The Use of Plant Functional Types as a Method of Determining Plant Biodiversity and Keystoneness on a Northern New Zealand Isocline.

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Abstract

New Zealand vegetation, like the rest of the world, is undergoing increased perturbations due to global climate change. Whether anthropocentric in origin or part of a natural climatic cycle, increased CO_2, increased temperature plus changing regimes of precipitation have been recorded. Environmental change, especially at local levels, does affect community structure. New Zealand's ancient endemic trees and shrubs face the greatest threat of extinction, mainly due to habitat destruction by man for development and by introduced pests. The consequence could be that these trees and shrubs would not be able to migrate naturally in the time frame that climatic change will allow.

The use of Plant Functional Types in climate change research is extensive and these groupings are being used more frequently in the study of diversity response to environmental change.

The objectives of the Maunganui Bluff study were to develop a methodology to construct PFTs and to utilise these functional groupings in an analysis of the isocline. These analyses were; a diversity study based on richness and abundance, a site ordination and a group analysis. A total of forty-eight PFTs were constructed, then reduced to seventeen. The final seventeen functional groups were used in the following analyses.

1. *A diversity analysis.* While not appearing useful in comparing species evenness to PFT evenness over the isocline, the analysis did confirm that at that point in space and time when sampling was undertaken, PFTs did conform

to the assembly rule for groups. This rule states that there should be equal representation of functional groups at each site from the total available pool

2. *Ordination.* The second analysis was to determine the effect of the local environment on the spatial position of the PFTs on the isocline. Detrended Correlation Analysis (DCA), an ordination technique, was used to map the groups and the sites against environmental gradients. The results signified that a small number of groups were strongly influenced by potassium (K) but the majority of groups occupied specific sites, on an altitude – phosphorus and nitrogen gradient, due to competition for resources. This summation is supported by altitude being linked to precipitation and leaching, since most of the other environmental data, measured and analysed, were correlated to altitude.
3. *Group analysis using Indicator Species Analysis in the computer programme PCORD.* The statistical analysis highlighted three PFTs with high keystone rankings p*>.800), one of which was missed by a subjective analysis of the site map of PFTs distribution. When these three groups were deconstructed back to species, the membership of each group was only one species. Of these three species, only *Haloragis erecta* appeared to be out of place within the gradient. Four hundred metres in altitude is well beyond the plants recognised limit of approximately 120 metres. Since sea level to one hundred and fifty metres is the shrubland zone and site K is also, by species sampled, designated a shrubland, there is evidence that some environmental factor may be associated with these sites. Obviously, this cannot be tested, as there were no *Haloragis erecta* in the sampled sites from sea level to one hundred and fifty metres.

The analysis suffered from a lack of replication for the site under study, as well as comparative sites, to determine the validity of the methodologies. The results while encouraging only reflect a point in both space and time. The work would have needed a much larger range of environmental data, over a longer time frame to ensure that the results were not chance, and would be sustained under more detailed statistical rigor. Many of the premises that the work was based on are subjective.

However, despite the lack of statistical rigor, the study confirms the work being carried out using PFTs in other countries. New Zealand's endemic plants do have assembly rules and PFTs constructed with New Zealand natives are valid assemblages that can be used in statistical analysis, and may well turn out to be important in monitoring environmental change.

Certification

I, William Frederick Lee, certify that this thesis represents original work by me, except where acknowledged.

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Structure of Thesis

This thesis is based on the premise that studying the effects of environmental change at the species level is too complex to be able to make predictions about changes to ecosystem structure and function both spatially and temporally. One methodology to reduce complexity is to group species into Plant Functional Types (PFTs).

The thesis is divided into two distinct sections. Chapter One (General Introduction) introduces the rationale behind using PFTs for biodiversity studies and identification of keystone species/groups with regard to monitoring environmental change. Chapters two to four (Literature Review) attempt to explain the major biotic and abiotic influences on, or as a consequence of, environmental change: CO_2, temperature, nutrient use efficiency, herbivory and fire. Chapter two deals specifically with the general theory of each of these abiotic influences in relationship to environmental change. Chapter three focuses on the effects of environmental change on the biota of New Zealand and looks at the effects of expected scenarios on the diversity of New Zealand's natural broadleaf – podocarp forests. Chapter four explores how functional groups evolved and examines the current theories regarding the use of functional groups to characterize changes in biodiversity and to identify keystone species or groups containing a keystone identity.

