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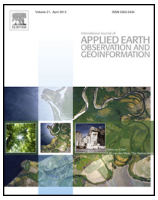

Potential of satellite-derived ecosystem functional attributes to anticipate species range shifts

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ABSTRACT

In a world facing rapid environmental changes, anticipating their impacts on biodiversity is of utmost relevance. Remotely-sensed Ecosystem Functional Attributes (EFAs) are promising predictors for Species Distribution Models (SDMs) by offering an early and integrative response of vegetation performance to environmental drivers. Species of high conservation concern would benefit the most from a better ability to anticipate changes in habitat suitability. Here we illustrate how yearly projections from SDMs based on EFAs could reveal short-term changes in potential habitat suitability, anticipating mid-term shifts predicted by climate-change-scenario models. We fitted two sets of SDMs for 41 plant species of conservation concern in the Iberian Peninsula: one calibrated with climate variables for baseline conditions and projected under two climate-change-scenarios (future conditions); and the other calibrated with EFAs for 2001 and projected annually from 2001 to 2013. Range shifts predicted by climate-based models for future conditions were compared to the 2001–2013 trends from EFAs-based models. Projections of EFAs-based models estimated changes (mostly contractions) in habitat suitability that anticipated, for the majority (up to 64%) of species, the mid-term shifts projected by traditional climate-change-scenario forecasting, and showed greater agreement with the business-as-usual scenario than with the sustainable-development one. This study shows how satellite-derived EFAs can be used as meaningful essential biodiversity variables in SDMs to provide early-warnings of range shifts and predictions of short-term fluctuations in suitable conditions for multiple species.

1. Introduction

In a world facing rapid environmental changes, anticipating impacts of climate and habitat change on biodiversity, particularly on threatened species, is of utmost relevance for monitoring and conservation (Guisan, 2014). Hence, effectively predicting the spatiotemporal patterns of change to anticipate the vulnerability of species and ecosystems have become a quest for scientists and managers, and thereby a hot topic in ecological research (Dawson et al., 2011). Currently, the increasing availability of remote sensing data offers a great potential for biodiversity assessment and monitoring (Nagendra et al., 2013; Pettorelli et al., 2016). In particular, the inclusion of satellite-derived descriptors of ecosystem functioning in Species Distribution Models (SDMs) is gaining interest (Cabello et al., 2012; Nagendra et al., 2013; He et al., 2015; Rocchini et al., 2015).

Remote sensing can provide meaningful information on species distributions through the direct detection of large species, the mapping of land-cover classes linked to species habitats, and the provision of biophysical descriptors of ecosystem functioning (Parviainen et al., 2013; He et al., 2015; Requena-Mullor et al., 2014). The latter are known as Ecosystem Functional Attributes

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(EFAs) and describe the exchanges of matter and energy between the biota and the physical environment including, among others, indicators of productivity, seasonality, and phenology of carbon gains (Alcaraz-Segura et al., 2006, 2009). The use of satellite-derived EFAs as predictor variables in SDMs has several advantages. First, EFAs offer an integrative response to environmental drivers and changes (Nagendra et al., 2013; Vaz et al., 2015), so species responses can be linked to pressures on ecosystem functioning and status (Pettorelli et al., 2005). Second, EFAs can be monitored through remote sensing (Alcaraz-Segura et al., 2006) and derived globally under common protocols at relatively high temporal and spatial resolutions (e.g. Tuanmu and Jetz 2015). Third, EFAs show a quicker response to environmental changes than structural or compositional attributes (e.g. land-cover, species richness; Mouillot et al., 2013), potentially allowing, when used as inputs in SDMs, to anticipate and provide early-warnings of future potential changes in species distributions. Fourth, with remotely sensed EFAs, both spatial and temporal (seasonal and interannual) variability can be easily included into SDMs (e.g. Tuanmu and Jetz, 2015), which has been shown to improve SDMs performance, compared to average conditions (Zimmermann et al., 2009; Fernández et al., 2012; Cord et al., 2014).

Based on the niche concept, both fundamental and realized (Araújo and Peterson, 2012), SDMs are often used to project habitat suitability and range change of species under different future scenarios of environmental conditions (Oliver et al., 2012). Climate-only-driven SDMs have been shown to provide better estimates for widely distributed species (Stockwell and Peterson, 2002), whereas for narrowly distributed species (usually rare and threatened) multiple predictors often become necessary (Lomba et al., 2010). Biodiversity monitoring and conservation can benefit from SDMs techniques (e.g. Amorim et al., 2014; Carvalho et al., 2016), but this requires models that can adequately predict potential future distributions or habitat suitability, particularly for rare and threatened species (Lomba et al., 2010; Sousa-Silva et al., 2014). Frequently, law protects these species of conservation interest and countries are subject to reporting obligations on their conservation status, trends and threats. An example of this is the Habitats Directive, a European legal framework aiming to promote the maintenance of species and habitats at a favorable conservation status (Bilz et al., 2011; Sousa-Silva et al., 2014). These assessments often include evaluations of forecasted species range shifts considering contrasting climate change scenarios. In addition, monitoring and early-warning systems often assess historical trends in the distribution of species and habitats, which may help to anticipate range changes and extinction risks (Virkkala et al., 2014).

