvium	Well-drained soils of low fertility from basic igneous rocks, Tertiary mudstones and sandstones, and quartz conglomerates	Imperfectly drained soils of moderate fertility from schist with greywacke west of the Alpine Fault
Level IV	a. steep hills b. easy rolling hills, imperfectly drained	a. – no subdivision at Level IV – same as O2.2	a. higher monthly water balance ratios b. much lower monthly water balance ratios

Environment O3

Environment O3 consists of areas of poorly-drained soils scattered along the coastal plains of the West Coast. The climate of Environment O3 is mild, with moderate solar radiation, low vapour pressure deficits and high monthly water balance ratios. Parent materials are dominated by old deposits of granite and greywacke alluvium, Tertiary mudstones, sandstones and peat. Soils are generally poorly-drained and of very low natural fertility.

Level III & IV Descriptions

Level III	O3.1	O3.2	O3.3
Area	70,920 ha	5276 ha	12,800 ha
Elevation	135 m	45 m	25 m
Location	West Coast	South Westland	West Coast
Climate	Mild temperatures, moderate solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits	Mild temperatures, low solar radiation, low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits	Mild temperatures, low solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits
Landform	Gently undulating plains	Undulating plains	Flat plains
Soils	Imperfectly drained soils of moderate fertility from granite and greywacke alluvium	Imperfectly drained soils of low fertility from the Fiordland complex, granite and greywacke	Very poorly-drained peat soils of very low fertility
Level IV	a. lower monthly water balance ratios b. as for O3.1 c. cooler winter temperatures d. warmer winter temperatures	a. – no subdivision at Level IV – same as O3.2	a. – no subdivision at Level IV – same as O3.3

Environment O4

Environment O4 has the most southerly distribution of the Level II O environments, occuring mainly along the eastern margins of the Fiordland mountains. Climatically this environment is the coldest O environment as a result of its high average elevation. This, along with its low solar radiation, low vapour pressure deficits, and moderate monthly water balance ratios, distinguishes it from the other O environments. The steep slopes of O4 are covered with soils of imperfect drainage including Tertiary mudstones and sandstones, granites and old granite and greywacke alluvium. Soils are imperfectly drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	O4.1	O4.2
Area	94,764 ha	49,316 ha
Elevation	540 m	310 m
Location	Inland parts of western Southland	Coastal parts of western Southland
Climate	Cool temperatures, low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits	Cool temperatures, low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, slight annual water deficits
Landform	Steep hills	Rolling hills
Soils	Well-drained soils of low fertility from Tertiary sandstones, gravels and granite	Imperfectly drained soils of low fertility from Tertiary sandstones and gravels, and basic igneous rocks
Level IV	a. as for O4.1 b. extremely steep hills, strongly weathered, coarse-textured soils	a. as for O4.2 b. cooler temperatures, very poor drainage, very low fertility

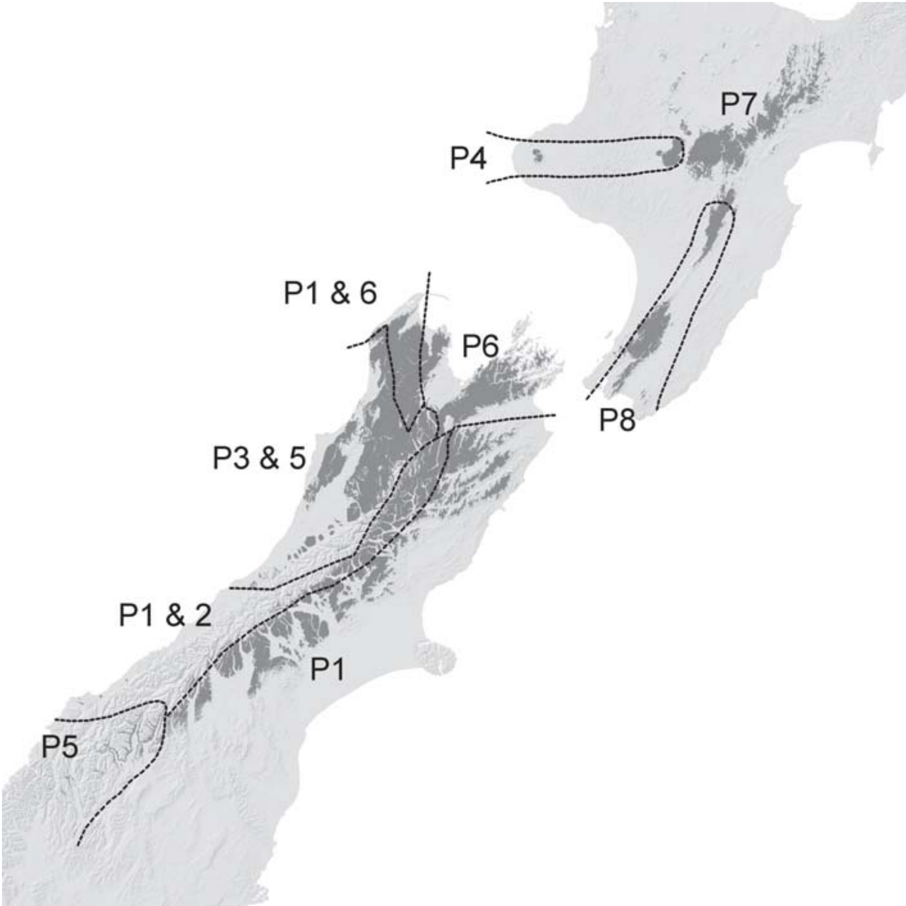
Environment O5

Environment O5 occurs on the southwestern flanks of the Fiordland mountains, around Puysegur Point, and over most of Stewart Island. Climatically this environment is cool, with very low solar radiation, low vapour pressure deficits, and intermediate monthly water balance ratios. The parent materials are diverse, with extensive areas of granite, igneous rocks, andesites, alluvium from Fiordland mountains, some Tertiary sandstones and peat. Soils are of poor to imperfect drainage and of low natural fertility.

Level III & IV Descriptions

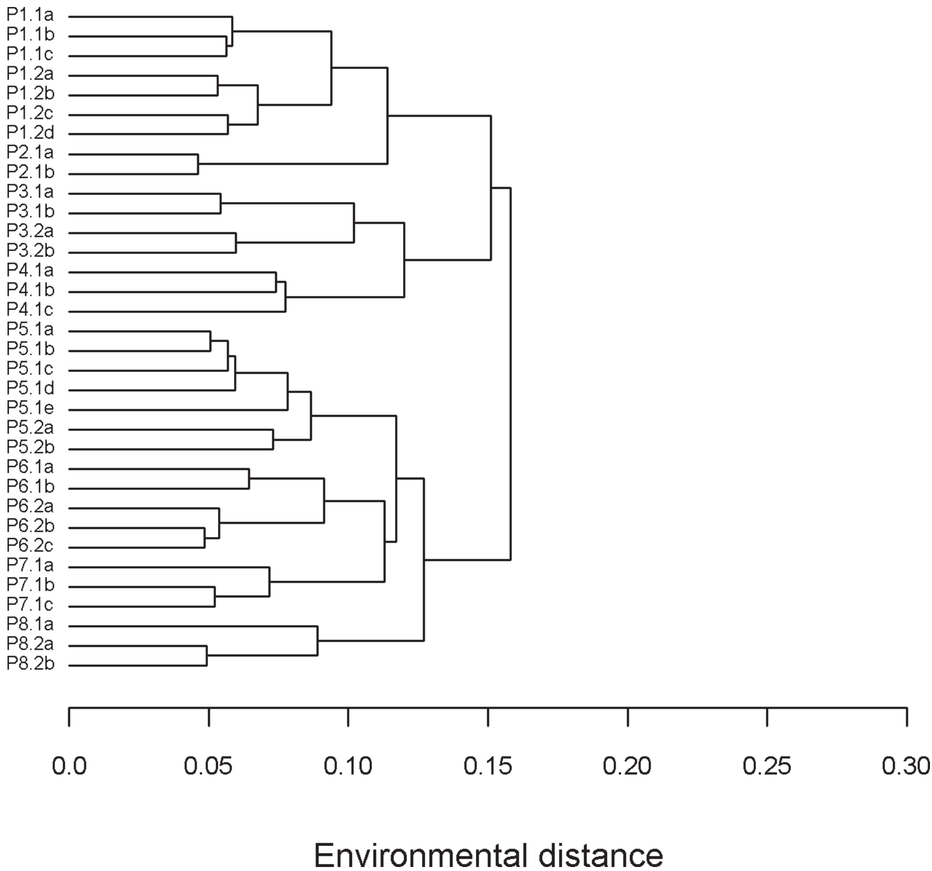
Level III	O5.1	O5.2
Area	30,748 ha	180,804 ha
Elevation	280 m	175 m
Location	Fiordland	Fiordland, Stewart Island
Climate	Cool temperatures, very low solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits	Cool temperatures, very low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits
Landform	Easy rolling hills	Easy rolling hills
Soils	Imperfectly drained peaty soils of very low fertility	Imperfectly drained soils of low fertility from fresh granite and intermediate igneous rocks
Level IV	a. as for O5.1 b. much lower monthly water balance ratios, rolling hills, very poorly-drained, very weakly indurated, very fine-textured soils, peaty soils	a. as for O5.2 b. strongly rolling hills, high fertility c. very poor drainage, very low fertility d. strongly rolling hills, slightly imperfectly drained soils, very low fertility

P - Central Mountains



Environment P is one of the most extensive and widely occurring Level I land environment, including the mountains of the central and southern North Island and the northern and eastern South Island. The climate of Environment P reflects both its high elevation and, in the south, its partial sheltering from prevailing southwesterly winds by the Southern Alps. Temperatures are cold, with high annual and moderate winter solar radiation. Rainfall deficits are only slight, the average monthly water balance ratio is moderate, and vapour pressure deficits are low. Landforms in Environment P mostly consist of mountains and steep, lower-elevation hills, along with the andesitic volcanic cones of Taranaki and the Tongariro National Park. Greywacke is by far the predominant soil parent material, but granite, schist, Tertiary mudstones and sandstones and gravels are also locally important. Extensive areas in the North Island are mantled with andesitic or rhyolitic tephra, and andesitic rocks are dominant on the volcanoes. Soils are mostly well-drained and of low natural fertility.

DENDROGRAM OF P



Environment	P1	P2	P3	P4	P5	P6	P7	P8
Area (ha)	1,156,252	171,587	359,292	46,559	491,772	401,897	432,100	192,911
Altitude (m)	1281	1469	859	1414	577	536	961	746
Mean annual temperature (ºC)	5.8	4.7	7.8	5.7	9.2	9.8	8.5	8.6
Mean minimum temperature of the coldest month (ºC)	-3.2	-4.2	-1.6	-1.4	-1.2	0.1	0.3	1.2
Mean annual solar radiation (MJ/m^2/day)	14.1	13.9	13.5	14.1	14.0	15.0	14.5	13.9
Mean winter solar radiation (MJ/m^2/day)	4.7	4.6	4.2	5.0	4.2	4.7	5.2	4.5
October vapour pressure deficit (kPa)	0.3	0.2	0.1	0.1	0.3	0.3	0.3	0.2
Monthly water balance ratio (ratio)	5.3	7.8	9.9	7.8	5.8	4.9	4.3	5.8
Mean annual water deficit (mm)	1.4	0.0	0.0	0.0	0.7	2.1	0.5	0.1
Slope (º)	27.1	28.2	24.9	14.3	18.6	23.6	18.1	23.2
Drainage (1=very poor to 5=good)	5.0	3.0	5.0	4.9	5.0	4.9	5.0	4.0
Acid soluble phosphorus (1=v. low to 5=v. high)	2.9	3.0	1.2	3.5	23.9	2.5	1.7	1.0
Exchangeable calcium (1=low to 5=v. high)	1.0	1.0	1.0	1.5	1.3	1.4	1.5	1.0
Particle size (1=clay/silt to 5=boulders–massive)	4.0	4.0	4.9	3.0	3.7	4.2	1.9	4.0
Induration (1=non-indurated to 5=v. strongly ind.)	4.0	4.0	4.8	3.4	3.3	4.0	2.6	4.0
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Environment P1

Environment P1 is a very extensive, including eastern slopes of the Tasman Mountains, lower elevation hills on the West Coast, higher peaks in the Marlborough sounds, parts of the seaward Kaikouras and mountains bordering the Canterbury Plains, such as the Torlesse, Craigieburn and Mount Hutt Ranges. Sheltered outliers extend as far south as the Ben Ohau and Barrier Ranges around Lake Ohau, and Lake Wanaka. Climatically this environment is cold, with high solar radiation, moderate vapour pressure deficits and intermediate monthly water balance ratios. As with all other P environments, its annual water deficits are very low to non-existent. The terrain is very steep with greywacke rock the dominant parent material. Soils are well-drained and of low natural fertility.

Level III & IV Descriptions

Level III	P1.1	P1.2
Area	203,504 ha	952,552 ha
Elevation	1060 m	1325 m
Location	Tasman Mountains	Mountains east of the Southern Alps from Marlborough to Otago
Climate	Cold temperatures, high solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits	Cold temperatures, high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Steep mountainous terrain	Steep mountainous terrain
Soils	Well-drained soils of low natural fertility from greywacke	Well-drained soils of moderate natural fertility from greywacke
Level IV	a. very low fertility b. moderate fertility c. much cooler temperatures, lower vapour pressure deficits, higher monthly water balance ratios, moderate fertility	a. warmer temperatures, higher monthly water balance ratios b. much cooler temperatures, higher solar radiation c. much cooler temperatures, lower vapour pressure deficits, lower monthly water balance ratios d. warmer temperatures

Environment P2

Environment P2 occurs at very high elevations on the eastern side of the Southern Alps from Nelson Lakes National Park to the Rakaia headwaters and in mountain valleys as far south as the Upper Waitaki Basin. The climate is very cold and solar radiation is moderate. Vapour pressure deficits are low and high monthly water balance ratios are common. The very steep slopes of P2 are predominatly greywacke with some granite. Soils, where present, are imperfectly drained and of low natural fertility.

