Population dynamics and spread of invasive species in response to changing scale of landscape pattern scenarios: current issues and challenges

Audrey Lustig[#1], Daniel Stouffer[*2], Mariona Roige[#3] and Susan P. Worner[#4]

[#]*Bio-Protection center, Lincoln University, PO Box 85084, Lincoln University 7647, Canterbury, New Zealand*

[*]*University of Canterbury,Private Bag 4800, Christchurch 8140, New Zealand*

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EXTENDED ABSTRACT

The current, global mass invasion by alien invasive species is creating a rapidly growing array of unique ecological, economic and social challenges of unprecedented magnitude in terms of its temporal rate and geographical extent [1]. It is now understood that the successful invasion and subsequent impact of alien species is a heterogeneous process, with the spatial distribution of invasive species resulting from several interacting factors: (1) species life history traits conferring high fitness to become problem invaders, (2) abiotic and biotic interactions that limit or facilitate the establishment of non-native species, (3) propagule availability, and, (4) the rapid evolution of introduced species [2]. These features are interrelated across multiple spatio-temporal scales and hierarchies emerge – all of which comprise key concepts and fundamental challenges to both the theory and practice of invasion ecology [3]. In practice, risk analysis of biological invasions and predictions of spread, traditionally focus on a single-species approach and habitat requirements. Theoretical and empirical studies lead to conclusions most applicable to the specific conditions under which they are developed, and are not readily transferred to other situations [4]. Under these circumstances, there is urgent need for more integrative approaches and a broader modeling framework that focuses on cross-study comparisons at different spatio-temporal scales to make better prediction regarding the vulnerability of organism and ecosystems to invasion.

The present research focuses on disentangling the influence of species life traits (factor 1) and spatial heterogeneity effects (factor 2 and 3) on the process of biological invasion. Critical to this effort is the development of a unique spatially-explicit model that links an individual-based model of insect species spread with spatial information through geographical information system technology [5]. Such an approach has emerged as one of the key methodologies for systematic investigation of the impact of changes in landscape structure on invasive species population dynamics. It comprises, (1) a spatially-explicit, organism centered dispersal simulation framework, (2) a landscape generator, allowing independent change in the composition and configuration of landscape components, and, (3) appropriate landscape measures that establish a quantitative relationship between landscape structure and population dynamics. Rather than focusing on individual species, a more a general approach is adopted where the pattern of invasion by multiple species are used to infer key drivers of invasion. Nevertheless, spatial modeling in invasion ecology is confronted with difficulties arising from a lack of conceptual framework to investigate quantitative measures of spatial patterns in terms of composition, configuration and habitat patch geometry (e.g. size and shape) [6]. Another aspect that still requires attention is the spatial extent and grain (i.e. buffer area and size of the individual unit of observation) at which landscape characteristics influence local invasions [7]. While much research has been directed toward developing and understanding simple quantitative measurements of various aspects of the 'patchiness' of the landscapes, these landscape metrics have not yet percolated into research in invasion ecology. The exploration of these variables (composition, configuration and habitat patch geometry) provide a novel basis for the development of radically new concepts that extend conventional boundaries of the ecological explanation for the success and persistence of invasive species across spatial scales.

The idea that the ecological processes underlying species' responses to habitat structure have several characteristic spatial scales is becoming increasingly accepted and requires a multi-scale description of spatial pattern and process [6]. However, the natural complexity of ecosystems make the search for an appropriate measure of spatial heterogeneity challenging. There are probably no particular metrics that will appropriately characterize all aspects of the landscapes [8]. However, recent studies do conclude that particular landscape metrics capture at least some apsects of the spatial patterns [9]. Such studies are limited to the analysis of a restricted number of metrics. In this study, we considered the application of a non-linear method to the problem of assessing change in a large number of landscape metrics in response to changes in spatial pattern scales.

We used the neutral landscape model Qrule 4.2 [10] to generate 1650 binary landscapes across gradients of percentage of landscape cover (P), aggregation of landscape cover (H), grain (R) and extent (E). For each landscape, we calculated 111 metrics, describing the landscape as a whole, using the computer program FRAGSTATS 4.1 [11]. We extracted a 'weighted list' of individual metrics whose variance of change across all experiments correctly defines the boundary of a given cluster (corresponding to variation in E, R, H, and P). This enabled us to assess the discriminative ability of different metrics in characterizing the same topological characteristics of the landscape across different scales.

The contribution of each individual metric to define clusters of predictor variables is shown in Figure 1. The metrics are ordered by rank frequency along the horizontal axis. The landscape samples are ordered along the vertical axis and each tick corresponds to the pairwise comparison of groups of sampling percentage of either E, R, P or H. Each metric is presented graphically as a colored image with color saturation directly proportional to the rank order of the metrics (bluish colors are associated with most discriminant metrics, reddish colors are associated with less discriminant metrics).

