

Measuring environmental distinctiveness

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ABSTRACT

Recognising areas that are distinctive in ecosystem character is essential for the management and protection of the entire range of biodiversity. Here, we use areas of high environmental distinctiveness as indicators of areas of high ecosystem distinctiveness. The purpose of this report is to: first, provide a context for environmental distinctiveness; second, describe the calculation of environmental distinctiveness and its relationship to environmental domains; and third, demonstrate the application of environmental distinctiveness with a national analysis of New Zealand. Environmental distinctiveness and environmental domains analysis use the same environmental information in different ways to provide complementary methods of ecosystem depiction and spatial analysis. Environmental domains analysis identifies discrete areas that have similar environments, while environmental distinctiveness provides a continuous measure of ecosystem dissimilarity. Calculations of distinctiveness are made for every pixel of a digital elevation model (DEM), relative to some reference set, and produce a surface that shows how dissimilar (distant in environmental space) each pixel is from the reference set. A surface of distinctiveness relative to the entire nation identifies areas with environmental combinations that are rare in New Zealand. A surface of distinctiveness relative to the reserve network identifies areas that are most different from protected areas.

Keywords: environmental distinctiveness, environmental domains, climate, landform, environment, conservation priorities, New Zealand

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1. Introduction

A move to smarter, more informed ecosystem management and biodiversity conservation has led to an increased interest in the development of spatial frameworks for planning and decision making. Fundamental issues such as sampling designs for environmental monitoring, and conservation reserve design and management all benefit from being able to judge areas of similar ecological character. The surfaces of environmental distinctiveness shown here identify areas with rare environmental combinations in the nation or the protected area network, and can be used to identify which areas would add most to the environmental range protected, and how each area relates to the entire nation.

Environmental distinctiveness and environmental domains analysis use the same environmental information in different ways to provide complementary methods of ecosystem depiction and spatial analysis. Environmental domains analysis identifies discrete areas that have similar environments, while environmental distinctiveness provides a continuous measure of ecosystem dissimilarity.

2. Comparison between environmental distinctiveness and environmental domains

Environmental distinctiveness and environmental domains provide complementary methods of ecosystem depiction and spatial analysis. Each approach has advantages, and applications for which it is better suited. Both methods use environmental variables that are: first, known to be of fundamental physiological importance in determining plant growth and survival; and second, have been demonstrated to have ecological importance in determining species distributions and ecosystem characteristics. The calculation of both methods uses a digital elevation model (DEM) that represents a region with a grid of pixels of a given size, each with a grid (or geographic) location. The elevation of each of these pixels is estimated, providing a surface that represents the topography of the area. Since elevational and orographic effects are important drivers of many climate variables, DEMs are important in the prediction of climate surfaces. Similarly, many landform variables, such as slope and aspect, can be derived from DEMs. Here we use a DEM of New Zealand with 267 392 pixels that are 1 km².

Environmental domains analysis (Leathwick et al. 1998) is becoming increasingly well known as a means of ecosystem classification. To produce an environmental domains classification, environmental variables are predicted for

each pixel of the DEM (see Appendix 1). Thus, just as each DEM pixel has a location in geographic space (i.e. a value for easting and northing), it now also has a position in environmental space (i.e. a value for temperature, solar radiation, etc.). Pixels are then clustered into groups (domains) that are close in environmental space (i.e. have similar environments). This process is illustrated on the left side of Fig. 1 for two environmental variables. Figure 1 is not a completely accurate representation of the clustering process, however, since it depicts clusters of equal numbers of pixels, with different variation in environmental space. In fact, the clustering algorithm used to produce environmental domains produces groups that are of different numbers of pixels and roughly equal within-group variation in environmental space. A characteristic of the domains classifications is that they identify rare environmental combinations as distinct groups.

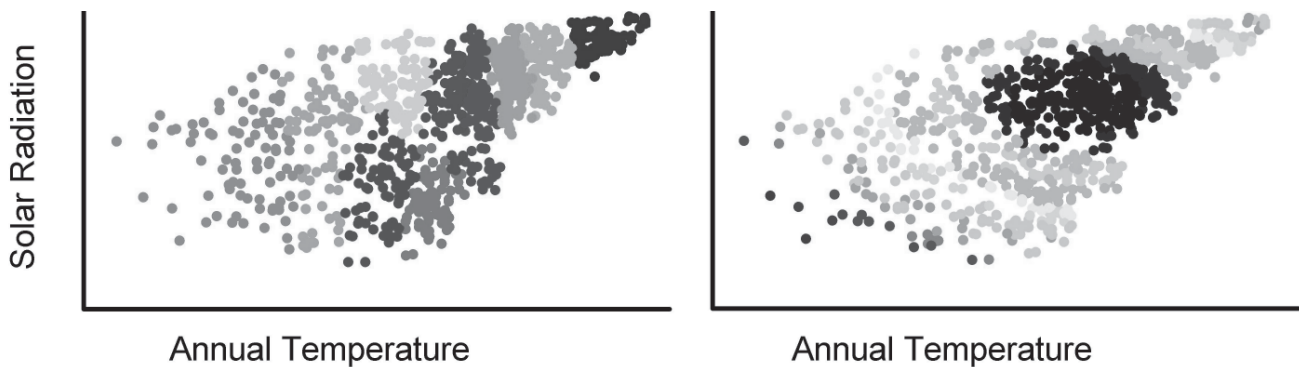


Figure 1. Clustered domains versus continuous distinctiveness.

