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# Towards the planning and design of disturbance patterns across scales to counter biological invasions

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ABSTRACT

The way in which disturbances from human land use are patterned in space across scales can have important consequences for efforts to govern human/environment with regard to, but not only, invasive spread-dispersal processes. In this context, we explore the potential of disturbance patterns along a continuum of scales as proxies for identifying the geographical regions prone to spread of invasive plant species. To this end, we build on a previous framework of cross-scale disturbance patterns, exercising the approach for the Apulia region (South Italy). We first review procedures and results introducing disturbance maps and sliding windows to measure composition (amount) and configuration (contagion) of disturbance patterns both for real and simulated landscapes from random, multifractal and hierarchical neutral models. We introduce cross-scale disturbance profiles obtained by clustering locations from real and simulated landscapes, which are used as foils for comparison to the real landscapes on the same pattern transition space. Critical percolation thresholds derived from landscape observations and theoretical works are discussed in order to identify critical scale domains. With reference to the actual land use and invasive alien flora correlates of disturbance patterns, a cross-scale "invasibility" map of the Apulia region is derived, which shows sub-regions and scale domains with different potentials for the invasive spread of undesirable species. We discuss the potential effect of contagious and non-contagious disturbances like climate change and why multifractal-like disturbance patterns might be more desirable than others to counter biological invasions in a multi-scale and multi-level context of adaptive planning, design and management of disturbance.



## 1. Introduction

The claimed objective of physical planning is the optimization of spatial composition (what and how much there is) and configuration (how it is spatially arranged) of landscape elements like habitats or land uses (Van Lier, 1998), focusing on land-use allocation. Since human land use is a major force driving landscape change (MEA, 2005), physical planning should ultimately adopt a landscape perspective (Turner and Gardner, 1991; Ricketts, 2001). This should be based upon the increasing understanding of landscape dynamics in the context of complex adaptive socioeconomic and ecological systems (Levin, 1998; Berkes and Folke, 1998), integrating phenomena across multiple scales of space, time and organizational complexity. In social–ecological landscapes (SELs) (Zaccarelli et al., 2008) social-economic drivers are generally imposed on biophysical components to generate change in landscape pattern (Lambin et al., 2001; Black et al., 2003; Foley et al., 2005). In particular, interactions between land ownership and landscape position have emerged as strong determinants of land-cover patterns and contagious disturbances (Mladenoff et al., 1993; Spies et al., 1994; Wear and Bolstad, 1998). In addition, non-contagious disturbances are imposed by climate change with possible cross-scale interactions with contagious disturbances (Fig. 1). In this respect, climate changes relate to two main issues of potential risks to biodiversity: rise in average temperature, and an increased fluctuation of weather conditions (weather extremes),

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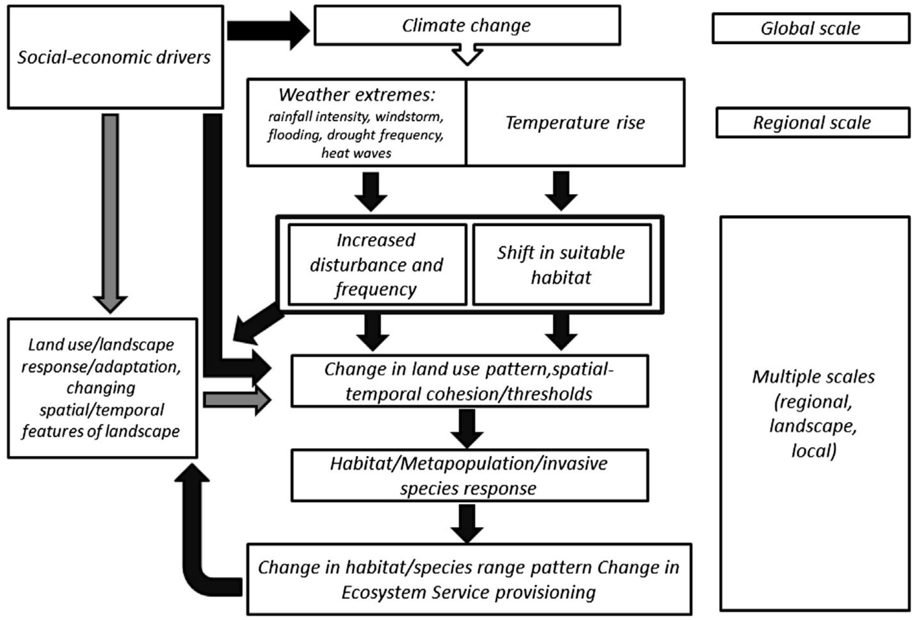


