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Assessment of ecosystem functioning from space: Advancements in the Habitats Directive implementation

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ABSTRACT

The Habitats Directive (HD) and the Natura 2000 network establish a common framework for maintaining European natural habitats in a favourable conservation status and represent the main instrument used by conservation decision makers in the European Union. Habitat conservation status depends on the sum of the influences acting upon the habitat and its typical species that may affect its long-term natural distribution, structure and functions. Thus, ecosystem functioning is influenced by the diversity, number and functional traits of the species occurring in a habitat. Although the HD establishes that representative species should be selected to reflect favourable structure and functioning of the habitat type, it would not be realistic to associate species with all aspects of structure and functioning given the variability of Annex I habitats. This constraint led us to seek new approaches that allow a more direct assessment of the ecosystem functioning for natural habitats in space and time. We propose a remote sensing-based approach to characterize and assess the ecosystem functioning of habitats. As a case study, we applied our approach to three Mediterranean natural habitat types from the Iberian Peninsula included in Annex I of the Habitats Directive, i.e., Mediterranean sclerophyllous forest, Mediterranean deciduous forest and Sub-Mediterranean and temperate scrub. First, we estimated two key descriptors of ecosystem functioning derived from the Enhanced Vegetation Index and related them to primary production dynamics by using satellite images captured by the MODIS sensor for each year between 2001 and 2012. Second, we arranged these functional descriptors in two-dimensional space and calculated the distances from the habitats assessed to the reference sites, i.e., habitat patches that showed an optimal conservation status of composition and structure. Then, the distances were averaged over the period, and the habitats were categorized according to their mean distances as favourable or unfavourable-inadequate or unfavourable-bad, as outlined in the reporting guidelines under Article 17 of the Directive. Our approach provides new procedures to assess ecosystem functions across space and time, while complying with reporting obligations derived from the HD.

1. Introduction

The European Habitats Directive (HD) (Habitats Directive, 1992) and the associated Natura 2000 network comprise one of the most challenging conservation frameworks. Based on habitats, i.e., biodiversity elements identified at higher organizational levels than species, the HD represents a major instrument used by European conservation decision makers. It aims to maintain natural habitats in a favourable conservation status (FCS), which is periodically assessed (every six years) by the member states, under the legal obligation derived from Article 17. FCS occurs when the specific structure and functions that are necessary for a habitat's long-term maintenance exist and are likely to continue to exist for the foreseeable future (Art. 1e of the HD).Though ecosystem function is specifically considered a criterion for the FCS assessment; so far, most of the indicators used for this assessment have relied on compositional and structural attributes of habitats, such as species composition, presence/absence of typical species, or habitat spatial variation, as well as on environmental parameters (Lengyel et al., 2008). Nevertheless, the natural range of a habitat in terms of species composition may vary geographically and some characteristic species may even be entirely absent from certain areas and are still considered typical for that habitat (Mehtälä and Vuorisalo, 2007). In such cases, it would be beneficial to have more direct measures of ecosystem functioning.

The use of feasible indicators to inform about the functional dimension of a habitat's conservation status represents a major challenge

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for reporting obligations because functional indicators should be sensitive to both long-term and rapid environmental changes (Pettorelli et al., 2005; Cabello et al., 2012; Díaz et al., 2013). A rapid response to changes would be particularly useful for the monitoring programmes implemented into the Natura 2000 network because it would allow implementation of early-warning systems that enable conservation managers to actively manage in the short term (Cabello et al., 2012). As an example, the Autonomous Organization of National Parks of Spain is developing a remote sensing-based system for monitoring ecosystem functioning of national parks that informs managers of their conservation status at a fine temporal resolution (Cabello et al., 2016). In addition, Maes et al. (2012) highlighted the challenges of incorporating the monitoring of ecosystem functioning and services under current conservation schemes. These authors considered that the concept of ecosystem services has great potential in adding value to current conservation approaches. Although the quantitative relationship between ecosystem functioning and ecosystem services is still poorly clarified (Balvanera et al., 2014, 2016; Bastian, 2013), Maes et al. (2012) showed how habitats in a favourable conservation status had a higher potential to supply ecosystem services than habitats in an unfavourable conservation status. In this sense, functional indicators would help to assess the benefits provided by the Natura 2000 network (Brink et al., 2013) because they are conceptually linked to ecosystem services (Harrison et al., 2014).

To characterize the FCS, the HD promotes the identification of reference values for parameters, including range, area, structure and functions and future prospects. Reference values report the range of variability in ecological structures and processes, reflecting recent evolutionary history and the dynamic interplay of biotic and abiotic conditions and disturbance patterns (Morgan et al., 1994; Fulé et al., 1997). These conditions depict the baseline for comparative purposes and are a frame of reference for designing conservation actions (Bull et al., 2014). Therefore, an objective specification of such reference sites is crucial for properly determining a habitat's conservation status (Bull et al., 2014). To address this, long-term temporal series are necessary to determine past baselines and the extent of human-induced habitat change (Turvey et al., 2015).