Level III & IV Descriptions

Level III	P2.1 – No Subdivision at Level III
Area	171,432 ha
Elevation	1465 m
Location	Eastern side of the Main Divide, closely associated with Environment P1
Climate	Very cold temperatures, moderate solar radiation, low vapour pressure deficits, high monthly water balance ratios, no annual water deficits
Landform	Steep mountains
Soils	Imperfectly drained soils of moderate natural fertility from greywacke, with some granite
Level IV	a. higher monthly water balance ratios b. lower monthly water balance ratios

Environment P3

Environment P3 is located in both the western Tasman Mountains and northern West Coast ranges such as the Paparoa and Victoria Ranges. The climate of this environment is strongly influenced by its exposure to moisture laden westerly winds, with cool temperatures, moderate solar radiation, very low vapour pressure deficits and high monthly water balance ratios. Granite, Tertiary mudstones and sandstones are the dominant parent materials. Soils are well-drained but of very low fertility due to leaching.

Level III & IV Descriptions

Level III	P3.1	P3.2
Area	322,864 ha	36,072 ha
Elevation	875 m	740 m
Location	Paparoa and Victoria Ranges, western Tasman Mountains	Behind Westport, Matiri and Hope Ranges
Climate	Cool temperatures, moderate solar radiation, very low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits	Cool temperatures, high solar radiation, very low vapour pressure deficits, high monthly water balance ratios, no annual water deficits
Landform	Steep mountains	Easy rolling plateau
Soils	Well-drained soils of very low natural fertility from fresh granite	Well-drained soils of very low natural fertility from quartz gravels, conglomerates, sandstones and coal measures
Level IV	a. higher solar radiation, lower monthly water balance ratios b. as for P3.1	a. lower monthly water balance ratios b. higher monthly water balance ratios

Environment P4

Environment P4 consists of the volcanic landforms of Mount Taranaki, Ruapehu and Tongariro, and differs significantly from both the immediate surrounding environments and from the other P environments. This difference is caused by environment P4's warmer winter temperatures as compared with other South Island P environments. Although the climate is cold, winter temperatures are warmer than in the P environments of the South Island. It also has high solar radiation, low vapour pressure deficits and high monthly water balance ratios. Volcanic parent materials particularly andesitic and rhyolitic tephra dominate P4.

Level III & IV Descriptions

Level III	P4.1 – No Subdivision at Level III
Area	46,314 ha
Elevation	1415 m
Location	Mount Taranaki, Ruapehu and Tongariro
Climate	Cold temperatures, high solar radiation, very low vapour pressure deficits, high monthly water balance ratios, no annual water deficits
Landform	Strongly rolling volcanic cones
Soils	Well-drained soils of high natural fertility from andesitic and rhyolitic tephra
Level IV	a. easy rolling mountains, moderate fertility, fine-textured soils, lower slopes of Mt Ruapehu b. much cooler temperatures, peaks of the Taranaki, Ruapehu and Tongariro Mountains c. much warmer temperatures, lower slopes of Mt Taranaki

Environment P5

Environment P5 occurs at lower elevations than the other P environments, extending from coastal sites on the western slopes of the Tasman Mountains to the extensive rolling country in the upper reaches of the Maruia, Grey and Buller Rivers. Small areas also occur in western Otago along rivers such as the Hunter, Makarora and Matukituki. Climatically P5 is cool, with high solar radiation, moderate vapour pressure deficits and moderate monthly water balance ratios. Landforms in P5 are generally strongly rolling to steep, include greywacke, granite, schist, alluvium, and the Moutere gravels of inland Nelson. Soils are well-drained and very low natural fertility.

Level III & IV Descriptions

Level III	P5.1	P5.2
Area	303,368 ha	188,380 ha
Elevation	610 m	525 m
Location	Western Tasman Mountains, upper reaches of the Maruia, Grey and Buller Rivers, western Otago	Inland Nelson and Buller
Climate	Cool temperatures, moderate solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, slight annual water deficits	Cool temperatures, high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Steep mountains	Strongly rolling mountains
Soils	Well-drained soils of moderate natural fertility from granite and greywacke alluvium, schist and mixed alluvium, Tertiary mudstones and andesite	Well-drained soils of low natural fertility from Moutere gravels, Tertiary mudstones, sandstones and greywacke alluvium
Level IV	a. warmer temperatures, very low fertility b. cooler winter temperatures, lower monthly water balance ratios c. cooler temperatures, weakly indurated, fine-textured soils d. higher monthly water balance ratios e. as for P5.1	a. moderate fertility b. very low fertility

Environment P6

Environment P6 is most extensive on the hills of the Abel Tasman National Park and along the lower flanks of the Tasman Mountains in the Marlborough Sounds and on the Richmond and Bryant Ranges. Climatically this environment is cool, with very high solar radiation, low vapour pressure deficits and moderate monthly water balance ratios. Parent materials are predominatly greywacke but significant areas of schist, weathered granite, marble and limestone also occur. Soils are well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	P6.1	P6.2
Area	38,160 ha	363,732 ha
Elevation	660 m	525 m
Location	Abel Tasman National Park	Lower flanks of the Tasman Mountains, Bryant and Richmond Ranges, Marlborough Sounds
Climate	Cool temperatures, very high solar radiation, moderate vapour pressure deficits, intermediate monthly water balance ratios, slight annual water deficits	Cool temperatures, very high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Steep mountains	Steep mountains
Soils	Imperfectly drained soils of very low natural fertility from limestone, granite and andesite	Well-drained soils of moderate natural fertility from greywacke
Level IV	a. cooler temperatures, rolling mountains, low fertility b. very steep mountains	a. warmer temperatures b. much cooler temperatures, moderate fertility c. warmer temperatures

Environment P7

Environment P7 occurs in the hill and mountain country of the central North Island, mainly in the Kaimanawa Mountains and Kaweka Range, but also at higher elevations on the Ikawhenua Range and along parts of the Ruahine Range. P7 also occurs sporadically on many small hills and peaks west of Lake Taupo to about Tokaroa. Climatically this environment is cool, with high solar radiation, low vapour pressure deficits and moderate monthly water balance ratios. Parent materials are mainly rhyolitic and andesitic tephra, greywacke, argillite and sandstone. Moderate areas of soils are developed on water-sorted pumice and hydrothermally altered material rocks. Soils are of moderate natural fertility and are well-drained.

Level III & IV Descriptions

Level III	P7.1 – No Subdivision at Level III
Area	432,376 ha
Elevation	960 m
Location	Northern end of the Ruahine Range, Kaimanawa, Kaweka, northeast Ikawhenua
Climate	Cool temperatures, high solar radiation, low vapour pressure deficits, low monthly water balance ratios, slight annual water deficits
Landform	Steep mountainous terrain
Soils	Well-drained soils of low natural fertility from rhyolitic and andesitic tephra with some greywacke, agillite and sandstone
Level IV	a. very low fertility, strongly indurated, coarse-textured soils b. warmer temperatures, weakly indurated, fine-textured soils c. much cooler temperatures, lower vapour pressure deficits, higher monthly water balance ratios, weakly indurated, fine-textured soils

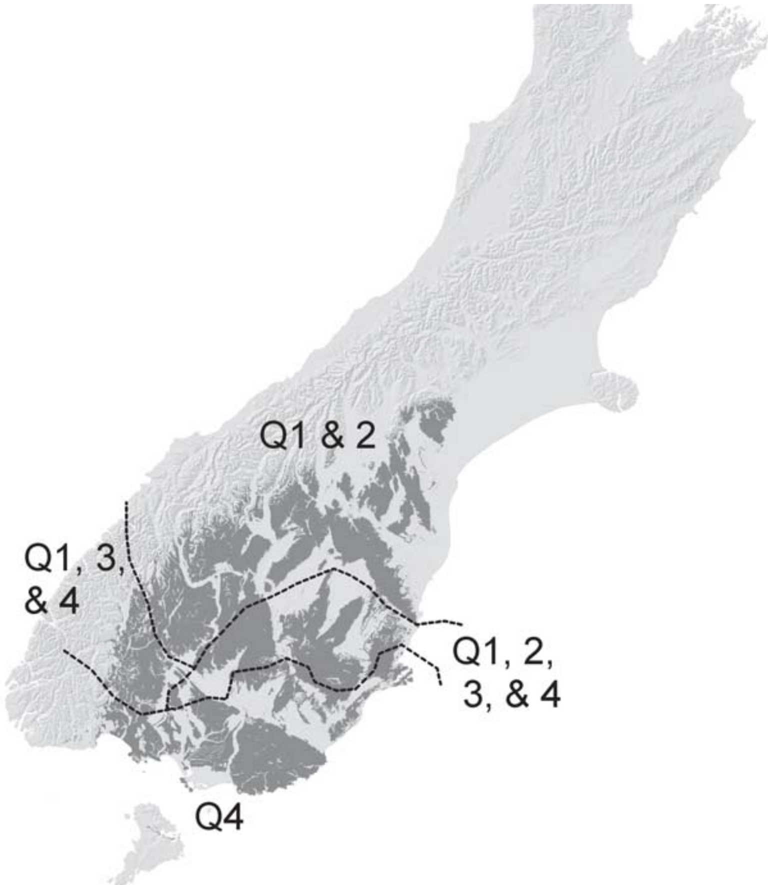
Environment P8

Environment P8 encompasses the Tararua Range and the southern portion of the Ruahine Range. Climatically this environment is cool, with moderate solar radiation, low vapour pressure deficits and moderate monthly water balance ratios. Parent materials consist of greywacke with some areas of andesite, old basalts and areas of significant peat development. Soils are imperfectly drained and of low natural fertility.

Level III & IV Descriptions

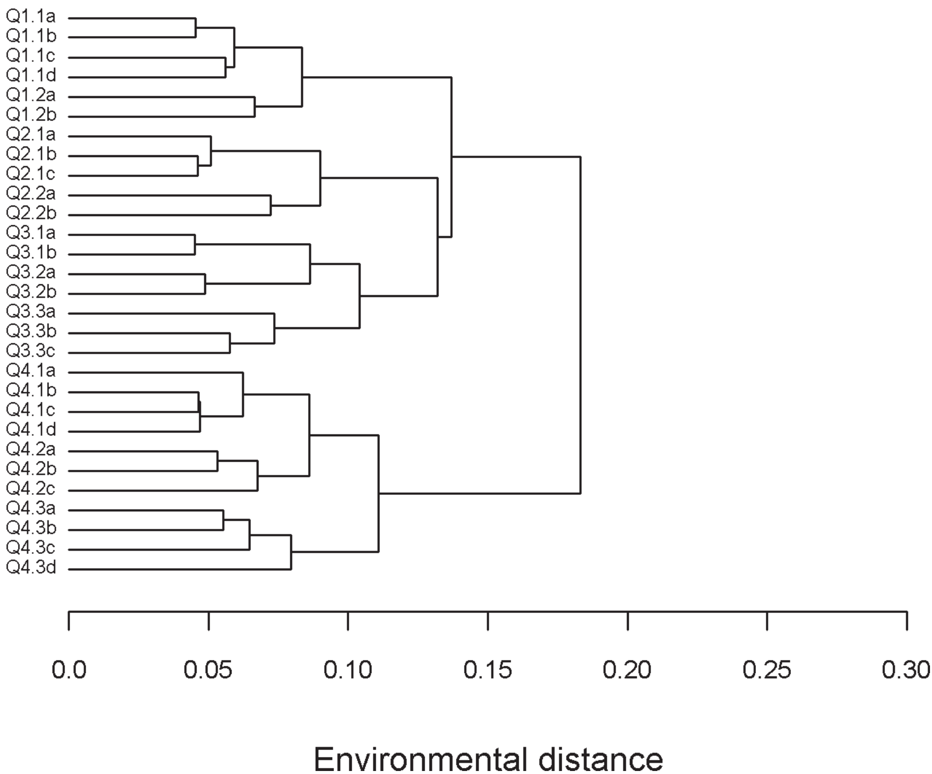
Level III	P8.1	P8.2
Area	4228 ha	188,760 ha
Elevation	1115 m	735 m
Location	Crests of the Ruahine Range	Middle parts of the Ruahine Range, Tararua and Rimutaka Ranges
Climate	Cold temperatures, moderate solar radiation, low vapour pressure deficits, low monthly water balance ratios, no annual water deficits	Cool temperatures, moderate solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, slight annual water deficits
Landform	Steep mountainous terrain	Steep mountainous terrain
Soils	Imperfectly drained peat soils of very low natural fertility – some greywacke	Imperfectly drained soils of very low natural fertility from greywacke with some argillite
Level IV	a. – no subdivision at Level IV – same as P8.1	a. much cooler temperatures b. much warmer temperatures

Q- Southeastern Hill Country and Mountains



Q is the dominant environment of the mountains and hill-country of the south-eastern South Island, extending from the Rangitata River in South Canterbury through Otago to the Catlins in eastern Southland and westwards to the eastern fringes of Fiordland. The climate of Environment Q is cool with low annual and winter solar radiation, reflecting its southern latitude. The climate is also strongly influenced by the sheltering effects of the Southern Alps, particularly in the north, resulting in low water deficits and moderate vapour pressure deficits - drier conditions than occur in most of New Zealand's other montane environments. Landforms consist mainly of rolling to steep hills and mountains, but extensive areas of rolling downlands occur in the south. Parent materials are mainly schist, greywacke, and Tertiary rocks, extensive areas of which are loess mantled. Substantial areas of alluvium from these rocks occur in the south, while other locally important parent materials include older basaltic and andesitic rocks and glacial till. The soils are generally moderately well-drained and are the most fertile of any montane environment.