Current domain classifications of New Zealand are produced by initially clustering to a large number (up to 400) of groups using non-hierarchical clustering algorithms, and then using a hierarchical clustering algorithm to produce a dendrogram of similarity between the domains (Fig. 2). This dendrogram provides the full domains classification for a region. Different numbers of groups can be produced by cutting the dendrogram at appropriate points. Once domains at a certain number of groups have been chosen, these domains can be mapped back into geographic space (Fig. 2). While domains are close in environmental space, they can be scattered and distant in geographic space.

Domains are defined as areas of similar environment, using environmental variables that have both fundamental functional significance in determining physiological performance and/or proven statistical correlation with species distributions (Leathwick 1998a, 1998b; Overton et al. 1999; Lehmann et al. 1998). Domains of similar environment are used as surrogates of areas of similar ecosystem character. Environmental domains classifications provide a method of depicting ecosystems that is consistent with many ecosystem properties. However, it is important to remember that the domains represent somewhat

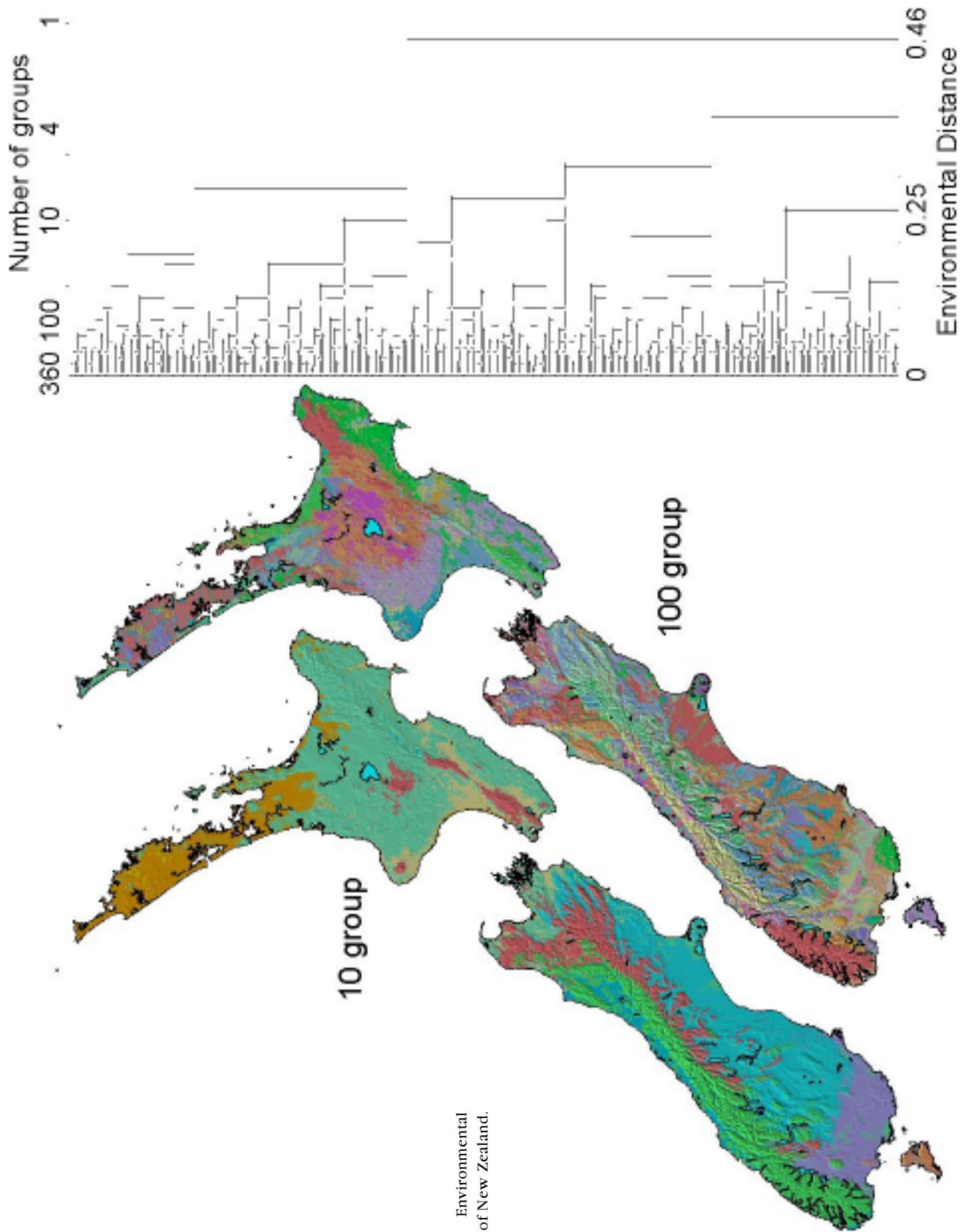


Figure 2. Environmental domains of New Zealand.

arbitrary divisions of what is usually continuous variation in environmental characteristics. In most cases, points that are immediately adjacent to each other on the ground, but on either side of a domain boundary, will be more similar to each other than to some of the other points within their respective domains. Furthermore, domains defined at any level of classification do not have a uniform distance from each other in environmental space. This is seen on the left side of Fig. 1 and the dendrogram of Fig. 2. Some domains are very distinct in environmental space, while others fall within clusters of similar domains. Eventually, the effective use of environmental domains for ecosystem management will require a shift in paradigms from traditional classifications (e.g. vegetation types or ecological regions) that have hard boundaries, to approaches that better represent the continuous nature of variation in ecosystem properties.

