Land Environments of New Zealand: A Quantitative Geographic Framework for Biodiversity and Resource Management

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ABSTRACT

Land Environments of New Zealand (LENZ) is currently being developed as a quantitative classification of the diverse terrestrial environments of New Zealand, funded by the Ministry for the Environment as part of its Environmental Performance Indicators Programme. LENZ defines geographic areas that have similar environmental character, as described using climate, landform, and soil characteristics chosen for their functional role in driving natural biotic patterns. Classification units are defined using a numerical clustering algorithm designed for analysis of very large data sets, with the groups arranged in a scalable, hierarchical structure. This allows varying degrees of classification detail to be used for different applications and at different spatial scales. Both the classification, and the underlying data layers will eventually be available to central and local government agencies as high-resolution raster layers suitable for use at national, regional, and local scales. LENZ is expected to have a diverse range of applications related to the management of both indigenous biodiversity and human land-use issues. For example, when assessing the current biodiversity values of surviving natural ecosystem fragments, it allows quantitative reconstruction of New Zealand's likely pre-human character, providing a crucial historical context for analysing the relative loss and fragmentation of natural values in different regions, and assessing potential changes to New Zealand's biodiversity. In environmental monitoring, the classification will be used as a framework both for monitoring and reporting on indices of environmental sustainability. LENZ will also form an important component of a numerically based system designed to manage biosecurity risks posed to New Zealand by biota from other global locations. Finally, applications aimed at managing productive land uses such as forestry, dairy, and cropping are also being explored.

***Keywords and phrases*:** quantitative, hierarchical, classification, land, terrestrial, resource, environment, ecosystem

1.0 ECOSYSTEMS AND ENVIRONMENTS

Funded by the Ministry for the Environment as part of its Environmental Performance Indicators Programme, Land Environments of New Zealand (LENZ) is currently being developed as a numerical classification of the diverse terrestrial environments of New Zealand. LENZ systematically and quantitatively classifies areas that have similar climate, landform, and soil characteristics. The environmental attributes associated with each land environment can indicate both potential indigenous ecosystem character, and suitability of land for various types of uses by humans.

Driving the development of Land Environments of New Zealand is the desire to move from single focus to ecosystem management, a shift that is firmly established in both New Zealand legislation and policy. However, defining ecosystems in meaningful ways for management has proved challenging for scientists and resource managers alike (e.g. Christensen *et al*. 1996).

LENZ uses the abiotic environment as a surrogate for defining and mapping ecosystems based on the long-observed consistency of landscape-scale biotic patterns along gradients of latitude and elevation (e.g. Walter, 1979). However, latitude and elevation are only surrogates for more proximate environmental drivers such as light, temperature, water and nutrient supply that directly affect species either through impacts on their physiology or provision of resources required for survival and growth (Austin and Smith, 1989). This allows environment to be used as a surrogate for ecosystems, assuming that similar environments will have similar ecosystem character in the absence of human disturbance, at least at the level of functional groups if not of species. Clearly, this does not always hold because of the effects of natural disturbances, which range in magnitude and frequency from large-scale and generally infrequent events such as glaciations and volcanic eruptions (e.g., Leathwick and Mitchell, 1992; Leathwick, 1998), to more frequent but generally localised events such as landslides and wind-storms (e.g., Stewart and Rose, 1990.). Humans have also perturbed these relationships over much of the globe, but even in highly modified landscapes, environment-based classifications are finding wide use as frameworks for conservation and environmental management (e.g., Omernik, 1987; Mackey *et al*, 1988; Belbin, 1993; Bailey, 1996; Pressey *et al*, 2000).

2.0 ENVIRONMENTAL DRIVERS OF BIOTIC PATTERNS IN NEW ZEALAND

Environmental variables used to define LENZ were chosen on the basis of insights gained from a number of studies in which relationships between environment and the distribution of New Zealand's major tree species were analysed using an extensive set of quantitative plot data (Leathwick, 2001; Leathwick and Whitehead, 2001). Variables were selected for both for their high statistical correlation with observed species distributions, and their functional links with major processes.

2.1 Climate Variables

Seven climate layers were derived from thin-plate spline surfaces fitted to long-run average climate-station data, allowing climate parameters to be estimated at sites remote from weather-stations (Hutchinson, 1995). Most climate data were drawn from the period from 1950 to 1980 (New Zealand Meteorological Service, 1983). Climate estimates for mean annual temperature, mean minimum temperature of the coldest month, mean annual and winter solar radiation, and October vapour pressure deficit were derived for points on a 100-metre grid across New Zealand. Monthly estimates of mean daily temperature, total rainfall, and daily solar radiation for the same grid points were then analysed to derive estimates of the annual water deficit and the average monthly ratio of rainfall to potential evaporation.

2.2 Landform and Soil Variables

Estimates of slope were derived from a digital elevation model, a grid of elevations across the whole of New Zealand derived from digital contour data used in the production of New Zealand's NZMS 260 maps at a scale of 1: 50 000. Slopes were calculated for each grid cell by comparing its elevation with that in adjacent cells, followed by smoothing to remove artefacts produced during processing.

Parent material and soil attributes were derived either directly or indirectly from the New Zealand Land Resource Inventory (NZLRI— National Water and Soil Conservation Organisation, 1979), a geographic database that contains the most detailed currently available description of New Zealand's soil patterns. Drainage conditions across New Zealand were estimated using spatial descriptions of soils from the NZLRI coupled with soil drainage descriptions from soil surveys (Landcare Research unpublished data).

To describe variation in the availability of soil nutrients across New Zealand, soils were grouped together according to their soil parent material. Data stored in the National Soils Database describing chemical analyses of subsoil samples were used to estimate the abundance of phosphorus and calcium for each parent material.

