



Using landscape structure to develop quantitative baselines for protected area monitoring

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ABSTRACT

Changes in habitat extent as well as landscape and habitat structure are often caused by human pressure within protected areas and at their boundaries, with consequences for biodiversity and species distributions. Thus quantitative spatial information on landscape mosaic arrangements is essential, for monitoring for nature conservation, as also specified by frameworks such as the Convention on Biological Diversity (CBD), and the European Union's Habitat Directive. While measuring habitat extent is a relatively straightforward task, approaches for measuring habitat fragmentation are debated. This research aims to delineate a framework that enables the integration of different approaches to select a set of site- and scale-specific indices and synthetic descriptors and develop a comprehensive quantitative assessment of variations in human impact on the landscape, through assessment of habitat spatial patterns, which can be used as a baseline for monitoring. This framework is based on the use of established methodologies and free software, and can thus be widely applied across sites. For each landscape and observation scale, the framework permits the identification of the most relevant indices, and appropriate parameters for their computation. We illustrate the use of this framework through a case study in a protected area in Italy, to indicate that integrated information from multiple approaches can provide a more complete understanding of landscape and habitat spatial pattern, especially related to locations experiencing disturbance and pressure. First, identification of a parsimonious set of traditional LPs for a specific landscape and spatial scale provides insights on the relation between landscape heterogeneity and habitat fragmentation. These can be used for both change assessment and ranking of different sections of the study area according to a fragmentation gradient in relation to matrix quality. Second, morphological spatial pattern analysis (MSPA), provides a pixel based structural characterisation of the landscape. Third, compositional characterisation of the landscape at the pixel level is provided by landscape mosaic analysis. These three approaches provide quantitative assessments through indices which can be used singly or in combination to derive three synthetic descriptors for a comprehensive quantitative baseline representation of landscape structure that can be used for monitoring: the first descriptor, landscape diversity profiling, based on the output of landscape mosaic analysis, at the landscape level, complements the evaluation which at the pixel level can be obtained by more complex modelling; the second descriptor, obtained combining of the outputs of MSPA and the landscape mosaic analysis, informs on the local structural pattern gradient across the landscape space; the third descriptor, derived from the integration of selected LPs and those derived from MSPA into a discontinuities detection procedure, allows for the identification of "critical points" of transitions in management where threats to biodiversity and ecosystems integrity may be likely. The framework developed has significant potential to capture information on major landscape structural features, identify problematic areas of increased fragmentation that can be used to prioritise research, monitoring and intervention, and provide early warning signals for immediate response to pressures increasing habitat fragmentation, with the goal of facilitating more effective management.

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1. Introduction

Monitoring landscape and habitat change in protected areas has become a major issue for international nature conservation agencies, super-national, national and regional authorities, on the one hand, and local managers on the other. Such monitoring is required to assess the impact of conservation policies and evaluate the effectiveness of financial investments, and assess the effectiveness of response measures within an adaptive management perspective. Monitoring is also mandated under the Convention on Biological Diversity (CBD), wherein 22 biodiversity headline indicators have been internationally adopted (Strand et al., 2007). At the European Union (EU) and Pan European levels (Council of Europe, 2004), the framework suggested by the CBD has been used to develop a set of 26 indicators within the Streamlining European 2010 Biodiversity Indicators (SEBI 2010) project (European Environmental Agency, 2009).

In particular, the first three CBD focal areas (i.e., “Status and trends of the components of biological diversity”, “Threats to biodiversity”, “Ecosystem integrity, and ecosystem goods and services”), bear a strong relation to landscape structure, which according to landscape ecology is considered to be a component of biodiversity (Jedlicke, 2001), and thus regular observation for monitoring of the structure of landscapes containing habitats of concern is required. Such data are mostly derived by means of Earth Observation (EO) techniques, both satellite and airborne (Strand et al., 2007; Buchanan et al., 2008). In addition to indirect measures on ecosystem functioning, such as those based on climate, topography, primary productivity, disturbance (Duro et al., 2007; Nagendra et al., 2012), EO data can be very useful in providing the information base to derive landscape configuration and composition indicators.

Data on landscape spatial pattern is particularly required in the European context where great importance is given to the protection of habitats of “community interest” for species conservation (Council Directive 92/43/EEC of 21 May 1992 “Habitats Directive”), and where there is a legal obligation for EU Member States to report on changes in conservation status (including changes in habitat extent and configuration) every six years (Directive 92/43/EEC, articles 11 and 17). Habitat extent and landscape and habitat configuration are critical to monitor, as these provide indicators of human pressure within and around protected areas (DeFries et al., 2005). Moreover, as the processes driving landscape transformation in protected area-embedded landscapes act at quite fast rates and fine spatial scales, they thus require detailed temporal and spatial monitoring.