The second section discusses the application of the functional group theory to an altitudinal gradient analysis. Chapter five gives an overview of the survey site and details both history and biogeographical information. Chapter six is devoted to the methodology and analysis of the biotic and abiotic survey of the site. This includes the results of the construction of PFTs, the diversity analysis (Shannon H' and evenness), ordination (Regression and Detrended Correspondence Analysis (DECORANA)) and group analysis (Keystoneness) using the methodology of Dufrene & Legendre (1998). The results are discussed in chapter 6 and the major findings are summarised in Chapter seven (Conclusions).

The thesis is presented at three levels in relation to environmental change, species, PFTs and ecosystems. There is some repetition of environmental data, especially climate change, to set the scene for each of these chapters. This is done to remind the reader that environmental change has a differing effect on vegetation, depending on the hierarchial level the vegetation is studied at.

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Chapter 1 General Introduction

Vegetation all over the Earth is being subjected to massive disturbance in the form of wholesale exchanges of species between regions, introduction of alien predators and pathogens (Vitousek et al. 1997), over harvesting, habitat destruction, pollution, and in the future, climate change (Sutherst et al. 1996; Forseth 1997). Changes in land use in New Zealand over the past 100 years have created extensive areas of agricultural lands and early successional patches at the expense of late successional and climax communities (farm or scrub land instead of broadleaf – podocarp forest). Along with these changes are major reductions in population sizes and the extinction of species that depend upon the habitats which are being degraded or destroyed. The consequences of these changes to remaining remnants in New Zealand are not well known. Loss of species that may accompany forest destruction is irretrievable. Habitat loss can only be recovered over long periods of time.

Worldwide, ecologists have been concentrating on estimating the extent of species loss, identifying major causes of the losses, and developing ways to reduce the rate of species extinction. Conservation ecology in a myriad of forms has become a specialist branch of ecology. Habitat destruction has been highlighted as the most important cause of the estimated extinction of species since the advent of human change from hunter / gatherer to agriculturist. Less attention, however, has been paid to the consequences of the loss of species in terms of functional processes.

Research efforts are now being directed towards understanding species contributions to ecosystem functioning and to how the alteration of the species composition of ecosystems affects the maintenance of ecosystem processes (Woodward 1994). Specifically, how and to what degree do the key functional processes of ecosystems depend upon the richness of species in them, and how will these properties be changed by the losses of some of their component species (Berendse 1994; McNaughton 1994)?

The complex topic of the role of biological diversity in ecosystem functioning can be addressed in many ways and at population, community, and ecosystem levels. An important result of the past three decades of theoretical and empirical research into the causes of patterns in species richness is the demonstration that these patterns are the products of complex interacting forces that vary in relative importance in both time and space (Solbrig 1991). Similarly, the consequences of biodiversity for system-level processes are certain to be equally complex; their elucidation will require analysis of many factors operating at many spatial and temporal scales.

Lawton and Brown (1993) consider that *ecosystem processes*, *behaviour of ecological systems*, and *ecosystem functioning* are equivalent terms. Ecosystems process materials and energy. The productivity and stability of the process is likely to be influenced by biodiversity. *Biodiversity* means the number of species (species richness) and also the richness of the evolutionary lineage, the variety of functional groups of plants, and the variety of types of ecological communities. The number of species in ecological communities usually exceeds the number of major ecosystem processes. Since many species are involved in each process, groups of species that participate in a particular process are termed a *functional* *group* (Smith et al. 1993; Gitay & Noble 1997; Shugart 1997). A given species may participate in more than one ecosystem process and so be a member of more than one functional group.