DENDROGRAM OF Q



Environment	Q1	Q2	Q3	Q4
Area (ha)	908,456	643,400	426,927	1,296,995
Altitude (m)	1154	672	860	264
Mean annual temperature (ºC)	5.6	8.1	6.5	9.1
Mean minimum temperature of the coldest month (ºC)	-3.3	-2.4	-3.1	0.4
Mean annual solar radiation (MJ/m^2/day)	13.3	13.4	13.0	12.4
Mean winter solar radiation (MJ/m^2/day)	3.7	3.9	3.6	3.3
October vapour pressure deficit (kPa)	0.3	0.4	0.3	0.3
Monthly water balance ratio (ratio)	4.4	2.4	3.2	3.2
Mean annual water deficit (mm)	2.0	51.3	22.5	20.6
Slope (º)	22.1	17.3	9.5	7.0
Drainage (1=very poor to 5=good)	4.8	4.6	3.5	4.4
Acid soluble phosphorus (1=v. low to 5=v. high)	3.0	3.0	3.0	3.1
Exchangeable calcium (1=low to 5=v. high)	1.4	1.4	1.8	1.8
Particle size (1=clay/silt to 5=boulders–massive)	4.0	4.0	4.0	3.2
Induration (1=non-indurated to 5=v. strongly ind.)	4.0	3.9	4.0	3.2
Soil Age (1=raw/recent, 2=older)	1.0	1.0	1.0	1.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0	1.0	1.0

Environment Q1

Environment Q1 consists of cold, high elevation mountain tops and range crests including the tops of the Eyre and Harris Mountains of inland Otago, Hawkdun Range, Grampian Mountains and Hunter Hills of South Canterbury. Climatically Environment Q1 is cold, with moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and slight annual water deficits. Parent materials are predominately greywacke and schist with some areas of greywacke alluvium and loess. Typical steep mountain landforms are dominant and the well-drained soils are of low to moderate natural fertility.

Level III & IV Descriptions

Level III	Q1.1	Q1.2
Area	654,932 ha	253,352 ha
Elevation	1095 m	1305 m
Location	Hawkdun Range, Grampian Mountains and Hunter Hills, South Canterbury, lower elevation slopes of the Eyre and Harris Mountains, ranges of inland Otago	Eyre and Harris Mountains, ranges of inland Otago, Takitimu Mountains
Climate	Cold temperatures, moderate solar radiation, low vapour pressure deficits, low monthly water balance ratios, and slight annual water deficits	Very cold temperatures, moderate solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits
Landform	Steep mountains	Very steep mountains
Soils	Well-drained soils of moderate fertility from greywacke, schist	Well-drained soils of moderate fertility from greywacke rock, colluvium and basalt
Level IV	a. much cooler temperatures, lower vapour pressure deficits, strongly rolling mountainous terrain b. as for Q1.1 c. very steep mountainous terrain d. warmer temperatures	a. as for Q1.2 b. much warmer summer temperatures, high fertility

Environment Q2

Environment Q2 is usually found in close proximity to Q1 but at lower elevations. The climate for this environment is cool, with moderate solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios and low annual water deficits. Parent materials are generally greywacke, schist and loess but with extensive gravelly alluvium and colluvium, and smaller areas of basic volcanic rocks, limestone and mudstone. Soils are well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	Q2.1	Q2.2
Area	407,532 ha	235,740 ha
Elevation	640 m	730 m
Location	Eyre and Harris Mountains, ranges of inland Otago	Hawkdun Range, Grampian Mountains and Hunter Hills in South Canterbury, Takitimu Mountains, southern end of the Two Thumb Range
Climate	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, low annual water deficits	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, low annual water deficits
Landform	Steep mountains	Steep mountains
Soils	Well-drained soils of moderate fertility from greywacke	Imperfectly drained soils of moderate fertility from schist
Level IV	a. lower annual water deficits b. much cooler temperatures, higher annual water deficits c. warmer temperatures, higher annual water deficits	a. as for Q2.2 b. much warmer temperatures, strongly rolling mountainous terrain, moderately indurated

Environment Q3

Environment Q3 is dominant on the mountains and ranges of southern Otago and northern Southland, including the Garvie Mountains, and the Rough Ridge, Rock and Pillar and Lammermoor Ranges. Climatically this environment is similar to the previous Q environments, with cold temperatures, moderate solar radiation, moderate vapour pressure deficits and slight annual water deficits. Parent materials are predominantly greywacke and schist with some loess, mudstone, and quartz gravels, conglomerates and sandstones. Soils are of moderate natural fertility and are imperfectly drained.

Level III & IV Descriptions

Level III	Q3.1	Q3.2	Q3.3
Area	84,900 ha	53,008 ha	289,156 ha
Elevation	690 m	415 m	990 m
Location	Eyre, Thompson Mountains and the southern end of the Garvie Mountains	Northern side of the Takitimu Mountains and the Taringatura hills	Garvie Mountains and the North Rough, Knobby, Lammerlaw and Rock and Pillar Ranges
Climate	Cool temperatures, moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Cold temperatures, moderate solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, low annual water deficits
Landform	Steep mountains	Undulating hills	Undulating mountains
Soils	Imperfectly drained soils of moderate natural fertility from greywacke	Imperfectly drained soils of moderate natural fertility from schist, calcareous mudstone, quartz gravels and greywacke	Imperfectly drained soils of moderate natural fertility from schist

Level III	Q3.1	Q3.2	Q3.3
Level IV	a. cooler temperatures b. much warmer temperatures	a. cooler temperatures b. warmer temperatures	a. much cooler annual temperatures, lower vapour pressure deficits, higher monthly water balance ratios, much lower annual water deficits b. warmer annual temperatures, cooler winter temperatures, higher vapour pressure deficits, lower monthly water balance ratios, much higher annual water deficits c. much lower annual water deficits

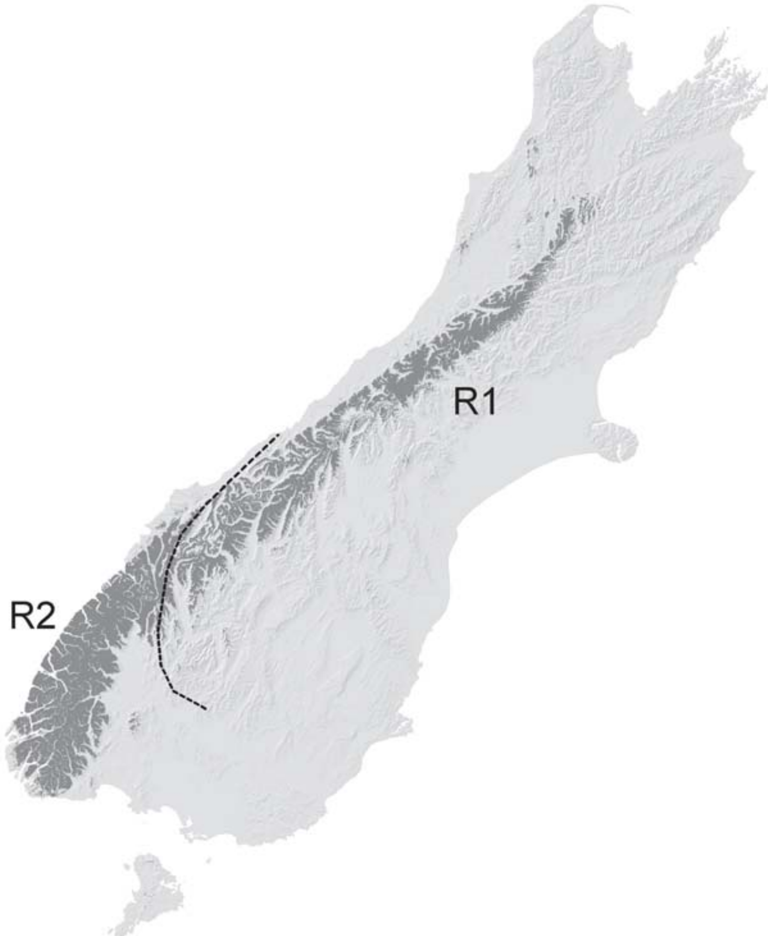
Environment Q4

Environment Q4 consists of low rolling hills that extend from Dunedin to the Catlins and through much of Southland to the eastern margins of the Fiordland mountains. Climatically this environment is cool, with low solar radiation (due to its more southerly location and generally close proximity to the coast), moderate vapour pressure deficits and low annual water deficits. The soils of Q4 are mostly derived from tuffaceous greywacke and schist but with extensive areas of alluvium and loess. There are also smaller areas of soft Tertiary rocks and scattered areas of andesite and basalt. Soils are moderate to well-drained and of moderate natural fertility.

Level III & IV Descriptions

Level III	Q4.1	Q4.2	Q4.3
Area	477,280 ha	464,636 ha	354,804 ha
Elevation	265 m	215 m	330 m
Location	Most of the Catlins, north of Te Waewae Bay up to Te Anau	Around Invercargill, east of Lake Te Anau and valleys in the Catlins	Eastern Otago including the Otago Peninsula
Climate	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, low monthly water balance ratios, slight annual water deficits	Cool temperatures, low solar radiation, moderate vapour pressure deficits, very low monthly water balance ratios, low annual water deficits
Landform	Easy rolling hills	Gently undulating hills	Rolling hills
Soils	Well-drained soils of moderate fertility from tuffaceous greywacke, Tertiary mudstones and gravels and andesite	Well-drained soils of moderate fertility from loess and alluvium from tuffaceous greywacke	Imperfectly drained soils of moderate fertility from schist and quartz gravels
Level IV	a. imperfectly drained b. weakly indurated c. much cooler temperatures d. very gently undulating hills	a. cooler temperatures, high fertility b. warmer winter temperatures, high fertility c. warmer annual temperatures, flat terrain, imperfectly drained, high fertility	a. lower annual water deficits b. much higher annual water deficits, strongly rolling hills c. warmer temperatures, low fertility d. much warmer temperatures, strongly rolling hills, well-drained

R - Southern Alps



Environment R extends along the main divide of the South Island from the Spencer Mountains of inland Nelson south along the Southern Alps to the Fiordland Mountains. It also includes small areas on the crests of ranges both to the east and west of the main divide. The climate of Environment R is cold with amongst the lowest temperatures of any Level I land environments, reflecting its average elevation of nearly 1100 m. This high elevation, coupled with its exposure to rain-bearing westerly winds, results in low solar radiation, very low water and vapour pressure deficits and very high monthly water balance ratios. Average slopes are steeper in Environment R than in any other Level I land environment, with mountain landforms predominating. Dominant soil parent materials in Environment R are granite, greywacke and schist with smaller areas of older volcanic rocks and gneiss. Soils vary in character depending on the parent material but are generally very thin (skeletal) and sometimes peaty.

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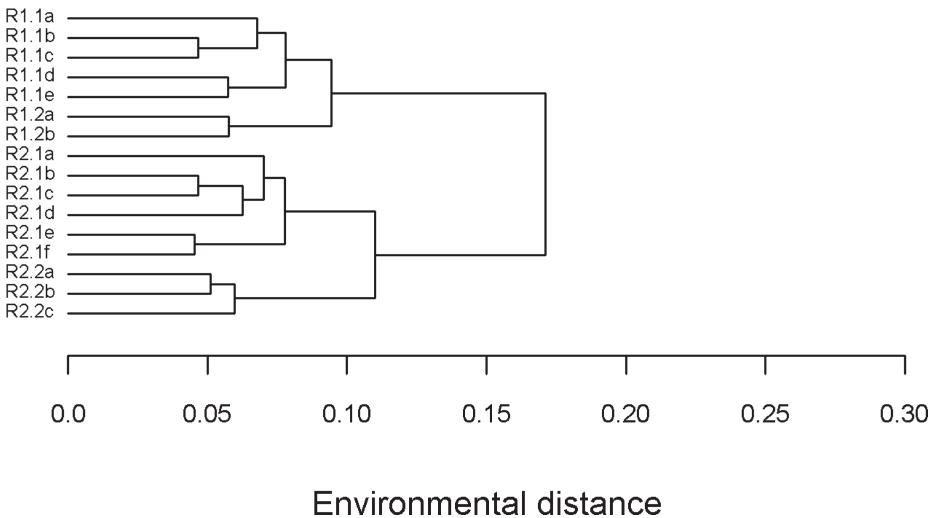


Environment	R1	R2
Area (ha)	974,462	956,344
Altitude (m)	1343	777
Mean annual temperature (ºC)	5.1	6.5
Mean minimum temperature of the coldest month (ºC)	-3.2	-0.7
Mean annual solar radiation (MJ/m^2/day)	13.0	12.1
Mean winter solar radiation (MJ/m^2/day)	4.0	3.1
October vapour pressure deficit (kPa)	0.1	0.1
Monthly water balance ratio (ratio)	15.1	14.3
Mean annual water deficit (mm)	0.0	0.0
Slope (º)	31.2	30.9
Drainage (1=very poor to 5=good)	4.8	3.5
Acid soluble phosphorus (1=v. low to 5=v. high)	3.0	1.3
Exchangeable calcium (1=low to 5=v. high)	1.6	1.0
Particle size (1=clay/silt to 5=boulders–massive)	4.0	5.0
Induration (1=non-indurated to 5=v. strongly ind.)	4.0	4.9
Soil Age (1=raw/recent, 2=older)	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	1.0	1.0

Environment R1

Environment R1 encompasses the Southern Alps north of Fiordland, stretching from Nelson Lakes National Park in the north to the Livingstone Mountains west of Lake Wakatipu in the south. It also occurs sporadically on the Paparoa and Victoria Ranges. The climate of this environment is cold, reflecting its very high average elevation. Solar radiation is moderate, with very low vapour pressure deficits and very high monthly water balance ratios. The degree of soil development in R1 is highly variable and those soils that do occur are rocky, well-drained and of low fertility. The parent materials of R1 are mainly schist and greywacke rocks and derived colluvium.