Estimates of the average particle size and hardness of each parent material were drawn from soil survey descriptions coupled with observations by soil scientists with extensive field knowledge of New Zealand's soils.

Data describing soil age, and the presence of chemicals toxic to plants were derived from extended legends that form part of the NZLRI database, and that classify each mapped soil unit according to the New Zealand Soil Classification. To describe soil age, soils classified as Recent or Raw soils, but excluding recent soils formed through erosion of older topsoil layers, were separated from older soils. Finally, soils with toxic chemicals present in sufficient amounts to limit plant growth were classified as having a moderate abundance of toxic chemicals (e.g., arid saline and estuarine soils), while soils formed on ultramafic parent materials were classified as having a high abundance of toxic chemicals.

3.0 DEFINING NEW ZEALANDS ENVIRONMENTS

Classification units were defined using classification procedures designed for analysis of very large data sets contained in PATN (Belbin, 1995). Because a data layer for New Zealand at a 100-metre grid resolution contains around 27 million data points, and requires 1.6 gigabytes of memory for analysis, a 25% subset of the 100-metre grid points was used to define the classification.

3.1 Phase one – non-hierarchical clustering

The first phase of the classification used a non-hierarchical clustering strategy designed to identify groups of points occupying similar positions in environmental space. Environmental space is similar to geographic space, where points are located in a three dimensional space defined by coordinates such as a latitude, longitude and elevation, except that environmental space is defined by environmental variables and can have more than three defining variables. Data points in LENZ were located within an environmental space defined by 12 environmental variables (the four soil fertility variables were treated as one variable). The environmental distance between data points was measured using the Gower Metric, a range standardised Manhattan Distance metric (Belbin, 1995). For LENZ, the distance between any two points along each environmental axis was expressed as a *proportion* (from 0 to 1) of the range of that variable across the entire set of data (Table 3.1). The overall environmental distance between points was then calculated as the average of the differences along each of the environmental variables

In running the clustering analysis the first sample point was used to establish the first group in the classification. All the other points were then examined in turn, and were either placed in an existing group or used to start a new group if they were more than a pre-specified distance in environmental space from any existing group of points. After performing this initial allocation, each sample point was then checked to make sure it was in the group to which it was most similar, and relocated to a different group if necessary. This relocation procedure was reiterated until all sample points were located in the group to which they were most similar. Approximately 800 groups were established in this first phase of analysis.

3.2 Phase two – agglomerative hierarchal clustering

The second phase of the analysis created a hierarchical classification from the 800 groups of points (Belbin *et al*, 1992). Environmental distances between all possible pairs of groups were calculated, and the two most similar groups, as indicated by their closeness in environmental space, were combined. The process was repeated, progressively merging the most similar groups or groups of groups, until all groups were finally combined to form a single large group containing all the points used in the analysis. Inter-group similarities or distances were then used to construct a dendrogram that shows the degree of similarity between individuals and among groups. Groups can be combined to form larger groups or conversely can be split to show more classification detail.

4.0 MAPPING THE CLASSIFICATION

The environmental distance was then calculated between each of the approximately 27 million 100-metre grid cells across New Zealand, and average environmental values calculated for each of the 800 groups in the classification. Each grid point was then allocated to the closest environmental group. The resulting geographic data layer and information about inter-group similarities from the hierarchical classification were combined to allow results to be displayed at any level of detail from one through to nearly 800 groups.

4.1 Land Environments of New Zealand Classification Layers

Four levels of classification, referred to as Levels I–IV were chosen to simplify understanding of the classification and to establish consistent groupings for use by managers (Table 1). Other levels of classification could be used, provided agreement is reached with management agencies on consistent use of particular levels for particular purposes. Level I and II have a 100-metre cell size, and Level III and IV have a 25-m cell size.

Level	Number of Land Environments	Basis of differences	Suggested map scale	Suggested geographic extent	Example Uses and Applications
I	20	Primarily climate, some soil parent material	1: 2-5 000 000	National	Educational, International reporting
II	100	Mix of climate and landform	1: 1 000 000	National	Biodiversity conservation, Biosecurity
III	200	Primarily landform, some climate	1: 250 000	Regional	Assessment of significance, Ecological restoration
IV	500	Almost exclusively landform, occasionally climate	1: 50 000	Regional and district	Monitoring, Site specific management

Table 1. LENZ classification layers.

5.0 APPLICATIONS

LENZ is expected to have a diverse range of applications related to the management of both indigenous biodiversity and environmental resources. For example, when assessing the current biodiversity values of surviving natural ecosystem fragments, LENZ allows quantitative reconstruction of New Zealand's likely pre-human character. This in turn provides a crucial historical context for the analysis of the relative loss and fragmentation of natural values in different land environments when combined with other data, such as the New Zealand Land Cover Database. LENZ and underlying data can also be used to provide guidance both on biodiversity targets for restoration projects and on eco-sourcing of suitable genetic material.

In environmental monitoring, LENZ will be used as a framework for monitoring and reporting on indices of environmental sustainability, providing a tool for local authorities to meet statutory monitoring requirements. LENZ will also form an important component of a numerically based system designed to manage biosecurity risks posed to New Zealand by biota from other global locations. For example, analyses of environmental similarities between New Zealand sites and different global locations can provide an important guide for assigning screening priorities for incoming ships and aircraft at international ports.

Finally, applications aimed at managing productive land uses, such as forestry, dairy, and cropping, are being explored. For example there is considerable potential to combine LENZ with data from exotic forest growth plots to provide spatially explicit predictions of forest productivity. Alternatively the environmental similarities between international sites that produce high-value crops and areas of New Zealand can be analysed to indicate suitable local sites for new cultivars, or to identify global locations where new crops suitable to New Zealand conditions might be found.

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