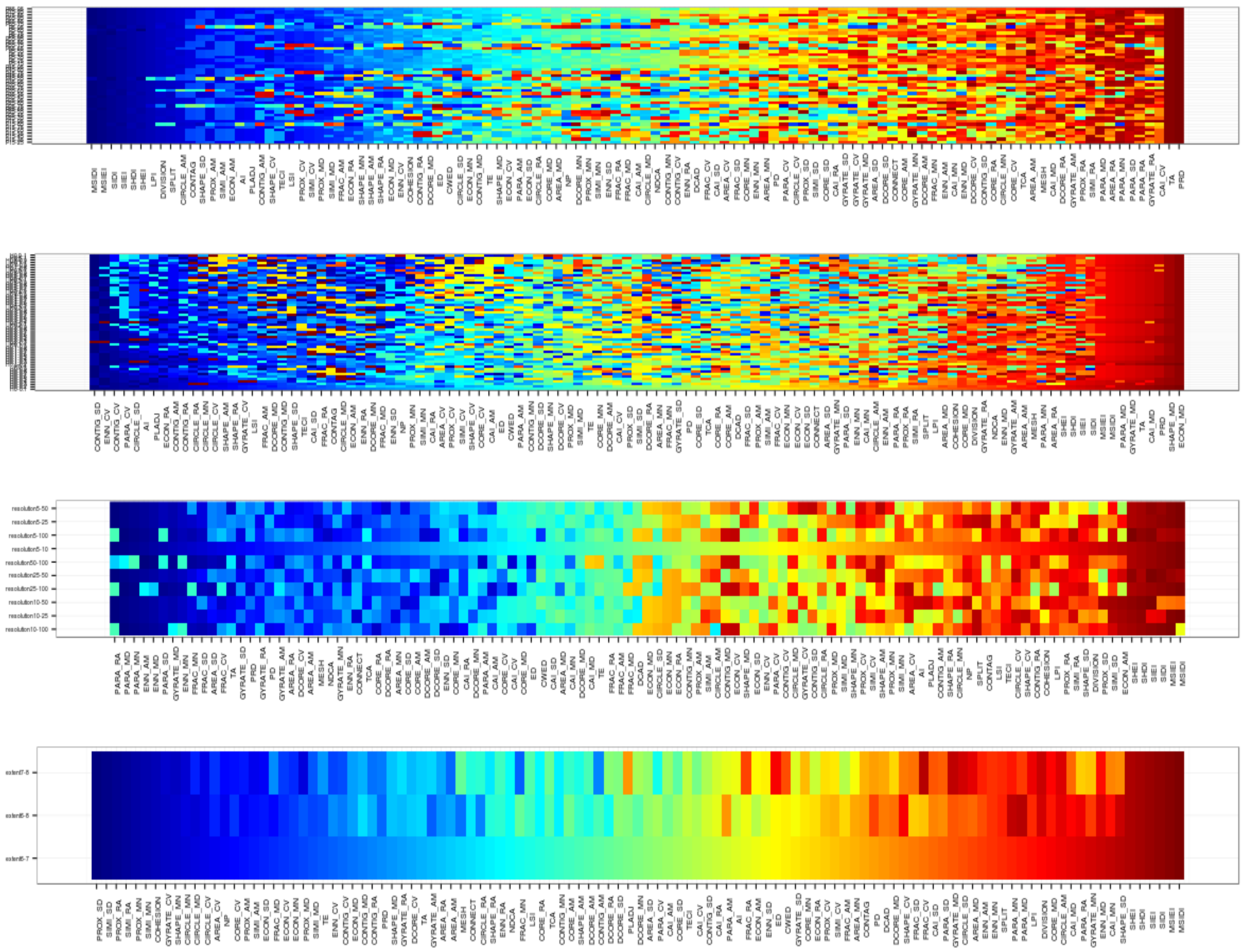

Fig. 1: Ranking metrics analysis of the landscape metrics according to their impact on minimising cluster volume and maximising centre to centre inter-cluster distance. Metrics are listed in order of decreasing weight (from left to right).

Metrics that were singled out to discriminate one sampling level from another performed relatively well discriminating each level of the same group (aggregation of bluish colors on the left part of the graph). The rank order of the contribution of each individual metric to define clusters of predictor variables is different for E, R, P and H. That indicates that particular metrics have different capacities for quantifying various aspects of the landscape. No metrics were found to characterize all four aspects of the landscape. Most of the metrics were able to discriminate only one or two aspects of the spatial patterns. However, a weighted discriminator offered the first mathematical indication about the relative capacity of each metric to represent the characteristics of the spatial patterns. Such scale and scaling based analysis can be used to guide the selection and processing of appropriate data sources for future research in landscape experimental design and modeling.

The primary aim of this study was to better understand the relationship between landscape metrics and spatial patterns at different scales. No inherent process of invasion was investigated. However, the results of this study could be easily incorporated into a theoretical analysis, using boosted regression trees for example, to explore the influence of patch and landscape characteristics on the process of invasion. In particular, the question of sampling extent and resolution is a major concern when trying to elucidate the importance of the spatial effect on the biological invasion process. Landscape metrics showed idiosyncratic responses to change in spatial scales. Thus, there is a need to assess the most relevant scales for each landscape predictor and the associated ecological process under investigation [6]. Meeting these challenges promises to give deeper insights into species traits driving spatial patterns of invasion that are key to preventing new incursions and the development of efficient monitoring, surveillance, control and eradication programmes.

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