Level III & IV Descriptions

Level III	R1.1	R1.2
Area	649,852 ha	346,180 ha
Elevation	1320 m	1415 m
Location	Southeastern and northwestern parts of the Southern Alps	Western parts of the Southern Alps from Hokitika south
Climate	Cold temperatures, moderate solar radiation, very low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits	Very cold temperatures, low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits
Landform	Steep mountains	Steep mountains
Soils	Well-drained soils of moderate fertility from schist and greywacke	Well-drained soils of moderate fertility from schist
Level IV	a. much warmer temperatures, higher vapour pressure deficits, much lower monthly water balance ratios b. much cooler temperatures, lower vapour pressure deficits, much lower monthly water balance ratios c. much cooler temperatures, higher monthly water balance ratios d. cooler winter temperatures, much higher monthly water balance ratios e. much warmer temperatures, much higher monthly water balance ratios	a. much lower temperatures, much higher monthly water balance ratios b. warmer annual temperatures

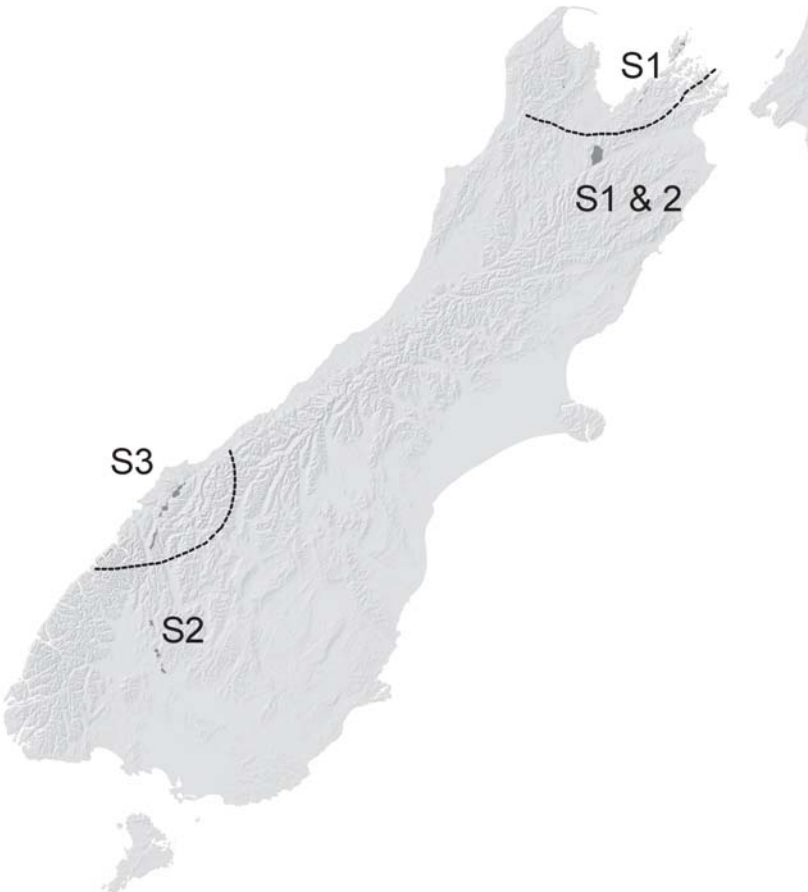
Environment R2

Environment R2 is restricted to the Fiordland mountains. R2 is warmer then R1 reflecting its lower elevation. R2 has low solar radiation, very low vapour pressure deficits and very high monthly water balance ratios. Environment R2 has more extensive soil development than Environment R1 with imperfectly drained soils of poor fertility. Parent materials are predominatly hard granite with some areas of old basalt and gneiss.

Level III & IV Descriptions

Level III	R2.1	R2.2
Area	405,048 ha	551,484 ha
Elevation	1110 m	530 m
Location	Higher elevation and eastern parts of Fiordland	Lower elevation and western parts of Fiordland
Climate	Cold temperatures, low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits	Cool temperatures, low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits
Landform	Steep mountains	Steep mountains
Soils	Imperfectly drained soils of low fertility from granite and basalt	Imperfectly drained soils of very low fertility from granite, older basalt and gneiss
Level IV	a. much warmer temperatures, much higher monthly water balance ratios, high fertility b. cooler temperatures, much higher monthly water balance ratios, very steep mountainous terrain, well-drained, very low fertility c. very low fertility d. cooler winter temperatures, much lower monthly water balance ratios, moderate fertility e. warmer temperatures, higher vapour pressure deficits, much lower monthly water balance ratios, very low fertility f. higher vapour pressure deficits, much lower monthly water balance ratios, well-drained	a. cooler annual temperatures , higher monthly water balance ratios b. much warmer temperatures, higher vapour pressure deficits, lower monthly water balance ratios c. cooler winter temperatures, higher vapour pressure deficits, much lower monthly water balance ratios, low fertility

S - Ultramafic Soils



Environment S with its highly distinctive ultramafic rocks occurs in several locations scattered through the western South Island, mainly in Nelson, Marlborough, South Westland, and inland Southland. The only other area of ultramafic rocks in New Zealand occurs near North Cape and is included in Environment A1.

The defining feature of Environment S is its ultramafic parent material, i.e. igneous rock, generally coarse grained, low in silica, and with unusually high concentrations of iron and magnesium minerals. Soils formed on these rocks are generally of very low fertility with concentrations of minerals such as nickel and magnesium that are toxic to plants. They also tend to be shallow and have low amounts of clay-size particles and organic matter, resulting in low water and nutrient holding capacity but good drainage. The climate of Environment S is cold, with high monthly water balance ratios and only slight water deficits, reflecting its mean elevation of around 900 metres. Solar radiation is moderate and vapour pressure deficits are low. Landforms are generally steep and mountainous.

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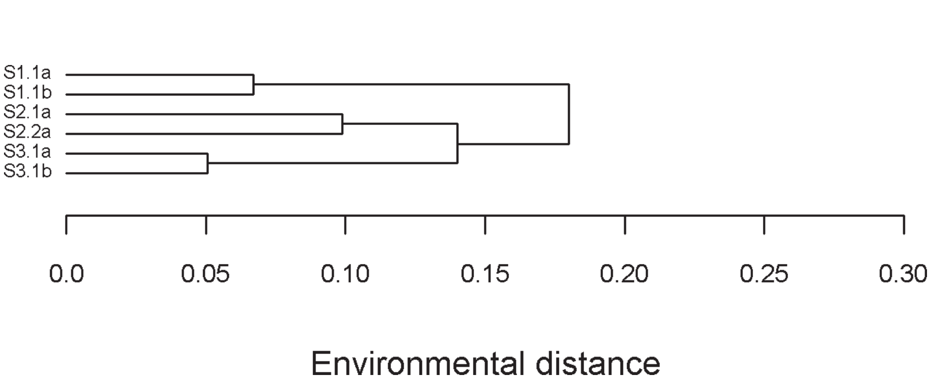


Environment	S1	S2	S3
Area (ha)	3778	16,989	12,752
Altitude (m)	390	1120	797
Mean annual temperature (ºC)	10.6	6.3	7.2
Mean minimum temperature of the coldest month (ºC)	2.1	-3.2	-0.7
Mean annual solar radiation (MJ/m^2/day)	14.8	14.2	12.4
Mean winter solar radiation (MJ/m^2/day)	4.7	4.3	3.6
October vapour pressure deficit (kPa)	0.3	0.2	0.1
Monthly water balance ratio (ratio)	3.6	5.0	17.0
Mean annual water deficit (mm)	15.6	0.0	0.0
Slope (º)	16.1	22.3	23.9
Drainage (1=very poor to 5=good)	5.0	5.0	5.0
Acid soluble phosphorus (1=v. low to 5=v. high)	1.0	1.0	1.0
Exchangeable calcium (1=low to 5=v. high)	1.0	1.0	1.0
Particle size (1=clay/silt to 5=boulders–massive)	5.0	5.0	5.0
Induration (1=non-indurated to 5=v. strongly ind.)	4.0	4.0	4.0
Soil Age (1=raw/recent, 2=older)	2.0	2.0	2.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	3.0	3.0	3.0

Environment S1

Environment S1 occurs as small patches throughout Nelson and Marlborough: just east of Nelson city, on D'Urville Island, on the Bryant Range and on the lower flanks of the Red Hills. The climate of this environment is mild, with high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and slight annual water deficits. Ultrabasic and extremely basic igneous rocks are the sole parent material, with soils having higher levels of elements such as nickel and magnesium that inhibit the growth of plants. Soils are well-drained and of very low natural fertility.

Level III & IV Descriptions

Level III	S1.1 – No Subdivision at Level III
Area	3756 ha
Elevation	385 m
Location	Nelson and Marlborough – just east of Nelson city, D'Urville Island, Bryant Range, lower flanks of the Red Hills
Climate	Mild temperatures, high solar radiation, moderate vapour pressure deficits, low monthly water balance ratios and slight annual water deficits
Landform	Strongly rolling hills
Soils	Patchy, well-drained soils of very low natural fertility from ultrabasic and extremely basic igneous rocks. High levels of nickel and magnesium
Level IV	a. much warmer temperatures b. much cooler temperatures

Environment S2

Environment S2 occurs in three distinct locations: the inland Red Hills of Marlborough, the Lockett Range of west Nelson and near the Livingstone Fault in western Southland. Climatically this environment is cold, with high levels of solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios and no annual water deficits. As in the other S environments, parent materials consist of solely ultrabasic and extremely basic igneous rocks with soils that are well-drained and of very low natural fertility.

Level III & IV Descriptions

Level III	S2.1	S2.2
Area	12,144 ha	4840 ha
Elevation	1170 m	990 m
Location	Inland Red Hills around Marlborough	Lockett Range and along the Livingstone Fault
Climate	Cold temperatures, high solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits	Cold temperatures, low solar radiation, low vapour pressure deficits, intermediate monthly water balance ratios, no annual water deficits
Landform	Steep hills	Steep hills
Soils	Patchy, well-drained soils of very low natural fertility from ultrabasic and extremely basic igneous rocks	Patchy, well-drained soils of very low natural fertility from ultrabasic and extremely basic igneous rocks
Level IV	a. – no subdivision at Level IV – same as S2.1	a. – no subdivision at Level IV – same as S2.2

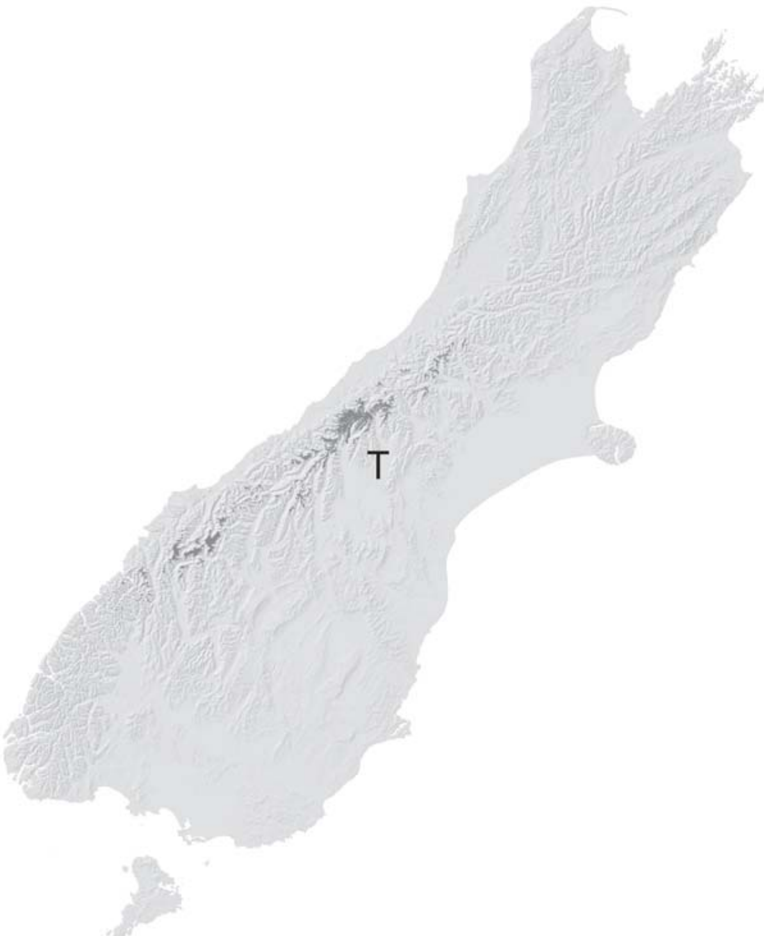
Environment S3

Environment S3 encompasses areas of ultramafic rocks near the Livingstone Fault, in the northern Fiordland mountains, near the Cascade River in the Olivine Range, and the adjacent Red Mountain on the Red Hills Range. Small areas also occur from Milford Sound to Sutherland Sound. Climatically this environment is cold, with low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios and no annual water deficits. The sole parent material is ultrabasic and extremely basic igneous rocks. Soil development is patchy and those that do occur are well-drained, with very low natural fertility.

Level III & IV Descriptions

Level III	S3.1 – No Subdivision at Level III
Area	12,784 ha
Elevation	805 m
Location	Northern Fiordland mountains near Milford Sound, the Cascade River in the Olivine Range and the adjacent Red Mountain on the Red Hills Range
Climate	Cold temperatures, low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios and no annual water deficits
Landform	Steep hills
Soils	Patchy, well-drained soils of very low natural fertility from ultrabasic and extremely basic igneous rocks
Level IV	a. much warmer temperatures, lower elevations b. much cooler temperatures, higher elevations

T - Permanent Snow and Ice



Environment T consists of the ice caps and permanent snowfields of the Southern Alps. Although it has the highest mean elevation (1800 m) of any Level I land environment, it includes features such as the Franz and Fox glaciers, which extend to lower elevations. The climate is typified by very cold temperatures, very high precipitation, much of it as snow, very low vapour pressure deficits and low levels of annual and winter solar radiation, particularly in the south. Slopes vary from undulating to very steep. No subdivision of Environment T has been made beyond Level I.