Environmental distinctiveness provides another method for using the same environmental information for complementary applications to environmental domains. Rather than imposing a discrete classification onto the continuous environmental variation, environmental distinctiveness calculates a continuous measure of the distance of each pixel from some reference set of pixels. However, environmental distinctiveness is not useful as a method of ecosystem classification *per se*.

3. Calculation of distinctiveness

3.1 ENVIRONMENTAL VARIABLES

Environmental variables used in the calculations of distinctiveness are the same as those used for environmental classifications using the environmental domains approach (Leathwick et al. 1998). Climatic variables (Leathwick & Stephens 1998) were either derived directly from surfaces fit to climate station data or were secondarily calculated (from primary surfaces transformed by mechanistic models). Primary climate variables are: mean annual temperature, minimum winter temperature, mean annual solar radiation, and winter minimum solar radiation. Derived climate surfaces are: minimum ratio of rainfall to potential evapotranspiration, October (spring) air saturation deficit, and annual soil water deficit. Landform variables, derived from the New Zealand Land Resource Inventory (Ministry of Works 1974), are: slope, drainage, and soil parent material in 15 classes.

3.2 ASSESSMENT OF PROTECTION

The reserve network was defined as the areas of public land managed for conservation by the Department of Conservation (DOC). This includes a small proportion of land not actively managed for conservation (e.g. recreation reserves) and excludes other types of conservation reserves (e.g. covenants).

The DEM was overlaid onto a digital version of the reserve network using Arcview (ESRI 1998). Pixels of the DEM were considered protected if their centres fell inside the reserve network.

3.3 CALCULATION OF DISTINCTIVENESS

To understand the calculation of distinctiveness, two essential points must be kept in mind:

- Distinctiveness is calculated for **every** pixel of the digital elevation model.
- Each pixel is compared with some **reference set**.

Therefore, calculations of distinctiveness produce a surface that shows how distinct every pixel is from the reference set. For instance, a surface of distinctiveness relative to the nation (termed *national distinctiveness*, Fig. 3) uses all pixels of the nation as reference set and shows how distinct each pixel is from the rest of the nation. Similarly, a surface of distinctiveness relative to the reserve network (termed *DOC distinctiveness*, Fig. 4) uses the reserve network as a reference set and shows how distinct every pixel is from what is currently protected. Note that in these analyses, each pixel is considered protected if the centre of the pixel falls within a protected area, and no attempt has been made to assess the proportion of the 1 km² pixel that is protected. While this is an approximation, it is an unbiased approximation, and works well at national scales. Further analyses with smaller pixels are being prepared.

Distinctiveness is calculated as the mean environmental distance from each pixel to the reference set. For each pixel, the distance of that pixel to another pixel in the reference set is calculated along each environmental axis. The mean of the distances along each of the axes then provides a measure of the environmental distance between the pair of pixels. These mean environmental distances are then averaged across all pixels in the reference set to provide the environmental distinctiveness of the target pixel. This process is repeated for every pixel of the nation (or region of interest). Environmental distances are measured using the Gower metric, which is based on a range-standardised manhattan distance. To reduce computation time, the calculations of distinctiveness presented here use only a 10% random sample of the reference set.

Equations for the calculation of distinctiveness are given in Appendix 2.