The monitoring, management, and conservation of species of high conservation concern would benefit the most from a better capacity to anticipate the ecological effects of environmental variability. Since satellite observations can be used to derive EFAs annually (Müller et al., 2014), rates of change in habitat suitability derived from EFAs could be used as trends in the inferred distributions of species. Regions experiencing extreme interannual changes in EFAs can be considered more prone to showing fluctuations in habitat suitability, and therefore in population size, extent of occurrence, or area of occupancy (International Union for Conservation of Nature –IUCN– criteria B and C; IUCN 2012). Furthermore, in the European context, applying interannual changes of EFAs to estimate fluctuations in habitat suitability can be used to report on the conservation status of species of interest, which is required every six years under the Habitats Directive (European Commission, 1992). A comprehensive assessment of the potential effects of interannual changes of EFAs on multiple species can also be used to set priorities in multi-species monitoring schemes (Amorim et al., 2014; Carvalho et al., 2016).

Here we test the potential added value of using satellite-derived EFAs as input in SDMs to anticipate range shifts for a diverse set of plant species of conservation concern, covering different IUCN categories, range sizes, life-forms and habitats in the Iberian Peninsula. We illustrate how the annual frequency of EFAs reveals short-term changes in suitable conditions that could be used to anticipate mid-term shifts predicted by traditional climate-change-scenario models, and hence to improve biodiversity monitoring and management. SDMs fitted with EFAs were projected annually using remote-sensing observations, and SDMs fitted with climate variables were projected to two future contrasting scenarios of climate change: business as usual and sustainable-development. Since CO_2 emissions remained in the upper bound of emissions scenarios (Friedlingstein et al., 2014), we expected that changes in suitable habitat using remote-sensing observations should be closer to mid-term projected changes following a business as usual climate change scenario than a sustainable-development one. We discuss our results in the context of improving the conservation of biodiversity under environmental changes and the monitoring of ecosystem function essential biodiversity variables that are meaningful at the species level (Pettorelli et al., 2016).

2. Materials and methods

2.1. Study area and test species

The study area was the Iberian Peninsula, a very heterogeneous region in terms of biogeography, climate, orography, geology, and soil types. Such heterogeneity, its role as a Quaternary refuge, and the crossroad situation between Europe and Africa, the Mediterranean Sea and the Atlantic Ocean, have favored a unique environmental mosaic where many species with different ecological requirements coexist (Molina-Venegas et al., 2013), making this area a hotspot within the Mediterranean Basin biodiversity hotspot (Essl et al., 2013).

Our study targeted 41 plant species that are assessed due to legal obligations from the European Union Habitats Directive (Annexes II and IV), listed under the IUCN European Red List of Vascular Plants (Bilz et al., 2011) and Spanish Red List (Bañares et al., 2011). Datasets on species occurrences were available from ICNF (Portuguese Institute for the Conservation of Nature and Forests) and from the *Inventario Español de Especies Terrestres* (Spanish Ministry for the Environment), complemented with confirmed records from the ANTHOS (www.anthos.es) and FLORA-ON (www.flora-on.pt) online databases. The spatial resolution of the final dataset was the UTM 10′ × 10 km cell grid (6212 cells in the Peninsula), in agreement with the resolution required by Article 17th of the Habitats Directive for reporting (http://bd.eionet.europa.eu/activities/Reporting). As rule of thumb, a minimum of 5 occurrence records per predictor variable was considered for selecting species suitable for fitting SDMs (see section 2.2 Predictor variables; Araújo and Peterson, 2012). Accordingly, 41 plant species were selected under different IUCN (2012) categories (Table S1 in Supporting Information). The IUCN status was obtained from the European (Bilz et al., 2011) and national Red Lists (Bañares et al., 2011). For species with transboundary distribution across Portugal and Spain, expert-knowledge supported the assignment of an Iberian IUCN category by applying the relevant IUCN criteria (current status and recent trends) to the most-updated occurrence data across the Peninsula.

2.2. Predictor variables and future scenarios

Three climatic variables were selected due to their well-known role as drivers of species distributions at broader scales (e.g. Whittaker et al., 2007): annual precipitation (Prec), maximum