DENDROGRAM OF T

DENDROGRAM NOT REQUIRED

NO SUBDIVISION BEYOND LEVEL I

Environment	T1
Area (ha)	157,015
Altitude (m)	1855
Mean annual temperature (ºC)	2.5
Mean minimum temperature of the coldest month (ºC)	-4.4
Mean annual solar radiation (MJ/m^2/day)	12.8
Mean winter solar radiation (MJ/m^2/day)	4.0
October vapour pressure deficit (kPa)	0.0
Monthly water balance ratio (ratio)	21.8
Mean annual water deficit (mm)	0.0
Slope (º)	26.6
Drainage (1=very poor to 5=good)	0.0
Acid soluble phosphorus (1=v. low to 5=v. high)	0.0
Exchangeable calcium (1=low to 5=v. high)	0.0
Particle size (1=clay/silt to 5=boulders–massive)	0.0
Induration (1=non-indurated to 5=v. strongly ind.)	0.0
Soil Age (1=raw/recent, 2=older)	0.0
Chemical limitations (1=low, 2=saline, 3=ultramafic)	0.0

Environment T1

Environment T1 is a large environment that includes all the permanent ice and snow peaks of the Southern Alps. The climate is very cold, with low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios and no annual water deficits.

Level III & IV Descriptions

Level III¨	T1.1 – No Subdivision at Level III
Area¨	148,005 ha
Elevation¨	1780 m
Location¨	Peaks of the Southern Alps with permanent ice cover
Climate¨	Very cold temperatures, low solar radiation, very low vapour pressure deficits, very high monthly water balance ratios, no annual water deficits
Landform¨	Steep ice nevees and glaciers
Soils¨	Not applicable
Level IV¨	a. – no subdivision at Level IV – same as T1.1

CHAPTER FIVE
Using LENZ

INTRODUCTION

This chapter provides general guidelines for use of LENZ and technical details of the methods used in the case studies presented in Chapter Five of Land Environments of New Zealand. Guidelines for the use of LENZ include discussion of both conceptual issues related to the relationship between LENZ environments and ecosystems, and more practical questions related to the use of LENZ as a management tool. Our presentation of the case studies is designed to complement that in Land Environments of New Zealand, which focuses primarily on rationales and results. Here we concentrate more on the data used for each case study and how the analyses were carried out. Each case study is described using a one-page summary of the input data, followed by an outline of the key steps used in the analysis and descriptions of the resulting outputs, together forming a 'how-to' guide that will help users adapt LENZ to their particular needs.

GUIDELINES FOR APPLYING LENZ

Conceptual issues – the dynamic nature of ecosystems

As discussed in Chapter One of Land Environments of New Zealand, ecosystems are typified by dynamic relationships between species (biotic) and their environment (abiotic). Predicting the ecosystem character at any site is complicated by the manner in which these components change at different rates over time. Abiotic components such as average climate conditions tend to change more slowly over broad time scales than biotic components. The latter may show much greater short-term variability, reflecting the effects of different types of disturbance such as storms, landslides, fires, etc. By focusing on the more stable abiotic ecosystem components as a basis for classification, LENZ provides a framework to characterise the broad potential biological conditions at a site. For example, when used in combination with knowledge from historic sources[1] and/or surviving indigenous ecosystems, it provides a powerful tool that allows reconstruction of New Zealand's general pre-human or potential ecosystem character, including environments where only a few small fragments of native vegetation now survive.

When combined with information describing local disturbance history and its effects, the predictive ability of LENZ can be extended to provide a more detailed picture of actual biological character. However, little data are available describing geographic variation in disturbance regimes across New Zealand, reflecting the difficulty in measuring events that vary markedly in their extent, frequency and patchiness of occurrence. For example, volcanic eruptions may drastically affect vast areas and alter vegetation composition so that the changes may still be discernable centuries after the event.[2] By contrast, although local tree falls caused by a gale or heavy snowfall may individually affect only a few or perhaps tens of square metres, in aggregate they may favour a shift in vegetation composition at a landscape scale towards tree species with faster growing but more light demanding seedlings[3] or trigger a cascade of events leading to widespread forest decline[4]. Alternatively, landslides induced by an earthquake may initiate primary successions that, while of only limited extent, allow the persistence of pioneering species in a landscape otherwise dominated by species characteristic of stable growing conditions.

The dynamic nature of New Zealand's ecosystems, in common with those in most other parts of the world, is further accentuated by disturbance related to human activity. This includes both the clearance of former native land cover and the introduction of new species. A major period of modification of New Zealand's vegetation by fire began with the arrival of Maori, with the most extensive changes occurring in dry climates, particularly those with flat terrain that facilitated the spread of fire.[5] European settlers continued clearing and modifying native vegetation and also introduced large numbers of alien species that included competitors,[6] browsers,[7] and predators.[8] Some were introduced deliberately as a source of food or fibre (e.g., many agricultural and horticultural species, goats, pigs, possums, and rabbits), while others were introduced for sport (e.g., several species of deer, chamois, thar, pheasants and trout) or to control previously introduced species (e.g., mustelids introduced to control rabbits). Other introductions were accidental, such as rats brought by boat or weeds transported with grain seed.[9]

Finally, while LENZ does not explicitly consider the local disturbance regimes of indigenous ecosystems, in many cases the underlying data layers indicate the broad character of natural physical disturbances prevailing in particular landscapes. For example, data describing soil parent materials indirectly delineate that part of the central North Island that is periodically affected by devastating volcanic eruptions. Similarly, environments along the Southern Alps that are subject to frequent landslides are identified by their combination of very high rainfall, steep slopes and hard but shattered parent rock. In many of these disturbance-prone environments existing process-oriented studies[10] indicate the relationship between disturbance and local scale variation in ecosystem character.

Conceptual issues – the biological scope of LENZ

Although the underlying variables used to define LENZ were chosen because of their relevance to the physiological processes of trees as outlined in Chapter Two of *Land Environments of New Zealand*, we also expect them to summarise geographic patterns adequately for many other species groups. However, although variables such as temperature are likely to have strong mechanistic links with practically all biota, other variables used in defining LENZ may be important for only some groups of species. For example, variation in vapour pressure deficits would most likely affect plant distributions but would be less likely to be useful for predicting assemblages of soil invertebrates. Where LENZ applications are developed for species groups that are relatively insensitive to one or more such variables, it may be sensible to amalgamate environments that differ only in less relevant variables.

The degree to which LENZ can predict individual species distributions also requires clarification. The classification is designed to indicate areas having similar ecosystem character at a community level, with emphasis on functional groups rather than defining the distributions of individual species. In this regard, LENZ contrasts with historic, species-oriented classifications of New Zealand's land cover[11] that define units geographically, based on distributions of structurally dominant species. Correspondence between LENZ and species distributions are likely to be lowest for species with poor dispersal ability, such as *Nothofagus* or beech species or our native snails, and where we would expect correspondingly weaker sorting in relation to environment than in species with strong dispersal ability. As already indicated above, where weakly dispersing species play a dominant role in determining ecosystem structure, inclusion of data layers describing their distributions will be required to adequately predict ecosystem character.[12]

Analytical issues – environmental versus geographic classification

The most fundamental difference between LENZ and traditional land classifications such as New Zealand's Ecological Regions and Districts[13] revolves around their respective treatment of geographic and environmental space. In the latter, the classification units form discrete units in geographic space but, as a consequence, they vary widely in their within-unit environmental variability. By contrast, LENZ defines discrete and relatively uniform areas in environmental space but many of these show wide geographic dispersion. Although some may form one or two discrete geographic patches, many occur as small patches, often scattered over a considerable area. In this regard, LENZ represents more accurately the true character of environmental variation across New Zealand's landscapes.

In practical terms, physically locating all the scattered patches of a LENZ environment in the field may present a challenge, although the increasing availability of hand held geographic positioning devices (GPS) considerably reduces this difficulty. For some applications, users may set a minimum threshold area below which they merge patches of one environment with a surrounding more extensive environment. However, small, isolated patches of environments may have considerable value, for example, in identifying potential locations for rare or threatened species that have specific environmental requirements.

Analytical issues – limitations of scale

Geographic Scale

One of the most important factors affecting the ability of LENZ to predict biological components of ecosystems is the geographic scale limitations of the underlying data layers. In general, as the scale of application becomes progressively finer, the limitations of the underlying data layers will become progressively more important. Moreover, these vary from layer to layer, reflecting differences in both the manner in which the different layers were created and how they vary across New Zealand's landscapes. The seven climate variables generally show continuous variation, with changes in solar radiation and rainfall occurring at broad geographic scales mostly reflecting variation in latitude and exposure to westerly winds. By contrast, temperatures decline at only a moderate rate with increasing latitude but show strong and consistent variation in relation to altitude at more intermediate to local scales. As a consequence, when working at fine spatial scales involving distances of less than a few hundred metres, geographic variation in climate is likely to be muted except in steep terrain. However, much more marked local-scale variation is shown by landform and soil variables, often in association with abrupt changes in topographic position or parent material. Data describing these attributes were derived from the New Zealand Land Resource Inventory, stored at a nominal scale of 1:50 000, and this effectively sets the finest scales at which LENZ should be used.

For work at finer spatial scales, improvements in LENZ's resolution could be gained through use of a layer describing topographic position, as this would allow much improved differentiation of local variation in factors such as drainage, nutrient supply and minimum temperatures during inversion frosts. However, processing national coverage digital elevation data with high enough resolution to define a suitable descriptive data layer to include in LENZ is beyond our current capacity. Use of established methods to correct our flat surface estimates of solar radiation to account for the effects of slope and aspect[14] is more feasible and would allow estimation of local scale variation in water deficits that in dry climates typically increase with progression from south to north facing slopes.

Temporal scale limitations

As described in Chapter Two, most of the underlying data used to define LENZ's climate layers were collected over the period from 1950 to 1980, while soil data were collected over approximately the last 40 years. LENZ therefore represents one snapshot in time of New Zealand's environment that, although relatively stable in terms of human life spans, has been typified by major, ongoing changes in geological time[15] . We expect that applications of LENZ within contemporary New Zealand are unlikely to raise major discrepancies between recorded and actual conditions, given the relatively limited effects of global warming to date. However, there is considerable uncertainty over the likely magnitude of changes in climate over the next decade or so, and use of more recent data may be desirable here, particularly for climate-critical applications. Using LENZ as a framework for predicting ecosystem character back in time involves less uncertainty in that variation, at least in temperature, has been reconstructed in some detail from various sources.

Analytical issues – use of the classification versus use of underlying data

In developing LENZ, one of our goals has been to make it easier for conservation and resource managers to capitalise on the benefits to be gained from recent advances in information technology. In particular, our hope is that LENZ will encourage users to explore the use of geographic information systems (GIS), reflecting our view that these offer much wider possibilities for problem solving than the relative static options offered by conventional paper-based classifications.

As part of our promotion of these increasingly available tools such as desktop GIS, we are keen to promote the use not only of LENZ but also of its underlying data layers. We anticipate that many LENZ applications in conservation and resource management will centre on its use as a generic environment-based land classification that can provide a common currency for description of land across a range of applications. Examples of direct LENZ applications are presented in the first three case studies described both in Land Environments of New Zealand and later in this chapter.

By contrast, we view the underlying data layers more as a toolbox that enables users to produce custom analyses that can be used to identify sites having particular environmental attributes. For example, a scientist who has a particular interest in the subalpine flora of limestone and marble substrates could perform a spatial query using the environmental data layers describing annual temperature and exchangeable calcium to identify sites that provide such habitat either nationally or regionally. A similar query might be used by a conservation manager to identify the likely historic distribution of lowland wetland sites using the LENZ drainage data layer perhaps in conjunction with the annual temperature and/or elevation layers. More complex examples of the use of underlying data layers are contained in the case studies and include calculation of environmental distances as a measure of similarity both within New Zealand and globally (restoration, biosecurity and crop suitability case studies), and use of a population growth model for predicting geographic variation in climatic suitability for disease-carrying mosquitoes.

Analytical issues – use of other geographic data

The increasing availability of geographic data in digital form provides a wide range of opportunities for more extended applications in which additional data is used to supplement LENZ’s underlying data layers. For example, in the first case study we refine our reconstruction of New Zealand’s likely pre-human vegetation patterns using a layer describing average daily temperatures of the warmest month to better define the upper altitudinal limit of forest. We then compare our reconstructed vegetation pattern with New Zealand’s current land cover as described in the Land Cover Database, a geographic layer based on recent satellite imagery. This analysis could be further extended to assess the adequacy of protection of indigenous vegetation for conservation using a digital layer describing the extent of land set aside for conservation purposes.

Similar uses of more extended climate layers are contained in our last three case studies. In two of these analyses we use climate data drawn from a global database assembled for use by scientists assessing the likely impacts of global warming. In our fourth case study we use these to compare Auckland’s climate with the rest of the globe, while in the sixth case study we compare the climate of the Bordeaux Region in France with that in the Wellington region. In both of these we also use growing degree day estimates that allow more robust comparison of the effects of temperature on plant growth and productivity. Finally, in assessing the suitability of New Zealand climates for the southern saltmarsh mosquito, we use monthly temperature estimates to calculate likely rates of population growth.

Although these examples focus on use of climate and land-cover descriptions, a wide range of other geographic data could be used with LENZ, including descriptions of land use, data describing individual species distributions, census data, or layers describing the distribution of cultural features such as roads, railway lines, high-voltage power lines, etc. The key requirements are that all layers share a common system of geographic coordinates, typically the New Zealand Map Grid, and have both spatial resolution and positional accuracy consistent with the scale used in the analysis.