Environmental Distinctiveness - Relative to nation

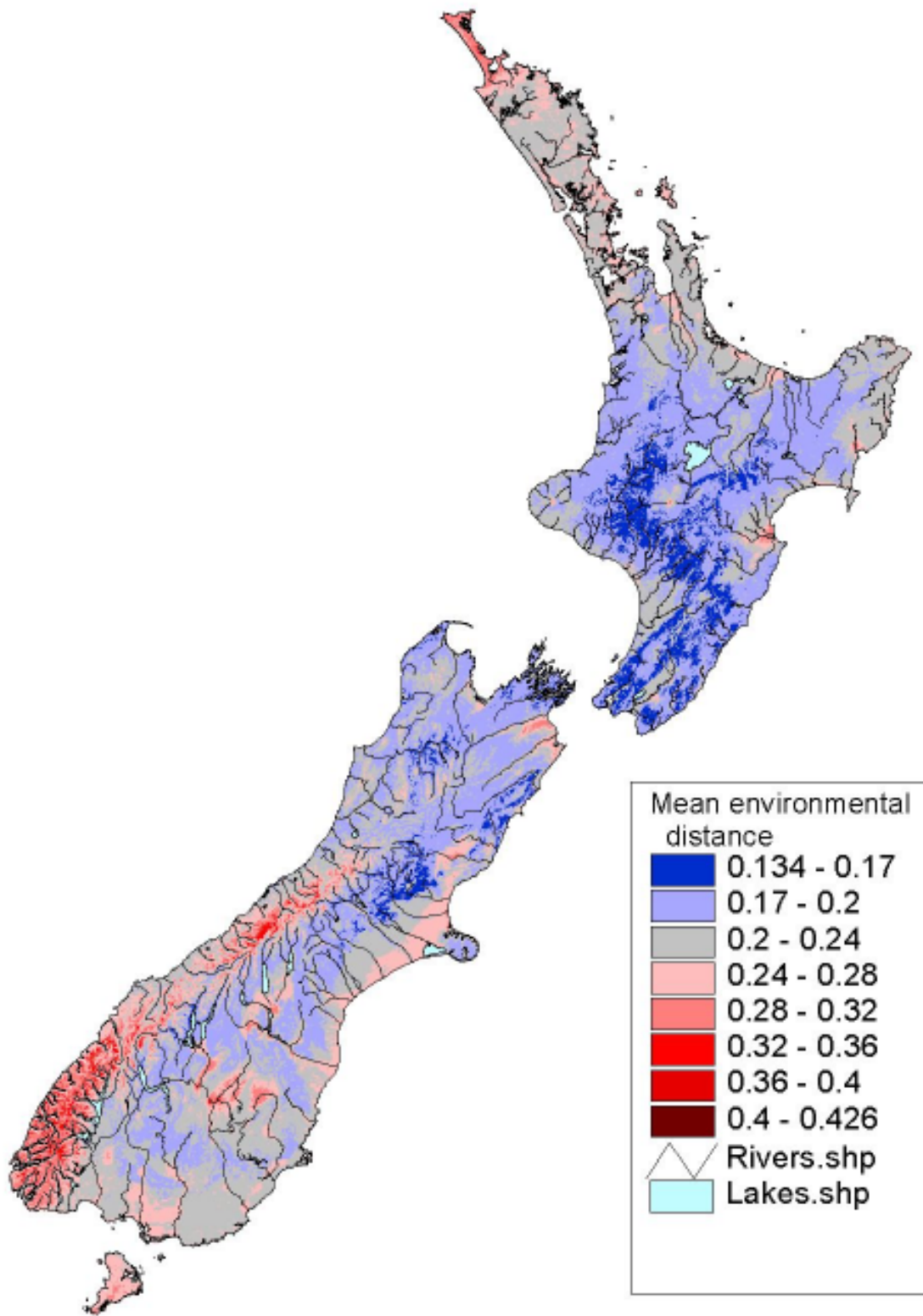


Figure 3. Environmental distinctiveness relative to the nation.

4. Results

Of the 267 392 pixels composing the national 1 km DEM, 28.96% had a centre that fell within DOC administered lands.

The surface of national distinctiveness (Fig. 3) has a mean of 0.212, and a range of 0.156 to 0.383. National distinctiveness highlights a number of areas that are rare environmental combinations in New Zealand, including Fiordland; the glaciated tops of the Southern Alps; interior, rainshadow valleys in central Otago with relatively continental climates; and warm, temperate Northland.

DOC distinctiveness (Fig. 4) has a very similar mean to national distinctiveness (0.221), but a greater range (0.134 to 0.426) and a 2.5-fold higher variance. This increase in variance is because some areas of low national distinctiveness are well represented in the reserve network, and so have even lower values of DOC distinctiveness. Similarly, areas of high national distinctiveness, such as the interior rainshadow valleys, dry eastern areas, and warm, temperate northern areas are all poorly represented in the reserve network, so their distinctiveness relative to the reserve network is even higher. Conversely, there are a number of areas of high national distinctiveness, such as Fiordland and the tops of the Southern Alps, which are well represented in the reserve network.

Environmental Distinctiveness - Relative to DoC Admin.