Two of the SEBI 2010 proposed indicators, “Ecosystem coverage” (relevant to the “Trends in extent of selected biomes, ecosystems and habitats” headline indicator of the “Status and trends of the components of biological diversity” focal area) and the “Fragmentation of natural and semi-natural areas” (relevant to the Connectivity/fragmentation of ecosystems” headline indicator of the “Ecosystem integrity and ecosystem goods and services” focal area) appear suitable for monitoring through the use of EO techniques (Jongman et al., 2011). EO data and associated approaches of spatial analysis are now capable of providing detailed, reliable and frequently updated information at the spatial and temporal scales required for protected area monitoring. These allow for the regular generation of land cover/land use (LC/LU) and habitat maps at different spatial scales based on the adoption of more meaningful classification taxonomies (Tomaselli et al., 2011), such as the FAO-Land Cover Classification System (LCCS, Di Gregorio and Jansen, 2005), the European Nature Information System (EUNIS, Davies and Moss, 2002), or General Habitat Categories (GHCs, Bunce et al., 2011).

Generating baseline measurement of habitat extent is a relatively straightforward task. In contrast, producing baseline measurements of habitat fragmentation that can be used for

continued monitoring of changes in landscapes of conservation significance constitutes a highly debated issue in the landscape ecological literature, lacking standardised and globally applicable approaches. An arsenal of landscape pattern indices (LPI) is available for landscape pattern analysis (LPA) on discrete (categorical) cartographic data (O'Neill et al., 1988; Forman, 1995; Baskett and Jordan, 1995; Haines-Young and Chopping, 1996), and reliable computational tools have been developed for this purpose (Baker and Cai, 1992; McGarigal et al., 2002). These have been widely applied to a range of landscapes and scales, yet, apart from few notable exceptions (e.g., Riitters et al., 1995; McGarigal and McComb, 1995; Tinker et al., 1998) the selection of specific LPIs for each site appears idiosyncratic, mainly based on researchers' knowledge, experience, and even personal preferences, often without extensive investigation of the range of possible indices. This is problematic, as although several metrics can capture some aspects of landscape configuration, and hence return some information on fragmentation, these are not intrinsically capable of disentangling the contribution of habitat loss to fragmentation from fragmentation per se (Fahrig, 2003). A further complication is introduced by the dependence of landscape heterogeneity on the spatial scale of analysis (Wu, 2004; Wiens et al., 1993). Therefore, it becomes difficult to propose a single recipe for the selection of a relevant set of LPIs, as the selection of a set of indices appears to be highly contingent on the landscape, as well as the question being asked (Fahrig, 2003; Wu, 2004; Taylor et al., 2006).

In addition to LPIs, two approaches have been recently proposed for the spatial analysis of landscape pattern from categorical maps, that seem to be promising for generating baseline information that can be of use for protected area monitoring, i.e., morphological spatial pattern analysis, MSPA (Soille and Vogt, 2009), and the analysis of landscape mosaics (Riitters et al., 2009). Both of these represent “local” approaches to landscape analysis, retaining information on the spatial properties of the surroundings within which pixels in a landscape are situated. Hence, they offer the possibility of explicitly testing the response of these indicators to changes in the spatial scale of observation, which can be very valuable when using EO data for monitoring, which is itself a highly scale-dependent approach.

These approaches to LPA, being relatively new, have not been compared against more standardly used approaches of “global”, i.e. patch, class and landscape based spatial pattern analysis, nor used in combination with these widely used approaches. Such a comparison appears extremely useful to investigate the potential of adopting EO data and associated spatial analysis techniques to provide baseline data for landscape monitoring, in order to better address conservation challenges.

The objective of this paper is to take a single case study as an illustrative example, and perform quantitative landscape structure analysis using both “global” LPI analyses and “local” pixel based approaches, in order to identify a set of indices and associated spatial scales that can be used to generate baseline data on landscape and habitat spatial arrangements that can serve as CBD/SEBI indicators (specifically for “Fragmentation of natural and semi-natural areas”), to be used within the framework of habitat monitoring in protected areas and their surroundings. Information derived from different approaches is compared with reference to its usefulness, and the possibilities of using of these indices for monitoring (either individually or in combination) are explored. While the specific set of indicators and spatial scales derived from this study will be location specific, the proposed approach for selection of site-specific and scale-specific indicators is standardisable, repeatable and robust, and can be extended to other locations with their own site-specific characteristics, conservation challenges and relevant spatial scales.

The analysis was intentionally performed by means of well established and consuetudinary techniques and the use of free

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