Analytical issues – data representation

In contrast to the New Zealand Land Resource Inventory in which data are stored within polygon-based layers, LENZ was developed exclusively from raster data. That is, data are stored in grids of fixed resolution with data values varying from grid cell to grid cell. This data format is more suited to storing information about factors that vary continuously across a landscape, such as LENZ's underlying climate layers. It also facilitated the classification process, providing us with discrete spatial units for which data could be extracted from the GIS and classified, with results returned to the GIS for display. One disadvantage of raster storage, however, is that maps become aesthetically unappealing where layers are shown at a scale where their inherent granularity becomes apparent.

All four LENZ classification levels are available at grid resolutions of either 100-m or 25-m. Two factors require consideration when choosing which grid resolution to use. First, the 25-m resolution layers are capable of display at map scales as fine as 1: 50 000, whereas the 100-m resolution layers become excessively grainy at map scales finer than 1: 250 000. The main drawback in using the finer resolution layers is their size, which is approximately 16 times greater than for their 100-m resolution counterparts. As a consequence, the finer resolution layers are much slower to display because substantially larger amounts of information have to be read into memory to display a map for a given geographic area. As a general rule we recommend use of the lowest resolution layer consistent with adequate display quality and anticipate that 100-m resolution layers will be most used for classification Levels I and II, while 25-m resolution classification layers will be required for many applications using Levels III and IV.

Conversion to vector representation

Users who have only limited access to raster analysis capability may be tempted to convert LENZ from its raster representation into polygon-based layers. However, this conversion is not recommended because the quality of the resulting line work will be strongly influenced by the grid structure of the raster data, and this will compromise display except at the coarsest display scales. If such conversion is unavoidable, prior processing of the classification layer with one or two passes of a majority filter would probably be advisable before conversion, depending on the intended application. This would reclassify isolated cells having a value differing from surroundings cells, and would substantially reduce the size and complexity of the resulting polygon file.

Analytical issues – defining a context when calculating statistics

In keeping with the national context of both Land Environments of New Zealand and this volume, all summaries of the underlying environmental attributes for different environments are calculated using data from the whole of New Zealand. However, we recognise that many LENZ applications will operate within some more limited context, for example, a regional or district council jurisdiction or some other geographic unit such as a research study area. In this case, use of summary statistics calculated within a national context may provide a misleading picture of environmental variation within the study area, particularly where it contains small pieces of otherwise extensive environments. More locally relevant statistics are easily produced by clipping a relevant piece(s) of a LENZ classification layer and calculating summaries for the underlying data layers for each environment in the clipped area. However, it is important that relevant metadata are also generated as part of this process to record clearly the geographic context within which these summaries were produced.

CASE STUDY ONE — LOSS OF INDIGENOUS ECOSYSTEMS

Objective	To estimate the extent of indigenous ecosystem loss across New Zealand.
Approach	Compare a LENZ-based reconstruction of New Zealand's likely pre-human vegetation cover with current land cover to determine percentage loss of indigenous ecosystems by Level II environment.
Assumptions	Land-cover classes can be used to describe the extent of indigenous ecosystems.
Inputs	LENZ Level II classification (raster GIS coverage) New Zealand Land Cover Database (LCDB) (converted from polygon to raster GIS coverage).
Methods	1. Assign likely pre-human land cover to LENZ Level II environments; 2. Analyse changes in the extent of indigenous land cover by comparing likely pre-human cover with current land cover by environment.
Outputs	Raster GIS coverage describing % loss of indigenous land cover by LENZ Level II environment.

Introduction

Government agencies involved with the management of New Zealand's landscapes require understanding of the changes in the extent of natural ecosystems that have taken place since the arrival of humans. This requires comparison of New Zealand's likely pre-human vegetation pattern with information describing the current extent of natural vegetation. An historical reconstruction is therefore required if mangers are to adequately assess the magnitude of changes to New Zealand's natural ecosystems and the significance of those remnants that remain .

Methods

Cover classes from the Land Cover Database (LCDB)[16] that correspond to indigenous vegetation were used to reconstruct the likely pre-human vegetation to allow comparison with the present land cover. Each Level II environment was assigned a land-cover class corresponding to the indigenous vegetation most likely to occur in that environment in the absence of human influence (Table 5.1). Most Level II environments originally supported indigenous forest and were assigned that cover class. Environments having peat soils, poor drainage and/or saline soils were assigned wetland cover classes, while recent sand dune soils and areas of ultramafic soils were assigned tussock and scrub cover classes, respectively. Those environments having very dry climates (N4–N6, N8) were assigned a land cover of scrub.

These initial land-cover assignments were refined further using an additional climate layer describing mean daily temperatures in the warmest month to define the upper altitudinal limit of forest cover or treeline. Based on studies of the correlation between summer temperatures and treeline, areas with mean daily temperatures in February of less then 11°C (Fig. 5.1) were assigned a land cover of scrub/tussock. The upper elevation limit for scrub/tussock was defined as corresponding with a mean daily temperature in February of 8.5°C, typically occurring at elevations approximately 500 m higher than the treeline. Sites with temperatures cooler than 8.5°C were assigned a dominant land cover of bare ground.

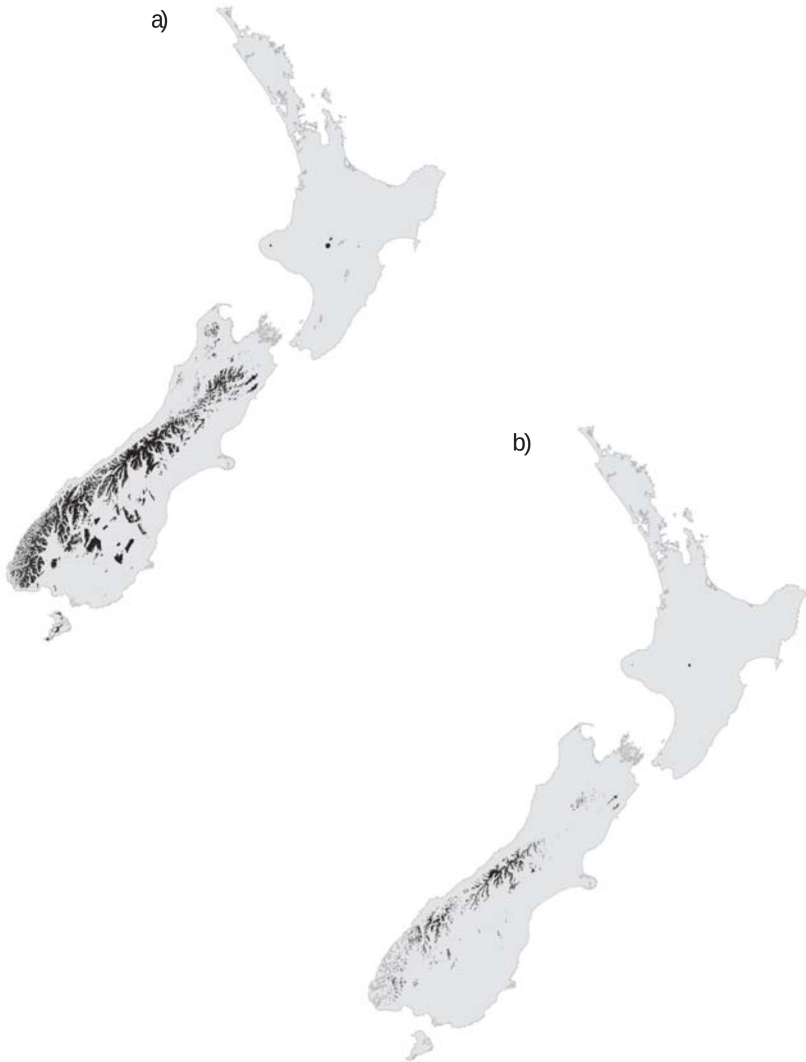


Figure 5.1: Areas of New Zealand with a mean daily temperature in February less than a) 11°C, b) 8.5°C

Table 5.1: Summary of final land-cover assignments to Level II environments. Numbers without brackets show the predominant land cover for each Level II environment. Bracketed numbers indicate where the land cover allocated to part of an environment was subsequently re-classified because of, for example, the presence of peat (allocated to wetlands), or because summer temperatures were below 11 ºC (scrub/tussock) or 8.5 ºC (bare ground)

	Forest	Scrub/tussock	Inland wetlands	Coastal wetlands	Coastal dunes	Bare ground
A	1–7		(2)			
B	1–9					
C	1–3		(1)			
D	1–4					
E	1–3	(1, 2), 4				
F	1–7	(7)				
G	3		4	5	1	2
H	1–4					
I	2, 5		3, 4	1, 6		
J	1–4					
K		1–3	4, 5			
L	1, 2, 4, 5		3		6	
M	1, 2, 4		3			
N	1–3	4–6, 8	7			(4)
O	1, 2, 4, 5	(1, 2, 4, 5)	3			
P	1–8	(1–8)				(1, 2, 4)
Q	1–4	(1–4)				(1, 3)
R	1–2	(1, 2)				(1, 2)
S		1–3				
T						1

Present land cover and estimation of indigenous vegetation loss

The polygon-format Land Cover Database was first converted into a raster format data layer at the same grid resolution as the reconstructed pre-human vegetation cover, i.e. 100 m. Both the predicted pre-human and current land-cover grids were then overlaid on the LENZ Level II environment layer to calculate areas of pre-human and surviving indigenous vegetation in each Level II environment. Results were then imported into a spreadsheet and percentage changes in indigenous vegetation cover were calculated for each environment. The estimated percent loss of indigenous land cover was then mapped by level II environment (Fig. 5.2).

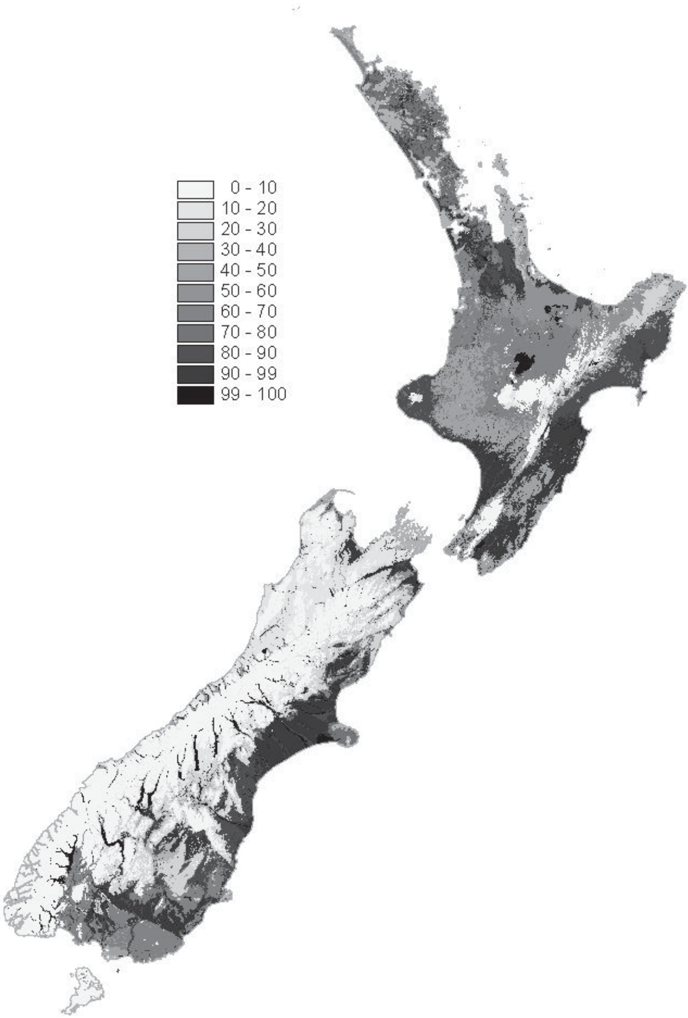


Figure 5.2: Estimated percent loss of indigenous vegetation cover since human settlement by Level II environment.

CASE STUDY TWO — LOSS AND FRAGMENTATION OF ECOSYSTEMS

Objective	To analyse forest loss and fragmentation as an indicator of indigenous biodiversity status in the Tasman District.
Approach	Use LENZ environments as framework for assessment of indigenous forest fragmentation.
Assumptions	Land cover can be used to describe the extent of indigenous ecosystems.
Inputs	LENZ Level I (raster GIS coverage) New Zealand Land Cover Database (converted from polygon to raster GIS coverage).
Methods	1. Estimate forest patch sizes, inter-patch distances, and edge to core ratios for pre-human and current land cover; 2. Compare pre-human and current forest patch statistics to assess changes since human settlement.
Outputs	Statistics describing changes in the extent and fragmentation of indigenous forest cover by environment, including mean and maximum patch sizes, mean inter-patch distances and edge to core ratios.
Secondary	Examine the potential of non-forest land cover classes to reduce the impacts of forest fragmentation.

Introduction

In this case study LENZ is used as a geographic framework within which to develop indicators of the state of biodiversity at a regional scale. Here it performs an important role by dividing a landscape into units likely to have similar ecosystem character, regardless of their geographic location.

Methods

This analysis required the assembly of three data layers: LENZ Level I, the reconstructed pre-human land cover from the first case study, and a polygon version of the Land Cover Database (LCDB). All data layers were clipped to the geographic extent of the Tasman District (Fig. 5.3).

