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JAG-975; No. of Pages 6
ARTICLE IN PRESS

International Journal of Applied Earth Observation and Geoinformation xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Very high resolution Earth observation features for monitoring plant and animal community structure across multiple spatial scales in protected areas

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
VHR EO features
Biodiversity surrogates
Functional groups
Habitat quality
Monitoring

ABSTRACT

Monitoring the status and future trends in biodiversity can be prohibitively expensive using ground-based surveys. Consequently, significant effort is being invested in the use of satellite remote sensing to represent aspects of the proximate mechanisms (e.g., resource availability) that can be related to biodiversity surrogates (BS) such as species community descriptors. We explored the potential of very high resolution (VHR) satellite Earth observation (EO) features as proxies for habitat structural attributes that influence spatial variation in habitat quality and biodiversity change. In a semi-natural grassland mosaic of conservation concern in southern Italy, we employed a hierarchical nested sampling strategy to collect field and VHR-EO data across three spatial extent levels (landscape, patch and plot). Species incidence and abundance data were collected at the plot level for plant, insect and bird functional groups. Spectral and textural VHR-EO image features were derived from a Worldview-2 image. Three window sizes (grains) were tested for analysis and computation of textural features, guided by the perception limits of different organisms. The modelled relationships between VHR-EO features and BS responses differed across scales, suggesting that landscape, patch and plot levels are respectively most appropriate when dealing with birds, plants and insects. This research demonstrates the potential of VHR-EO for biodiversity mapping and habitat modelling, and highlights the importance of identifying the appropriate scale of analysis for specific taxonomic groups of interest. Further, textural features are important in the modelling of functional group-specific indices which represent BS in high conservation value habitat types, and provide a more direct link to species interaction networks and ecosystem functioning, than provided by traditional taxonomic diversity indices.

Introduction

Over the past 50 years, the Earth's ecosystems have been altered rapidly by human pressures (Millennium Ecosystem Assessment, 2005). In addition to reducing available habitat through land-use change, humans significantly impact biodiversity through the effects of their activities on habitat quality. In particular, the degradation of habitat quality characteristics related to resource availability (e.g., nutrients, refugia), phytomass, vegetation structure and microclimate, can result in alterations in the distribution of biodiversity surrogates, BS (i.e. species community descriptors) (Nagendra et al., 2013b). However, effective measurement and monitoring of changes in habitat quality can be challenging, because 'quality' is an inherently taxon-specific attribute (Lindenmayer et al., 2002), influencing species distributions at specific combinations of scale components (extent and grain, *sensu* Kotliar and Wiens, 1990). This is why conservation managers frequently require information on changes in habitat quality, and on their impact on multiple aggregate components of biodiversity, at differing spatial scales. Yet, it can be prohibitively expensive

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http://dx.doi.org/10.1016/j.jag.2014.09.015
0303-2434/© 2014 Published by Elsevier B.V.

to obtain fine-grained habitat quality data at large spatial extents through field surveys alone.

Remote sensing enables the estimation of environmental heterogeneity at differing grains across differing spatial extents, which can then be related to variation in species diversity and distribution (Palmer et al., 2002; Nagendra et al., this issue). Of particular note has been the potential utilization of very high resolution (VHR) Earth observation (EO) imagery features to discriminate some aspects of habitat characteristics (Nagendra et al., 2013a).

Biodiversity surrogates (e.g., species presence, abundance, probability of site occupancy, aggregate measures such as species richness, diversity, or carrying capacity) can be predicted with reasonable accuracy using habitat modelling (Wintle et al., 2005; Marcot, 2006) based on remotely-sensed measures of environmental attributes (e.g., primary productivity, vegetation structure) representing habitat quality. Habitat modelling (e.g., Townsend et al., 2009; Rocchini et al., 2010; Feingersh et al., 2007) and environmental niche modelling (e.g., Peterson, 2003; Harney, 2008), are also increasingly being used to obtain information on habitat suitability with regard to both threatened and invasive species in terrestrial and marine habitats.

A range of approaches have been utilized to obtain inferences on habitat quality from remote sensing (Townsend et al., 2009; Rocchini et al., 2010; Feingersh et al., 2007; Costanza et al., 2011; Schmidtlein et al., 2012). These broadly include the use of VHR to high-resolution (HR) satellite images, and the use of spectral and spatial information extracted from the images. It is likely that BS relevant to different taxa and functional groups will exhibit different relationships with varying spectral and textural diversity measurements at different spatial scales, but the selection of methods for up-scaling and down-scaling has not been fully resolved (He et al., 2002; Wessman and Bateson, 2006).

In this paper, we explore the potential of VHR EO features to predict habitat attributes valuable for biodiversity assessment and habitat quality change detection in threatened grassland ecosystem of Southern Italy (Labadessa, 2014). We adopt a habitat modelling approach using VHR-EO features as proxies for attributes of habitat quality at multiple spatial scales, relating these to BS derived from an intensive field survey of plant, invertebrate and vertebrate taxa.

