



Habitats on the grid: The spatial dimension does matter for red-listing



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ABSTRACT

Besides species Red Lists, recently, a variety of frameworks have been proposed for assessing higher levels of biological organisation, i.e. ecosystems, habitats, plant communities. Most of these protocols refer to 'plant species assemblages' or 'vegetation types' as proxies for ecosystems or habitats. Indeed, the habitat concept based on plant communities has acquired a central role as a key approach for biodiversity conservation above the species level. Plant communities, like every complex biological system, hold scale-dependent 'emergent' properties which vary as a function of the scale of observation. With reference to red-listing, these scale-dependent properties have far-reaching consequences for both identification and classification, as well as for representation and evaluation, and become particularly challenging when dealing with criteria regarding decline in distribution or restricted distribution. The recent discussion on the red-listing protocols has evidenced several aspects that claim special efforts for a suitable use. In the present paper, starting with the analysis of some recently proposed protocols for the red-listing of habitats and ecosystems, we discuss and test some 'emergent' properties of species assemblages, providing cues for reflection. Based on a variety of theoretical models and scientific outcomes in literature from the last decades, we theorise that plant communities own some intrinsic, ecologically based and scale-dependent spatial features, which give rise to different types of pattern of spatial occupancy. We discuss a model where, in natural conditions, the possible patterns of spatial occupancy are referred to 3 basic types: areal, linear and point. This approach is here proposed as a tool to discriminate among different broad categories of plant community-based habitat types and optimise their assessment in the red-listing process. Starting from a homogeneous data set, the proposed case studies prove that the choice of the scale affects the comprehension of the habitats' occurrence, with a substantial relapse on the estimates of their distribution size. In particular, habitats with linear and point distribution, often naturally small in size and dispersed, are more susceptible to biased evaluation of their actual distribution and consequently of their threat status. The intrinsic spatial attributes of plant communities should not be neglected in a red-listing process and claim for a 'habitat-tailored' approach. The use of different grid-cell sizes and thresholds for the three main patterns of spatial occupancy here proposed, might certainly avoid inaccurate statements.

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1. Introduction

The conservation of biodiversity is a widely acknowledged target for humankind (Cafaro & Primack, 2014), as shown by an increasing array of regional, national and international agreements and frameworks for hindering biodiversity loss (see, e.g. CITES, 1973; European Commission, 2011; United Nations, 1976, 1992). The most challenging aspect stems from the complexity of biodiversity, that in itself comprises both multiple levels of organisation

(e.g. genes, species, communities and ecosystems) and their interacting relationships at all the integration levels (Allen & Starr, 1982; Margules & Pressey, 2000; Noss, 1990).

In the last decades, the International Union for Conservation of Nature (IUCN) has led the development of quantitative criteria for the creation of red lists of threatened species that allow for transparent, objective and repeatable risk assessments (IUCN, 2012, 2013; Mace et al., 2008). By ranking species at risk of extinction, the IUCN Red Lists provide a global indication on the state of one level of biodiversity and make governments and society aware of the trends in extinction risk (Baillie, Hilton-Taylor, & Stuart, 2004; Butchart et al., 2004; McCarthy, Thompson, & Garnett, 2008).

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Despite the cutting edge importance of species Red Lists, the realisation that an approach focused exclusively on the species level is unfit to conserve all components of biodiversity led the scientific community, conservation professionals and institutions to be increasingly concerned with biodiversity assessments, addressing higher levels of biological organisation (Izco, 2015; Keith, 2009; Keith et al., 2013, 2015; Kontula & Raunio, 2009; IUCN, 2015a; Nicholson, Keith, & Wilcove, 2009; Rodríguez et al., 2011, 2012, 2015). Ecological communities may more efficiently represent the biological diversity as a whole, compared to the species-level approach, which often lacks direct information about fundamental abiotic components, thus missing both the targets of protecting ecological patterns and processes, and ensuring the persistence of ecosystem functions and structure (Balmford et al., 2002; Cowling et al., 2004; Millennium Ecosystem Assessment, 2005; Noss, 1996; Secretariat of the Convention on Biological Diversity, 2010). Furthermore, the conservation of communities or ecosystems can also act as a surrogate for the species, particularly for those species yet undescribed or poorly known (Cowling & Heijnis, 2001; Nicholson et al., 2009), thus providing a precious service when considering that, despite strenuous efforts, only less than 5% of the estimated number of described species (less than 7% when considering only plants) has been evaluated for inclusion in the IUCN Red List by 2015 (IUCN, 2015b). The assessment of communities or ecosystems also allows to incorporate further information, such as the role of species richness/diversity, offering precious tools both for species and habitat's prioritization (see, e.g., Berg et al., 2014; Lindenmayer et al., 2008; Pärtel et al., 2005).