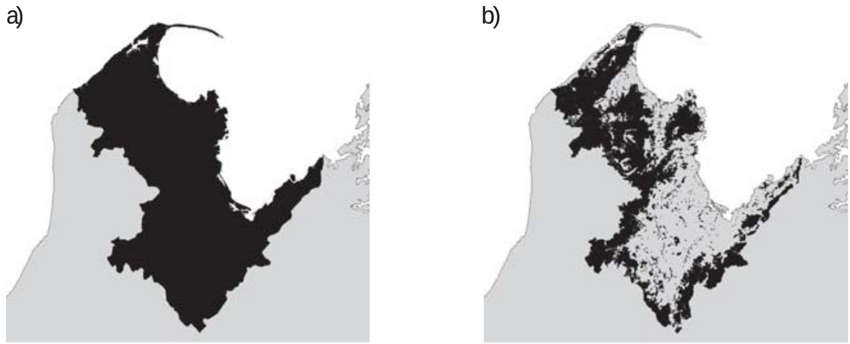


Figure 5.3: Forest distribution in the Tasman District: a) reconstructed pre-human forest extent; b) current forest extent as recorded in the Land Cover Database.

Calculation of forest extent and patch size

To calculate maximum forest patch sizes by environment we separately clipped the LENZ Level I classification layer to both our reconstructed forest layer from Case Study One and the current extent of forest as recorded in the Land Cover Database. Both of the resulting layers were then converted into polygon layers in ArcView during which each contiguous block of cells having the same environment label was formed into a polygon with a unique numeric identifier (Fig. 5.4). We then used X-tools, a freeware ArcView extension,[17] to add information to both polygon layers describing the area of each polygon. The data tables associated with the two polygon themes were then exported to a spreadsheet where the polygon area data for each environment were summarised.

Figure 5.4: Forest areas on the west Neslon coast subdivided by LENZ Level I environment.

Calculation of edge to core ratios

Calculating ratios of forest edge to forest core can provide valuable insight into the effects of fragmentation on the long-term viability of surviving areas of native forest. In general, microclimates of forest margins are markedly different from those of extensive forests, with elevated temperatures and much lower humidity reducing the regeneration of native species and encouraging invasion by weeds.

Edge to core ratios were calculated using the buffer wizard in ArcView, specifying a 40-m buffer size,[18] with buffers restricted to the inside of polygons and results written to a new shape file. X-tools was then used to calculate the area of each buffer and, once polygon identifiers had been copied to the buffer layers, the data tables were exported to a spreadsheet where buffer to core ratios were calculated for each polygon.

High ratios of edge to core habitat are associated either with small forest patches or with larger patches where an irregular shape leads to a very large perimeter relative to the total (Fig. 5.5). For example, a circular forest patch with a diameter of 80-m would all be classified as edge habitat when using a 40-m buffer as a basis for calculation. A much larger forest remnant would have a low ratio of edge to core habitat if its shape is circular, but a high edge to core ratio if it has an elongated shape, as is common for example in many forest patches on riparian sites.

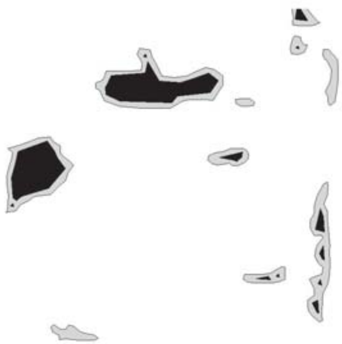


Figure 5.5: Forest patches showing the 40m internal buffer (light grey) and the area of core forest (in black)

Inter-Patch Distances

The geographic or spatial arrangement of forest patches across a landscape can also profoundly affect their long-term viability, with isolated patches often lacking mobile bird species. This in turn can alter forest dynamics through selectively affecting the ability of different bird-dispersed plant species to colonise. These effects are further complicated by the nature of the vegetation matrix within which surviving forest patches are embedded. For example, forest fragments surrounded by pasture may be more effectively isolated from neighbouring forest patches than those fragments surrounded by scrub or exotic forest. As well as ameliorating the drier, warmer climatic conditions typical of open pasture, scrub and exotic forest are capable of providing at least some of the habitat requirements of many forest species, and facilitate movement of those unwilling to venture across open pasture.

Patch Analysis 2.2 extension for ArcView[19] was used with three different vegetation patch layers to calculate inter-patch distances, that is the minimum distance from each forest fragment to its closest neighbour regardless of environment. Input data layers used for these calculations were derived from the Land Cover Database polygon coverage and contained patches consisting of (1) indigenous forest alone, (2) indigenous forest and scrub, (3) indigenous forest, scrub, and exotic forest. Polygon layers for the latter two sets of calculations were derived using the generalisation function in ArcView. Where forest patches were broken at environment boundaries, inter-patch distances were assigned a value of zero. Finally, each set of inter-patch distances were summarised by environment.

CASE STUDY THREE — RESTORATION OF A DEGRADED ECOSYSTEM

Objective	To set realistic goals for the restoration of a degraded forest remnant.
Approach	1. Use LENZ and its underlying data layers to identify areas of intact forest in similar environments that can be used to assist in setting restoration goals and as sites for seed collection; 2. Use underlying data layers in conjunction with regressions relating species distributions to environment to predict potential forest composition.
Assumptions	Similar environmental conditions are likely to support similar vegetation in the absence of human interference.
Inputs	1. LENZ Level IV (raster GIS coverage); 2. Underlying data layers (raster GIS coverage); 3. Regressions relating underlying data layers to tree species distributions.
Methods	1. Use LENZ Level IV to identify parts of the surrounding landscape that are in the same or closely related environments; 2. Use the underlying layers to provide a more refined analysis of similarities between the restoration site and the surrounding landscape; 3. Use average environmental conditions in conjunction with regressions relating tree species distributions to underlying environmental data layers to predict the abundance of tree species.
Outputs	1. Layer showing the distribution of Level IV environments in the surrounding landscape, classified according to their similarity to the environment of the restoration site; 2. Layer showing continuous variation in environmental similarity between the restoration site and the surrounding landscape. 3. Predicted forest composition for the restoration site.

Introduction

Public agencies and private organisations are showing increased interest in the restoration of degraded ecosystems, usually with the aim of enhancing the biodiversity or conservation values of a site. One prerequisite for the successful implementation of these projects is a clear understanding of the restoration goals. Usually this requires knowledge of the vegetation cover that would have been present before modification of the site by human activity, along with understanding of the natural sequence of vegetation change that would lead to re-establishment of vegetation of similar character. Suitable locations must also be selected from which to collect material for the propagation of seedlings. While geographic criteria are often proposed for this process, environmental criteria are also important to insure that ecotypes suited to the environment of the restoration site are selected.

In this case study we demonstrate the ability of LENZ to address such issues at three levels. Firstly, the LENZ classification layers are used to indicate broad environmental similarities between the restoration site and the surrounding landscape. Areas of similar environment can then be searched for intact forest remnants suitable for use as a reference in setting restoration goals. A more refined analysis of environmental similarities in the surrounding landscape can be achieved using the underlying data layers to calculate a layer showing continuous variation in environmental distance from the restoration site. In our third and most complex analysis, we demonstrate use of the underlying data layers in conjunction with regressions relating tree distribution to environment to predict the expected forest composition for the restoration site.

Methods

Restoration Sites and LENZ

The hypothetical restoration site used in this case study is located in a steep gully on the northern slopes of Mt Kaukau, north of Wellington City. Using the LENZ Level IV classification layer, we mapped the distribution of both the environment in which the restoration site falls (F1.4c), and of other closely related Level IV environments, as identified from the dendrogram for Environment F (see Chapter Four). The resulting map (Fig. 5.6) can then be used in conjunction with land-cover data such as the Land Cover Database or aerial photographs to identify intact forest remnants that could be used as a reference in setting restoration goals, and as sites for collection of material for propagation.

In our second analysis, we selected a representative point at the restoration site and calculated a layer that shows continuous variation in environmental distance from this point to all other points on the surrounding landscape. These distances were calculated using the Gower Metric distance measure, the same metric as used to define the LENZ classification (see box 5.1). The resulting data layer (Fig. 5.7) provides a continuous measure of environmental distance from the selected reference point, giving a more detailed picture than the previous analysis in which distances are stepped because of the loss of information inherent in use of the LENZ classification.

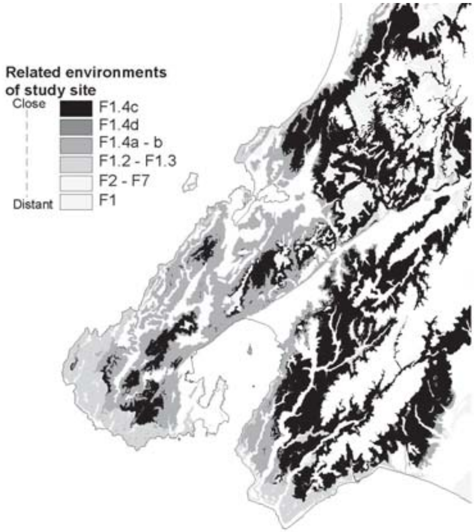


Figure 5.6: Level IV environments and their similarity to the environment of the restoration site.

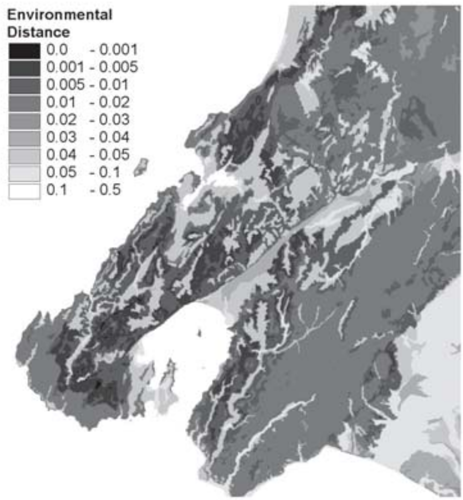


Figure 5.7: Environmental distances between the restoration site and the surrounding landscape.

In our third analysis we use regressions relating the distribution of major tree species to environment as fitted from an extensive set of plot data describing the composition of New Zealand's forests.[20] These were combined with estimates of the average environmental conditions at the restoration site to predict the expected forest composition expressed as numbers of trees per hectare. Given the lack of consistent data describing the topographic position at the plots used to fit the regressions, these predictions do not take account of the topographic preferences of different species. However, inspection of nearby forested sites or expert knowledge could be used to identify the specific planting sites required by the different species.

Box 5.1 — Calculating environmental distances

In the following example, we show how to calculate environmental distances using ArcView's map calculator. As the object-oriented syntax used in the calculator differs from conventional mathematical notation, formulae are best manipulated and stored in a text file and pasted into the map calculator as required. The calculation starts with an opening bracket that, with its partner in the second to last line, encloses the text required to sum the individual contributions from each of the grid data layers. Each of the main text lines calculate the contribution from one grid layer, with each grid converted to a real number (e.g., [nz_mat].float in the first line of the following example) and subtracted from the grid value for the reference point (134.asGrid) before the difference is converted to an absolute number (.abs). This absolute difference is them divided by the total range of the relevant grid (e.g., / 231.asGrid) to convert the difference into a proportion. Finally, the contribution is multiplied by its weight, which is set at 1.0 for all variables except the four soil parent material attributes, i.e., phosphorous, calcium, hardness, and particle size, which should be given a weight of 0.25.

Note that the scale factors associated with each grid as described in Chapter Two have been ignored in this example, a safe option provided that both the ranges and individual values are all taken directly from the relevant grid. Once the individual grid contributions have been calculated, a closing bracket is added and the sum of the individual grid contributions is divided by the number of grids (/ 15.asGrid).

```
(
((([Nz_mat].float  - 134.asGrid).abs  /  231.asGrid) *1.0.asGrid)+
((([Nz_mat].float  - 148.asGrid).abs  /  401.asGrid) *1.0.asGrid)+
((([Nz_vpd].float  -  35.asGrid).abs  /  66.asGrid) *1.0.asGrid)+
..
..
((([Nz_acid].float  -  5.asGrid).abs  /  5.asGrid) *0.25.asGrid)+
)
/ 15.asGrid
```

CASE STUDY FOUR — SETTING PRIORITIES FOR INTERNATIONAL BIOSECURITY SCREENING

Objective	To prevent harmful or undesirable organisms from entering New Zealand.
Approach	Calculate environmental distances from a New Zealand port of entry to the rest of the globe.
Assumptions	The likelihood of alien organisms establishing in New Zealand increases with the environmental similarity between their place of origin and point of entry.
Inputs	1. Climate data for the port of entry, i.e., Auckland, derived from the underlying data layers; 2. Equivalent global climate data to that used to define LENZ (regular grid of points at a half-degree spacing).
Methods	Calculate environmental distances from the port of entry to different global environments.
Outputs	Raster GIS coverage describing climatic similarity between Auckland and the rest of the globe.

Introduction

New Zealand's border control authorities are charged with preventing the entry of unwanted organisms into New Zealand. A number of factors are used to prioritise the searching of cargo and baggage from vessels and aircraft coming from different locations. One factor that can contribute to this priority setting is knowledge of the environmental similarity between the place of origin of a vessel or aircraft and its point of entry into New Zealand. In general, global environments that have a close similarity to New Zealand environments are more likely to be a source of potential pest organisms than those with markedly different environmental conditions. In this example we compare the climate of Auckland International Airport with global climates, carrying out this analysis with data describing climates both annually and seasonally.

Methods

Climate data from the environment around Auckland International Airport were derived from the underlying LENZ climate layers, while equivalent global climate data were derived from a regular grid of points at a half-degree spacing, assembled for use in studies of likely global change impacts. Climatic differences between Auckland and the rest of the globe were first calculated using the Gower Metric (see Box 5.1) with data describing average annual conditions (Fig. 5.8a). Distances were then calculated using data describing both the southern hemisphere spring (October — Fig. 5.8b), when conditions between sites of equivalent latitude in the northern and southern hemispheres are least pronounced, and the southern hemisphere summer (January — Fig. 5.8c) when differences between the northern and southern hemisphere are at their maximum.