Remote sensing, a cost-effective tool, can be particularly useful to address some challenges derived from the HD and can be related to ecosystem functioning dimension (Vanden Borre et al., 2011). The HD establishes that typical species should be selected to reflect favourable structure and functioning of the habitat type (Art. 1e). However, this is not realistic given the variability of the habitats included in Annex I of the Directive (Evans and Arvela, 2011) and the many species that characterize them. Beyond assessing changes in land-use or vegetation structure (Corbane et al., 2015; Schmidt et al., 2017), satellite images also provide repeated and synoptic information about the matter and energy exchanges between the biota and atmosphere, which support ecosystem functions and services. The translation of satellite spectral information into ecosystem functional attributes has been recognized as a valuable tool for conservation practice (Pettorelli et al., 2014; Cabello et al., 2012), and remote sensing-derived metrics related to changes in ecosystem functioning have been proposed as essential variables for monitoring biodiversity (Pereira et al., 2013; Alcaraz-Segura et al., 2017). Thus, remote sensing-derived functional attributes may be appropriate indicators for assessing the FCS of habitat functioning.

On the other hand, the HD establishes that reference values should be based purely on scientific grounds and adapt to changes in our knowledge of habitat types (Evans and Arvela, 2011). In addition, if knowledge is poor for a particular habitat, the reference values for each parameter can be adjusted by expert judgement using available information (Evans and Arvela, 2011). Remote sensing-derived information can help in defining reference conditions by providing temporal series at different spatial and temporal resolutions. In fact, satellite image-derived metrics related to ecosystem functioning have been used to define baseline and reference conditions in different ecosystems and regions (Stoms and Hargrove, 2000; Garbulsky and Paruelo, 2004; Dionisio et al., 2011). Some examples of remotely sensed ecosystem functions are food, water supply, and climate regulation monitored by primary production, evapotranspiration, and land surface temperature, respectively (for a review, see Pettorelli et al., 2017).

In this study, we propose a remote sensing-based approach to assess the ecosystem functioning dimension of the conservation status of habitats included in the HD. As a case study, we worked on three Mediterranean natural habitat types from the Iberian Peninsula that are included in Annex I of the Habitats Directive, i.e., Mediterranean sclerophyllous forest (code: 9340), Mediterranean deciduous forest (code: 9230) and Sub-Mediterranean and temperate scrub (code: 5120). To characterize the functional dimension of the conservation status of these habitats while adhering to the categories used in the reporting process under Article 17 of the HD (i.e., favourable, unfavourable-inadequate or unfavourable-bad), we first estimated two key descriptors of ecosystem function related to primary production and "greenness" canopy seasonality by using satellite images captured by the MODIS sensor. Second, we arranged these functional descriptors in two-dimensional functional space to calculate the distances from the assessed habitat to the reference sites identified through expert-criteria in terms of composition and structure. Finally, we categorized the habitats according to their mean distances, providing a spatially explicit characterization of the habitats in terms of the three reporting categories of conservation status.

2. Materials and methods

2.1. Study area

The study was conducted in the protected natural area of Sierra Nevada (37°09′N, 3°25′W), a Natura 2000 site that encompasses the three selected Mediterranean natural habitat types included in Annex I of the Habitats Directive (Fig. 1). The habitats differ in terms of the plant species composition and vegetation structure, the environmental conditions in which they occur, and the threats they are facing. Mediterranean sclerophyllous forest (habitat code: 9340) is dominated by the holm oak (*Quercus ilex*), a drought-resistant tree with perennial leaves. This habitat occurs between 700 and 1900 m a.s.l., and its main threats are fire, deforestation and anthropogenic reduction of habitat connectivity (Rodá et al., 2009). Mediterranean deciduous forest (habitat code: 9230) is dominated by the Pyrenean oak (*Quercus pyrenaica*), a deciduous tree that occupies humid and shadowed locations between 1000 and 2000 m a.s.l. Its presence in Sierra Nevada is considered relictic, showing an advanced state of degradation that is primarily due to deforestation and grazing (Camacho-Olmedo et al., 2002; García and Jiménez, 2009). Sub-Mediterranean and temperate scrub (habitat code: 5120) is dominated by the legumes *Genista versicolor* and *Cytisus purgans* and occurs between 1700 and 1900 m a.s.l. This habitat has shallow soils and is often associated with arborescent scrubs of *Juniperus sabina* and *J. communis*. Snow sport and leisure structures and grazing and fire have been identified as its main threats in Sierra Nevada (De la Cruz Rot, 2009).

2.2. Assessment approach

We proposed a remote sensing-based approach to characterize the ecosystem functioning dimension of habitat conservation status, using habitat patches that are considered to have an optimal conservation status in terms of composition and structure as reference sites. This is based on the fact that ecosystem functioning is influenced by species composition and structure. For example, Gross et al. (2017) have recently highlighted that diversity of the functional traits of the species occurring in a habitat maximizes ecosystem multifunctionality. In addition, structural vegetation characteristics such as plant species richness and the grass–shrub balance have also been found to play