Early lists of endangered plant communities/habitats/ecosystems have been compiled since the 1980s, focusing either on specific ecosystem types or on national boundaries (see e.g., Moravec et al., 1983; Schulte & Wolf-Straub, 1986). Many common criteria were used for the evaluation (e.g. rarity, range, species composition, naturalness, human pressure, aesthetic or educational value), but the assessment was mostly based on expert knowledge, e.g. long-term field experience (Blab, Riecken, & Ssymank, 1995; Noss, LaRoe, & Scott, 1995; Paal, 1998) and, in some cases, key concepts were not underpinned by sound theoretical backgrounds. More recently, a variety of frameworks, founded on relevant ecological theories, have been proposed for assessing the threat status of plant communities/habitats/ecosystems (Berg et al., 2014; Biserkov, 2011; Essl, Egger, & Ellmauer, 2002; Lindgaard & Henriksen, 2011; Walker et al., 2006), in some cases prompted by government agencies. Nevertheless, differently from species, as yet there is no acknowledged international methodology on which to base the habitat red-listing. In Europe, Rodwell, Janssen, Gubbay, and Schaminée (2013) recently started a project aimed at developing a Red List of the European habitat types, while the IUCN council (CEM-IUCN & Provita, 2012) formally endorsed the protocol proposed by Keith et al. (2013).

Besides a common origin from the protocol developed for species (IUCN, 2013; Mace et al., 2008), the various methodologies adopted for plant communities/habitats/ecosystems red-listing share several characteristics: (a) although some protocols define assessment units of large dimensions, such as 'ecosystems' (Keith et al., 2013) or 'Land Environments' (Walker et al., 2006), most of them refer to 'plant species assemblages' or 'vegetation types', used as proxies for ecosystems or habitats; (b) as a rule, the assessment is based on quantitative criteria and only few protocols rely on qualitative ones, i.e. on the best expertise supported by specific paradigms (e.g. Biserkov, 2011); (c) all the protocols include decline and restricted size in spatial distribution as key criteria, and almost all identify quantitative thresholds, often analogous yet less severe than those adopted for species; (d) they are still rather lacking in suitable tools to incorporate measures of 'ecological function', i.e. the capacity of communities to support their whole

diversity of species and to sustain their functional roles in landscapes (Nicholson et al., 2009), with some remarkable exceptions giving special importance to species diversity or to the presence of threatened *taxa* in the evaluation of habitat quality (e.g. Andreas & Lichvar, 1995; Bacchetta, Farris, & Pontecorvo, 2012; Berg et al., 2014; Gauthier, Debussche, & Thompson, 2010).

1.1. Emergent properties: the "pattern of spatial occupancy"

Plant communities, like every complex biological system, hold aggregate or 'emergent' properties, which cause the whole to be more than the mere sum of its parts (Bissonette, 1997; Halley & Winkler, 2008; van der Maarel & Franklin, 2013). In natural conditions, properties of plant communities such as composition and structure arise from the interaction of both coarse- and fine-scale filters (Dale, 1999; Lortie et al., 2004). On a fine scale, vegetation patterns are ruled by species size and growth pattern, as well as by the interactions among plant individuals. On a larger scale, they are influenced by physical and geomorphologic features (i.e. valleys, ridges, slopes, water bodies) that create spatial and ecological heterogeneity (Dale, 1999; Greig-Smith, 1979; Palmer, 1988).

By interacting with spatially distributed environmental gradients, organisms, communities and ecological systems are thus arrayed in space to form distinct patterns or configurations, i.e. 'specific arrangement of spatial elements' (Turner, Gardner, & O'Neill, 2001), that exhibit a certain amount of predictability (Dale, 1999). Thus, although the boundaries between different plant communities are inherently more uncertain than is the case for species (Nicholson et al., 2009), the recognition and delimitation of stands of vegetation in the field can be based on internal characteristics, e.g. structural, physiognomic and floristic uniformity, and external ones, e.g. discontinuity with the surrounding vegetation (van der Maarel & Franklin, 2013).

On this ground, it can be assumed that each plant community owns intrinsic spatial features, ecologically founded, which affect its spatial distribution in natural conditions. In particular, the environmental heterogeneity accounts for an intrinsic property of each plant community that we call 'pattern of spatial occupancy' (PSO).

In accordance with Dale (1999), we refer to spatial pattern as 'nonrandomness in spatial arrangement, which then permits prediction'. The abiotic environment is spatially structured, resulting in patchy patterns or gradients. In natural conditions, when the plant species and assemblages are not subjected to human constraints, plant communities can display several, yet predictable, PSOs. Dale (1999) proposed the concepts of 'point pattern' and 'pattern on an environmental gradient' with reference to the type of representation of plant individuals and communities distribution. With different although closely related aims, the French phytosociological-synusial school developed a geometric approach to plant communities, introducing the shape ('forme spatiale, linéaire continue, linéaire discontinue, ponctuelle') as an essential property of vegetation patches in landscape analysis (Géhu, 1974, 1991; Julve, 1986).

As a general model, we assume that the PSO mostly tends to display three main patterns: *areal* (i.e. with an extended distribution; e.g. broadleaved temperate forests, natural and semi-natural grassland formations), *linear* (i.e. with a distribution in strips, where length is much greater than width; e.g. riparian and water-dependant formations, coastal plant communities) or *point* (i.e. with a naturally scattered spatial distribution, e.g. vegetation of temporary ponds).

By reflecting the ecological driving forces, these 3 models of PSO are representative of natural conditions and as such they should be considered as an intrinsic feature of each plant community (namely they do not give account of artificial, human-induced distribution, due e.g. to land-use change and fragmentation processes).

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