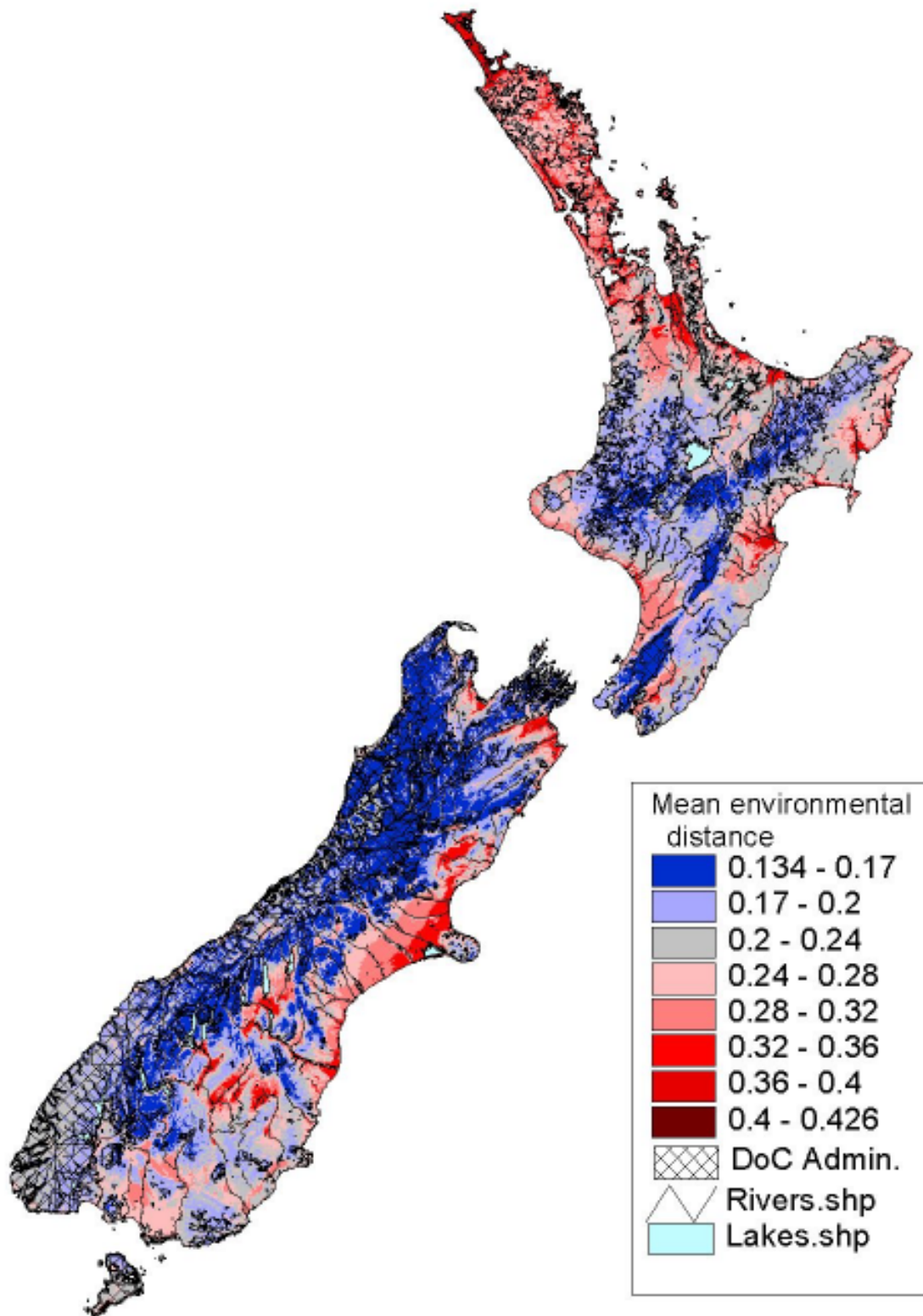


Figure 4. Environmental distinctiveness relative to DOC-administered lands.

5. Discussion

The actual values of distinctiveness have a straightforward interpretation. They are the average proportion of the range of each environmental variable from the reference set. For instance, a pixel with a distinctiveness value of 0.4 on average is at a distance from other pixels equal to 40% of the range of each environmental variable. Taking mean annual temperature as an example, if the minimum and maximum of mean annual temperature were -5 and 15°C , then the total range would be 20°C . A pixel with a distinctiveness of 0.4 along this axis would differ, on average, by 40% of 20 (8 degrees) from the pixels of the reference set.

There are two notable uses in the literature of measures very similar to environmental distinctiveness, although under different names. Belbin (1993) uses environmental distinctiveness to assess the distance of pixels from the centres of groups that are essentially environmental domains, to identify areas that are most characteristic of a particular environmental domain. This is termed environmental representativeness. It is worth noting that this is a somewhat different use of representativeness than is commonly used in conservation to refer to the degree to which a reserve system is representative of the entire range of ecosystem character. While this paper has been extremely influential in our understanding and development of domains, we do not see this use of environmental distinctiveness as particularly pertinent, since the locations of centroids of domains are fairly arbitrary. Another pioneering set of papers (e.g. Faith & Norris 1989; Faith & Walker 1996) uses environmental distinctiveness and another measure, 'environmental diversity'. Environmental diversity uses the structure of the dendrogram to assess the distances behind sites (or environmental domains). However, this is a complicated derivation of the same measure provided by environmental distinctiveness, since it first imposes a discrete structure on the continuous variation, and then recaptures the dissimilarity information from it. Environmental distinctiveness, as calculated directly here (and also by Faith & Walker 1996) provides a more natural way of dealing with continuous variation. Faith & Walker (1996) also argue that the best use of environmental distinctiveness is *minimum* distinctiveness using *unprotected* areas as a reference set, but their argument assumes that no species have optima outside the environmental range observed in the area. When this is allowed, then choosing areas with maximal environmental distance to protected areas (as advocated here) identifies sites with the least overlap in community composition and ecosystem characteristics to those already protected. Furthermore, the approach of Faith & Walker (1996) requires that distinctiveness would have to be calculated relative to regions of occupied environmental space rather than numbers of pixels in environmental space.

There is significant room for improvements in this work, including operational, computational, and conceptual work. We are continuing the development and refinement of biologically relevant environmental variables, and moving to higher resolution DEMs (smaller pixels) to allow finer spatial depiction. As this report is being finalised, we are preparing to repeat these calculations at 100 m or finer resolutions for all of New Zealand. Further conceptual work needs to be

done to develop new measures and to understand how best to use these measures for different applications. For instance, the relationship between the distinctiveness, and importance (*sensu* Stephens 1999) of sites needs to be investigated. Note also that each of these pure environment-based approaches does not consider the configuration of the reserves across the landscape. That is, reserves that are spatially scattered in geographic space are less valuable than larger, connected reserves. Thus, these analyses do not directly address trade-offs imbedded in Single Large Or Several Small (SLOSS) controversies.