When more than one species participates in a process there is *functional redundancy* (Walker 1997). This term does not imply that all species within a functional group can be substituted for one another with respect to maintaining that process. Because species differ in the quality and quantity of their contribution to a particular process, the loss of one species may not be compensated for by complementary performance of other species within the group (Orians 1997). However, if there is little change in the inputs or outputs of the process, then the functional system will be maintained within the ecosystem. Lawton and Brown (1996), while not disagreeing with the concept of redundancy and keystoneness, believe that in the plant kingdom the dominant species in a community is the usually the keystone species. Mooney (1997) lists only the dominant competitor as a keystone species among a list of animal keystone species. Lawton and Brown (1996) also note that it is still very unclear how keystone species may be identified a priori, as the dynamics of ecosystem functions change depending on community composition.

Functional redundancy makes sense only when referenced to some particular site and process. For example, because many plants on a site carry out photosynthesis using the same mechanism, there may be high functional redundancy in a community with respect to photosynthesis and primary production. However, these plants will produce highly distinctive litter (Hobbie 1992), and utilise nutrients from different parts of the soil profile. In regard to these processes, different species in the photosynthesis functional group may exert different influences on other ecosystem processes. Therefore, a species may be a *major actor* with respect to one process but a *minor actor* with respect to another. Walker (1995) refers to these interactions as *drivers* and *passengers*.

If the loss of a species results in a large effect on some functional property of an ecosystem, that species may be called a *keystone species* (Bond 1993). Keystone species are likely to be found in functional groups with few species or in functional groups having a species whose performance cannot be filled by other group members (i.e. no *passenger* species able to take over the role of system *driver*). Naeem et al. (1998) call this point the critical minimum species richness (CMSR). An example may be the role of nitrogen-fixing plants in plant communities. If nitrogen-fixing plants are removed, there may be some complementary redundancy by such plants as *Causarina spp*. However, quantity of nitrogen production will decline, thus influencing the dynamics of the system. Ecologists have looked for and identified keystone species by their effects on the species richness and composition of the community that they inhabit.

In regard to primary processes a keystone species may or may not significantly change the species composition of its community. Species within a functional group differ in the magnitude of their contributions, in terms of both their quantity and their quality. Species within a functional group may also differ in where they carry out these processes. For example, one organism might fix nitrogen on a branch high in the canopy of a forest, another in the soil. Where the fixation occurs, influences which other organisms have access to that nitrogen, and how the nitrogen moves through the ecosystem.

With respect to any particular process, the number of functional groups is termed the diversity (richness) of functional groups. The term diversity (richness) within functional groups refers to the number of taxa included in the group. Richness can therefore mean a simple listing of taxa, such as species or aggregates of them. Diversity is also applied to lists that are weighted by some meaningful ecological criteria such as plant morphology and physiology. In regard to processes this can be a functional group's response to external environmental factors that influence functional processes such as nutrient use efficiency, water use efficiency and productivity.

Analysing the functional significance of biodiversity is a difficult task because the richness of species in most communities is unknown and ecological roles of many described species are poorly understood. In addition, no accepted classifications of functional groups already exist, and no single classification can aggregate organisms appropriately for more than one major ecosystem process or for more than one instance in both a temporal and spatial sense. In other words, functional groups can only be constructed from available information for a set purpose. The groups formed, or the methodology (rules) of construction may not be applicable at any other location or point in time.

The Maunganui Bluff survey and analysis seeks to determine the value of PFTs constructed of non – numerical data in the form of traits, using a database and queries to construct the groupings, in a diversity study. Most studies, published in the Journals, use numeric data and construct the groups using Twinspan (Dufrene and Legendre 1997). These constructed groups were then used to test the rule concerning convergence of PFTs over a sampled altitudinal gradient, determination of the presence of groups in space and time in relation to the environmental data collected; altitude, light, soil temperature, soil nutrient levels and soil moisture. The same PFTs were analysed to determine group assemblages over all the sites and to place a value of the presence of any group occurrence at a site in relation to occurrences at all sites. The methodology used was devised by Dufrene and Legendre (1997) and available in the statistical package PCORD (McCune and Mefford 1997).