Use of growing degree day indices

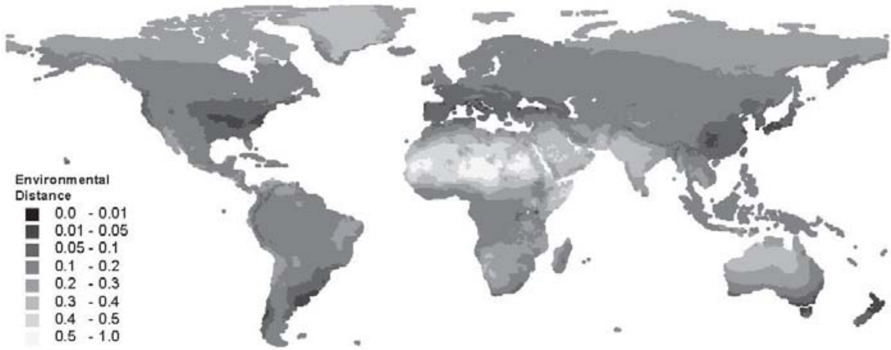
In making comparisons on a global scale use of mean annual temperature becomes problematic because of the effects of site-to-site differences in seasonal temperature ranges. In particular, sites with the same mean annual temperature may vary markedly in their summer temperatures and length of growing season. Such differences can profoundly affect the relationship between mean annual temperature and plant growth. Use of growing degree day indices largely overcome this problem, as these sum the number of days when temperatures exceed some threshold required for growth, multiplied by the amount by which temperatures exceed that threshold. This indicates the thermal conditions at a site in a way that much more closely corresponds with likely rates of crop growth, all other factors being equal.

More formally, the relationship between growing degree-days (GDD) and temperature (T) is calculated by summing daily contributions through one year as follows:

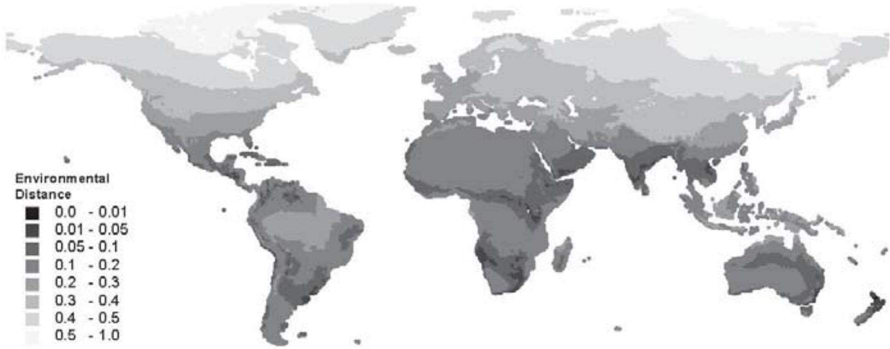
$$GDD = \sum_{i=1}^{365} \max(T_i - T_{base}, 0),$$

where T_i is the temperature on day i, and T_{base} is the threshold temperature required for the commencement of plant growth, assumed here to be 5ºC. The GDD index remains unchanged where the daily temperature fails to reach the threshold temperature, but on days where it is reached, it rises by the difference between the actual daily temperature and threshold temperature. Temperatures were estimated for each day through the year from monthly temperature estimates from a five-parameter multiple regression using trigonometric terms.[21] The resulting regression fits a generalised curve to the 12 monthly temperature estimates using trigonometric terms, allowing the average temperature to be estimated for any day through the year. While this gives only a small to moderate improvement in precision in winter and summer when between-month temperature differences are small, it gives a substantial improvement in spring and autumn when changes in temperature over time are more marked.

a) Annual



b) January



c) October

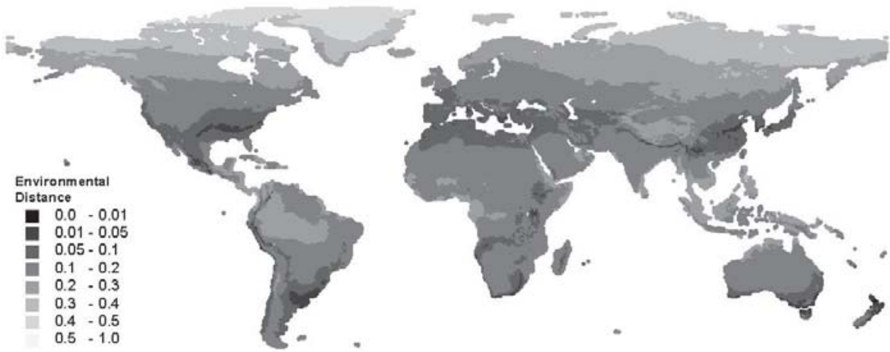


Figure 5.8: Climatic distances between Auckland and the rest of the globe calculated using a) annual climate statistics, b) climate statistics for January, and c) climate statistics for October.

CASE STUDY FIVE — PREDICTING PEST DISTRIBUTIONS WITHIN NEW ZEALAND

Objective	Develop surveillance priorities to monitor potential pest spread
Approach	Combine knowledge of the environmental relations of pest species (the southern saltmarsh mosquito) with climate and soil variables to indicate potential range.
Assumptions	1. A model that uses monthly temperatures to predict population growth potential will indicate climatic suitability; 2. Soil drainage and salinity layers will identify suitable breeding habitat.
Inputs	1. Monthly estimates of mean daily temperatures (raster GIS coverages); 2. Layers describing soil drainage and chemical limitations to plant growth (raster GIS coverages); 3. Population growth model for the southern saltmarsh mosquito.
Methods	1. Use population growth model with monthly temperature estimates to analyse geographic variation in climatic suitability for the southern saltmarsh mosquito; 2. Combine layer describing climatic suitability with layers identifying poorly drained and/or saline soils for locations of suitable breeding habitat.
Outputs	Map showing climatic and soil suitability for breeding by the southern saltmarsh mosquito.

Introduction

Managing invasive species once they have established in New Zealand is an important responsibility for national, regional and local authorities. Monitoring the status and predicting the potential spread of an invasive species is an essential component of an appropriate management programme. When combined with information about the distribution of other factors contributing to risk, this enables the development of surveillance programmes to monitor both the long-term spread of a species and short-term population fluctuations that might pose a risk to human health.

Methods

n the absence of specific information about the climatic relations of the southern salt-marsh mosquito, we used a model (Table 5.1) describing the relationship between monthly temperature and rates of population growth for the closely related Asian tiger mosquito (Aedes albopictus). Population growth is assumed to be zero at temperatures below 12ºC, increasing linearly with temperatures above this threshold until temperatures exceed 20ºC when population growth rates remain high but stable.

Table 5.2: Details of the relationship between climate and the mosquito population growth index

Average Monthly temperature	Growth Index
< 12 °C	0
12–20 °C	temperature – 11
> 20 °C	10

Twelve raster layers describing monthly mean daily temperatures were generated from a mathematical surface fitted to monthly temperature data from approximately 300 meteorological stations throughout out New Zealand. These were then used to calculate an annual population growth index[22] for the southern salt marsh mosquito using the map calculator function of ArcView's Spatial Analyst with the resulting growth index contained in a single output layer (Fig. 5.9).

The other key information required for predicting habitat suitability is the availability of saline pools of water, which are most likely to be found in very poorly or poorly drained estuarine sites. Such sites were identified using the LENZ drainage layer to identify very poorly drained and poorly drained soils and the LENZ layer describing chemical limitations to plant growth to identify saline soils. The intersection of these two layers shows the extent of poorly drained saline soils likely to provide breeding habitat for the southern saltmarsh mosquito.

Combining the two layers describing climatic and soil suitability with additional data describing the current distribution of the southern saltmarsh mosquito and the distribution of major human population centres would allow the development of a surveillance plan to minimise impacts on humans.

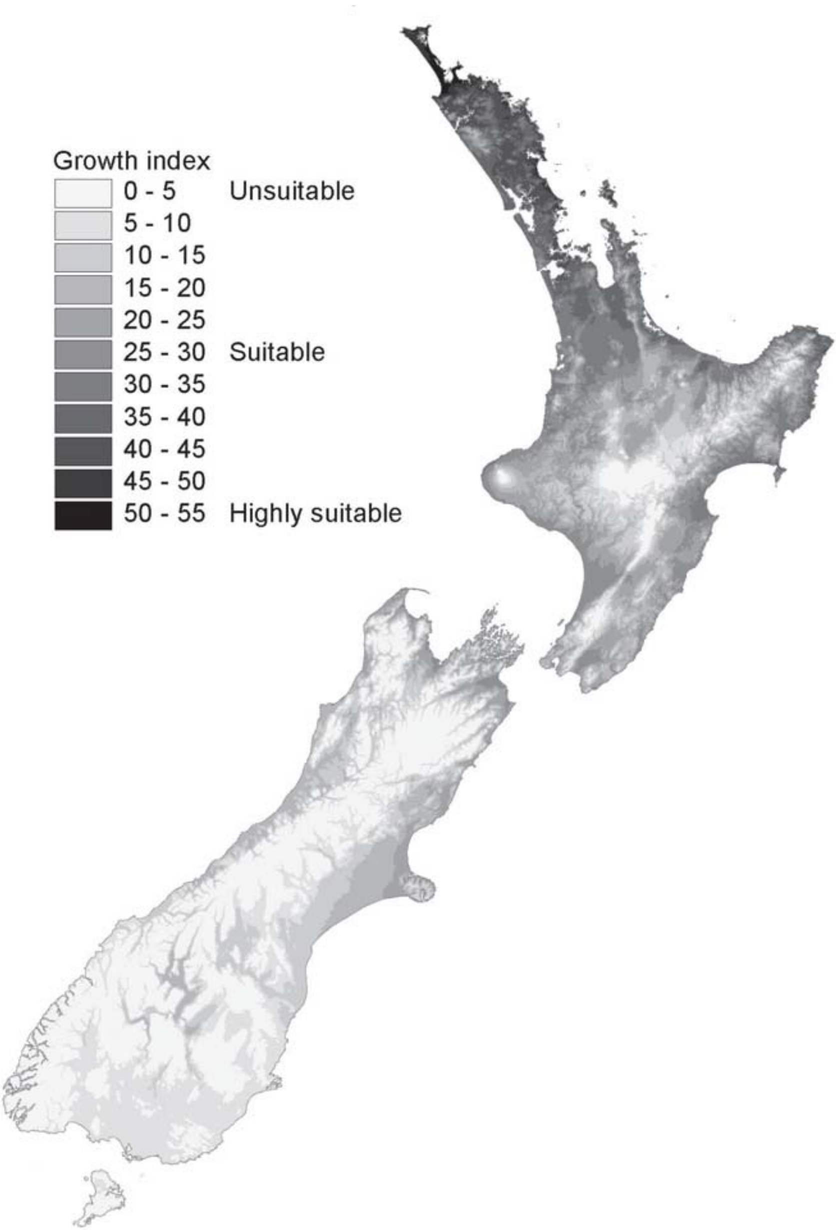


Figure 5.9: Climatic suitability for the southern saltmarsh mosquito

CASE STUDY SIX — FINDING SITES SUITABLE FOR CROPS

Objective	To identify areas in the southern North Island suitable for grapes.
Approach	Use knowledge of the climate of a high-quality grape-growing region (Bordeaux, France) to identify new areas with similar climates.
Assumptions	Macro-climatic parameters can be used to give a broad indication of climatic suitability for grape growing.
Inputs	1. Description of climate from a known high-quality wine-producing region; 2. LENZ climate layers supplemented by a raster layer describing growing degree days with a 5ºC threshold.
Methods	Use climate layers to calculate climatic distances between the reference region and the southern North Island.
Outputs	A raster layer showing climatic suitability of southern North Island sites for wine production.

Introduction

Although developed primarily for biodiversity and environmental management applications, LENZ can also be used for a range of other land management applications. This is because the factors that control indigenous biodiversity patterns also constrain human land uses such as agriculture, horticulture and forestry. In this case study we demonstrate use of LENZ's underlying data layers to identify sites having high climatic similarity to a known high-quality wine-producing region in France.

Methods

A broad description of the climate of the Bordeaux region in southern France was taken from the global climate data set used in Case Study Four. In this case study, we also substituted an index of growing degree days for estimates of mean annual temperature to enable more robust comparison with Bordeaux's more seasonal climate. We then used the Gower Metric (see Box 5.1) to calculate climatic distances between Bordeaux and the southern North Island using the following climate layers: growing degree days, mean minimum temperature of the coldest month, mean solar radiation, winter solar radiation, annual water deficit, mean monthly water balance ratio, and spring vapour pressure deficit as measured in October (Wellington) or April (Bordeaux). The resulting grid layer (Fig. 5.10) shows the proportional difference in climate between Bordeaux and the southern North Island, averaged across these variables. Further refinement of this analysis could be achieved using climate variables more specifically relevant to particular crops or cultivars. This might include information about the average length of the frost-free growing season, or year to year variation in rainfall as influenced by variation in the

El Niño - Southern Oscillation or ENSO cycle, a large scale pattern of ocean atmosphere circulation variation across the Pacific Ocean that produces sometimes marked year to year climatic variation across New Zealand.

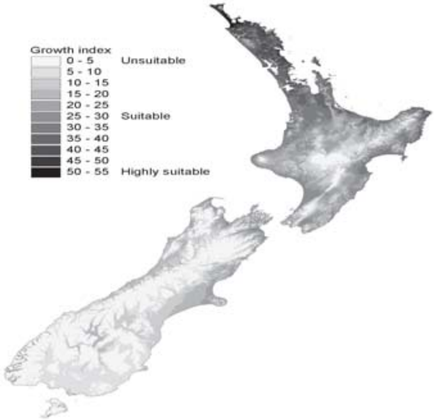


Figure 5.9: Climate similarities between the Bordeaux wine-growing region of France and the southern North Island of New Zealand.

ENDNOTES

Chapter Two: The underlying data layers

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