5.1 APPLICATIONS

Measurements of environmental distinctiveness are useful for any application in which the underlying environmental drivers are important. These methods are generally an extension of environmental domains, and apply not only to biodiversity issues, but many other land-use issues, such as finding suitable crop sites. Current applications of this work focus mainly on biodiversity conservation. Environmental distinctiveness and related measures are important criteria for use in optimal reserve selection algorithms (e.g. Margules et al. 1988, 1994) to establish priorities for reserve acquisition or management, and for establishing priorities for conservation management (Stephens 1999).

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Appendix 1

ENVIRONMENTAL INFORMATION

Current environmental domains classifications of New Zealand use climate (Figs A1.1 and A1.2) and landform (Fig.A1.3) variables that have fundamental functional significance to determine physiological performance and strong statistical correlations with the distributions of canopy tree species (Leathwick 1998a, 1998b), shrub and understory tree species (Overton et al. 1999), and fern species (Lehmann et al. 1998) in New Zealand.

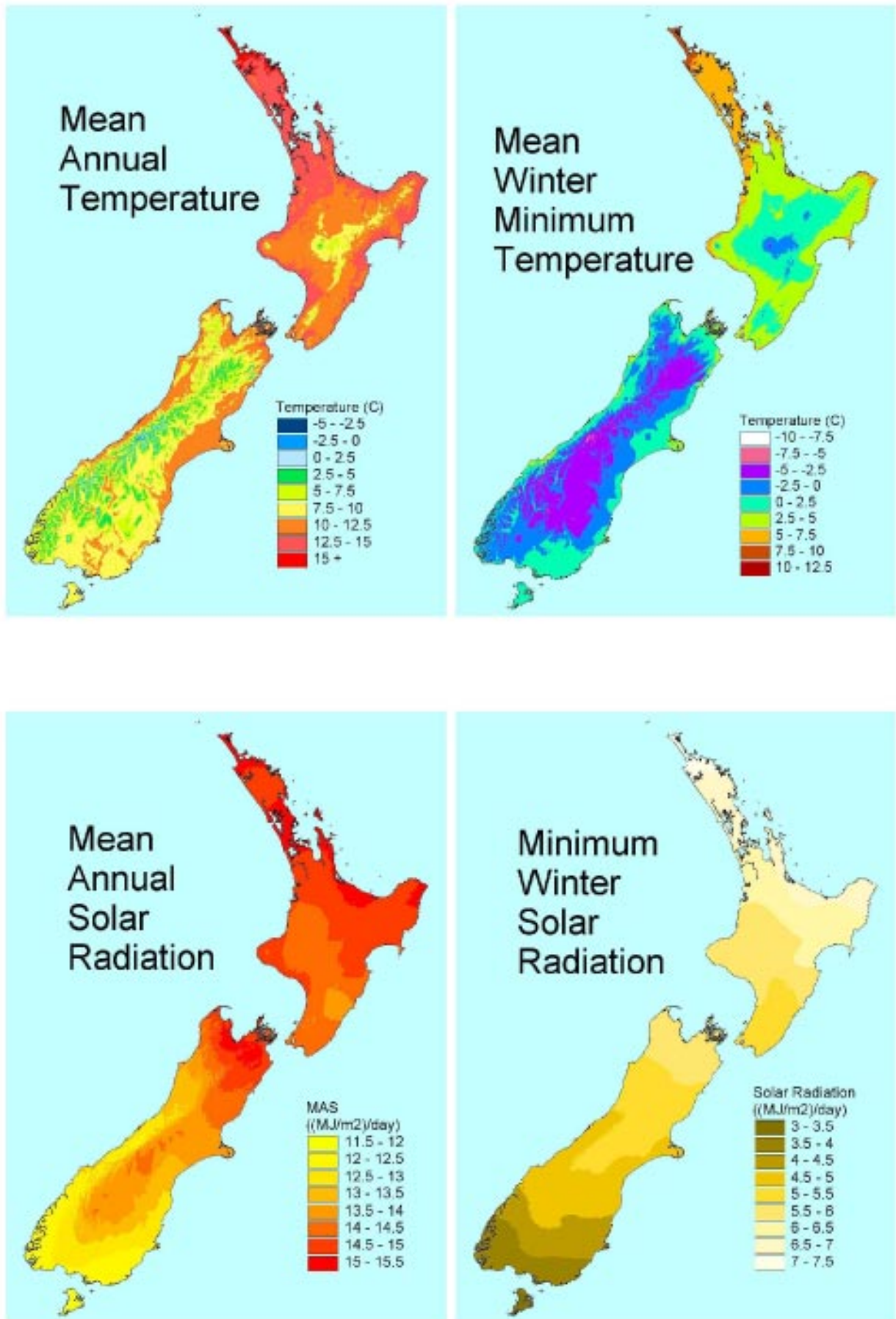


Figure A1.1.