**Fig. 1.** Outline of response chain of changes from climate and socioeconomic drivers to habitat/species distribution pattern and ecosystem service provisioning mediated by habitat loss and change both in land-use pattern and landscape connectivity. Different spatial scales interact (modified from Opdam and Wascher, 2004) (see text).

such as rainfall intensity, windstorm, flooding, and drought frequency, which both lead to increased disturbances in landscapes (Opdam and Wascher, 2004). Such disturbances can overlap and interact in varying degrees and patterns with disturbances generated by direct human interaction with the biophysical environment. An example of this is when temperature rise can affect the extent and magnitude of contagious disturbances (e.g., a fire made worse over a larger area due to greater temperature extremes).

The crucial problem of land-use allocation in planning and design is that many different global and local human-driven processes in the landscape are competing with each other and with natural processes at multiple scales having a major effect on landscape processes and biotic compositions (Koomen et al., 2012). As a result, the effects of land-use intensity on local biodiversity and ecological functioning in SELs depend on spatial scales much larger than a single field or land use (Zurlini and Girardin, 2008).

Traditionally, disturbance is broadly defined as any event that results in a sustained disruption of ecosystem structure and function (Pickett and White, 1985). Land-use change can be deemed as a "landscape-level" disturbance underlying fragmentation and habitat loss (Hobbs and Huenneke, 1992) and is considered the greatest threat to biodiversity (MEA, 2005). At landscape scale, disturbance due to land-use intensification can be expressed through the conversion of perennial habitat to arable fields, the destruction of edge habitats, fragmenting natural habitat, giving up low-intensity land-use management, reallocation of land to increase field size, avoiding set-aside fallows, cultivating of formerly abandoned areas, and farmer specialization on one or few crops (Zaccarelli et al., 2008). Landscape-level disturbance can facilitate biological invasion, from initial introduction through establishment and spread, which can threaten native diversity (Hobbs and Huenneke, 1992; Pyšek et al., 2010). As threats to biodiversity intensify (McKee et al., 2004) and rates of species invasion continue to rise, effective sustainable planning and management requires detailed understanding of relationships between disturbance, invasion and diversity (Hulme, 2006).

Since disturbances may be inflicted not just at one single scale, both habitats and native and invasive alien species may differentially respond to disturbance in the same place at different scales. A potentially useful way to appreciate these differences is to look at how disturbances are patterned in space based on a map of disturbance at multiple scales (Zurlini et al., 2006, 2007; Zaccarelli et al., 2008; Petrosillo et al., 2010).

Nassauer and Opdam (2008) expanded the field of landscape ecology to include research into a third aspect of pattern and process: design. Then, a crucial question might be how to optimize human-driven processes (disturbances) associated to land uses, and how to arrange them across multiple scales of space, time and organizational complexity both to favor native species and, meanwhile, to counter biological invasions.

The main aim of this paper is to draw attention to how disturbance patterns from human land use are patterned in space along a continuum of scales, and discuss some implications of such patterns for efforts to plan and govern human/environment relationships in the light, but not only, of countering biological invasions. Despite disturbance patterns having been successfully explored in many theoretical and practical ecological contexts (e.g., Moloney and Levin, 1996; With and King, 1997; Johst and Drechsler, 2003; With, 2004), little theoretical or practical work has explicitly addressed the implications of scaling of disturbance patterns for the purpose of physical planning and design of SELs (Jones et al., in press).

To this end, we address a spatially explicit approach to quantify landscape-level disturbance in the geographical real world domain along a continuum of scales, based on previous results (Zurlini et al., 2006, 2007; Zaccarelli et al., 2008), with the aim to characterize and interpret spatial patterns of cross-scale disturbances in the Apulia region (south Italy), exhibited on satellite imagery over a four-year time period.

We first briefly review procedures and results from our previous work introducing the disturbance map based on satellite imagery of the Apulia region, and the use of sliding windows (Milne, 1992) to measure composition (amount) and configuration (contagion) of disturbance patterns, Such measures are obtained both for real and simulated landscapes from random, multifractal, and hierarchical neutral landscape models (NLMs). Then, we introduce profiles of