This study was developed and tested within the European Union's Seventh Framework Programme (EU-FP7) project Biodiversity Multi-SOurce Monitoring System: From Space To Species (BIO_SOS), that aimed to develop tools and models for consistent multi-annual monitoring of protected areas and their surroundings by the integrated use of RS and in-field data.

Methods

Study area

The study area is located in Southern Italy within the Natura 2000 "Murgia Alta" site (SCI/SPA IT9120007, according to EU Habitats Directive 92/43 and Bird Directive 147/2009), spanning over 125,880 ha and partly designated as a National Park in 2004 (Fig. 1). Murgia Alta, a calcareous upland where semi-natural dry grasslands cover almost 24% of the total area of the site, represents one of the most important areas for the conservation of this kind of ecosystem in Europe (Mairota et al., 2013). Such grasslands are among the most species-rich plant communities in Europe (Wilson et al., 2012) and they host a remarkable set of endemic and protected plants (included within the Habitats Directive habitat categories, codes 62A0 and 6220*), together with threatened birds and insects listed in European and national red lists (van Swaay et al., 2010). The site has developed through a mix of anthropogenic and natural processes over long periods of time, and is maintained by human activities such as livestock grazing (Turbé et al., 2010). Therefore, any shift (e.g., agricultural intensification, land abandonment) from this long-term anthropogenic disturbance regime represents a pressure (*sensu* Nagendra et al., this issue) and induces impacts on habitat availability and habitat quality (e.g., grassland fragmentation, woody encroachment) and hence on biodiversity (Sutter and Brigham, 1998; Brotons et al., 2005).

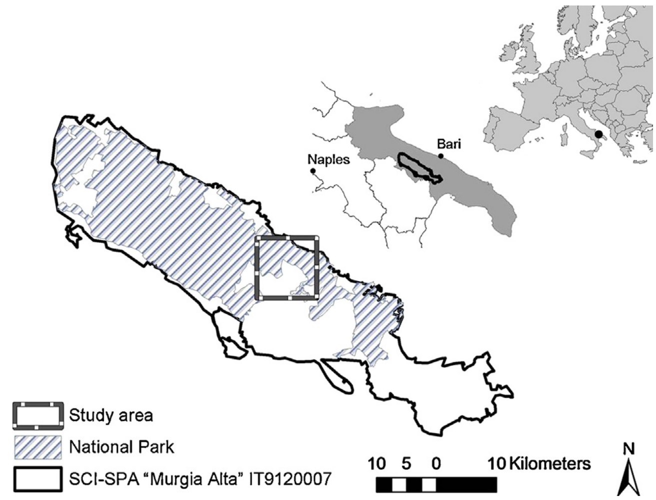

Fig. 1. Location map of the study region.

Data collection

Sampling design

A hierarchical nested sampling strategy was adopted at three spatial extent levels–landscape, patch, and plot – according to the protocols of the BIO_SOS project (Mairota et al., 2013) and following Wu and David (2002) (Fig. 2). Twenty 1 km × 1 km local landscapes (landscapes hereafter) were selected according to the fragmentation gradient (from not- to highly-fragmented, also in relation to matrix quality), of the focal habitat (Mairota et al., 2013) within a 10 km × 10 km regional landscape. Within logistical and financial constraints, 30 local ecosystems-1 (patches, hereafter, of the focal habitat), one or two per landscape, were selected, ranging in size from 0.38 to 56.28 ha, to which corresponded 30 (5 m × 80 m) randomly identified local ecosystems-2 (plots hereafter) for detailed field surveys of biodiversity.

Field data

Species occurrence and abundance were recorded along the length of each of the 30 plots for four taxonomic groups: herbaceous plants, passerine birds, orthopterans (Tettigonioidea, Acridoidea) and lepidopterans (Rhopalocera). Plants directly indicate environmental conditions and changes, birds are often linked to plant community and land cover change (Brotons et al., 2005), orthopterans represent the majority of insect biomass in the herbaceous layer (Gangwere et al., 1997) and are strongly influenced by variation in vegetation structure (Ryszkowski et al., 1993), and lepidopterans strongly respond to changes in plant diversity (Weibull et al., 2000).

Cover values of all herbaceous plant species were recorded within plots. Adults of lepidopterans and orthopterans were identified and released (Pollard, 1979). Breeding passerine birds were counted in the early morning at a central point within each plot (Bibby et al., 1992). Surveys for all taxa were repeated every two weeks from the end of March to September 2012 (12 sampling

Please cite this article in press as: Mairota, P., et al., Very high resolution Earth observation features for monitoring plant and animal community structure across multiple spatial scales in protected areas. Int. J. Appl. Earth Observ. Geoinf. (2014), http://dx.doi.org/10.1016/j.jag.2014.09.015