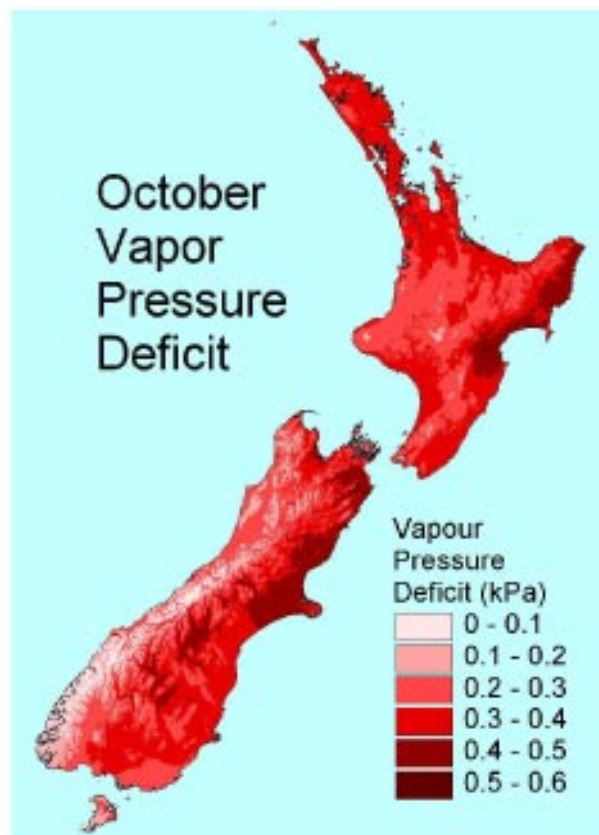
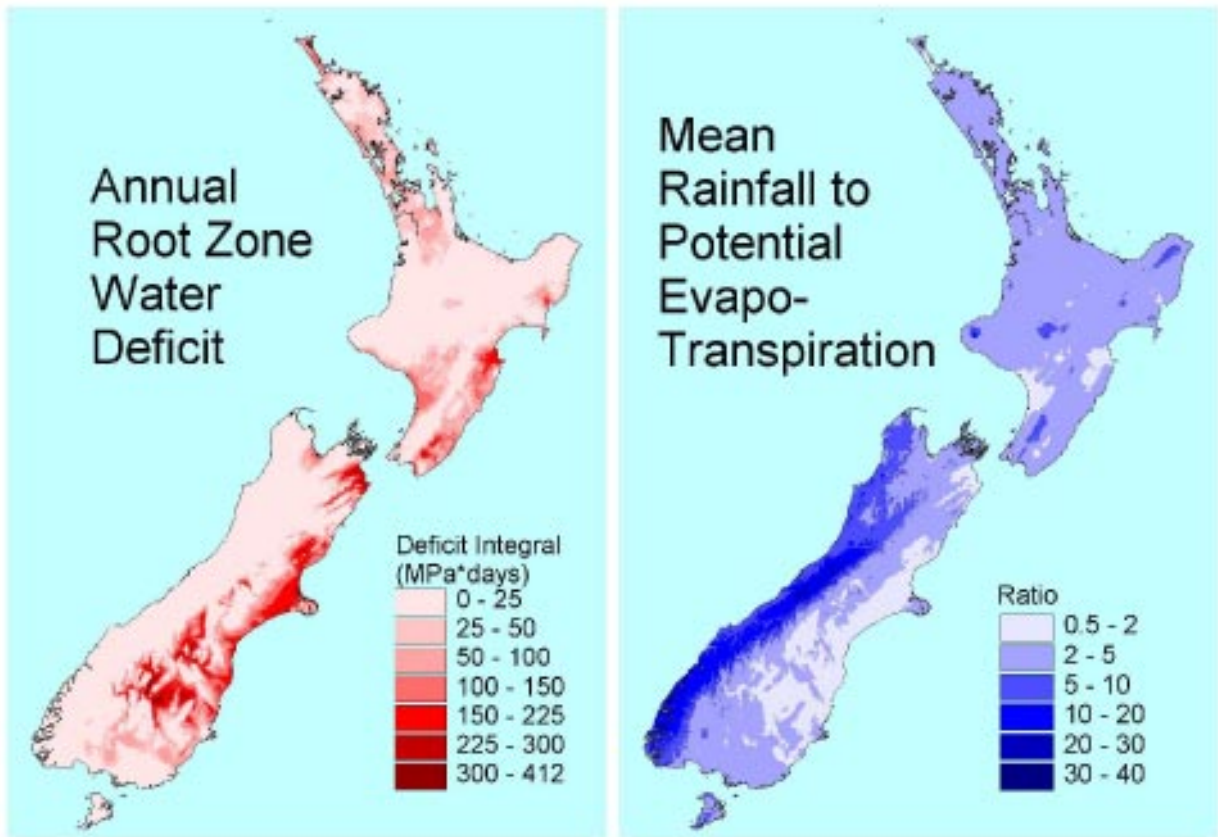


Figure A1.2.

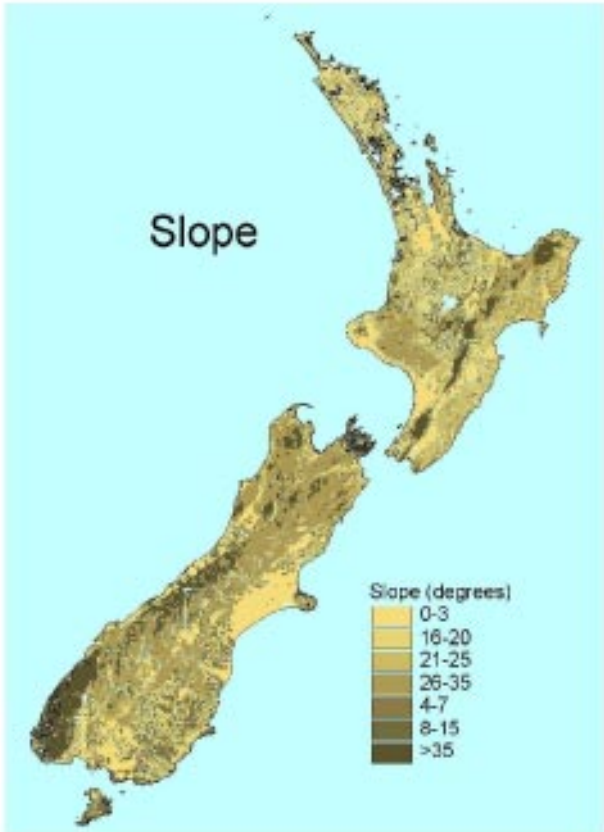
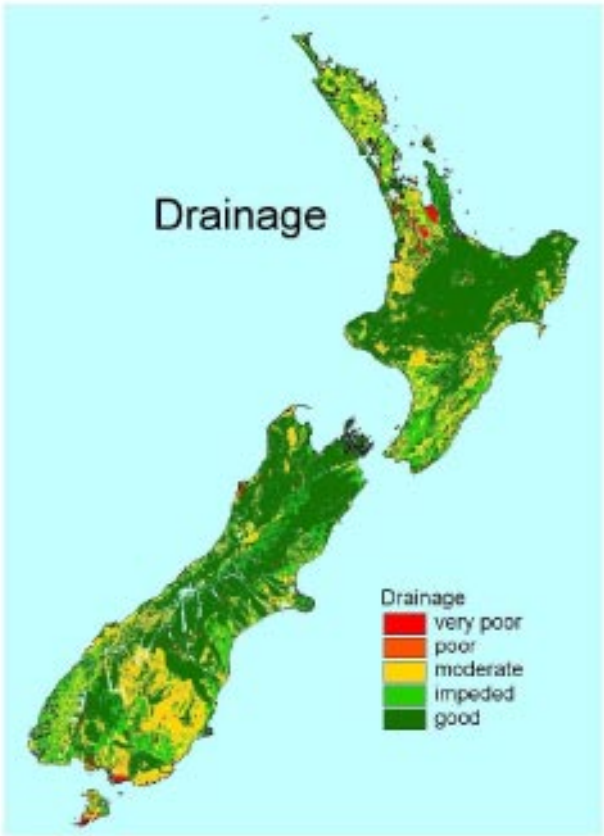
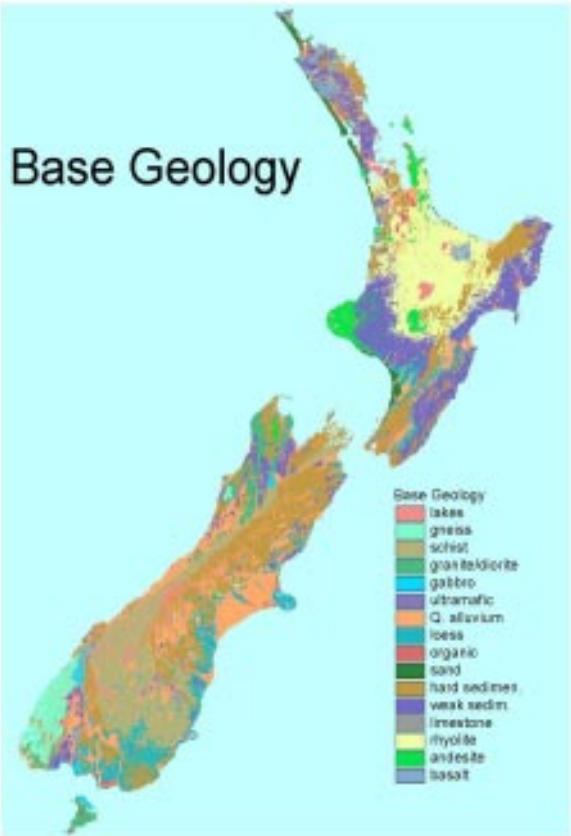


Figure A1.3.

Appendix 2

CALCULATIONS OF DISTINCTIVENESS

For each target pixel, the distinctiveness, D , is calculated as $\text{mean}(d_j)$, where d_j is the distance between the target pixel and reference pixel j .

$$D = \text{mean}(d_j)$$

$$d_j = \text{mean over } k (d_{jk}),$$

where d_{jk} is the distance to the j^{th} reference pixel along the k^{th} environmental axis.

$$d_{jk} = |E_k - E_{kj}| / (\max[E_k] - \min[E_k])$$

NB: This is the formula for the Gower metric

where E_k is the value of the k^{th} environmental variable for the target pixel and E_{kj} is the value for the j^{th} reference pixel.

The calculations of distinctiveness presented here use only a 10% random sample of the reference set to reduce computation time.