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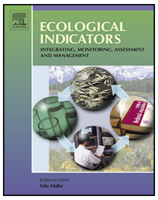

Quantifying structure of Natura 2000 heathland habitats using spectral mixture analysis and segmentation techniques on hyperspectral imagery

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ABSTRACT

Monitoring of habitat types protected under the Annex I of the EU Habitats Directive requires every 6 years information to be reported on their conservation status (area, range, structure and function) in the member states. Hyperspectral imagery can be an important source of information to assist in the evaluation of the habitats' conservation status, as it can provide continuous maps of habitat quality indicators (e.g., life forms, management activities, grass, shrub and tree encroachment) at the pixel level. Such local level information is highly needed for management purposes, e.g., the location of habitat patches and their sizes and quality within a protected site. This paper focuses on the use of continuous fraction images as derived from spectral mixture analysis of hyperspectral imagery (AHS-160), in combination with segmentation techniques, to facilitate habitat quality assessment in a heathland site in the Netherlands. This combined application of techniques on hyperspectral imagery demonstrates the usefulness of information from continuous fraction maps of grass abundance (*Molinia caerulea*) in heathlands – at and within the patch level – compared to traditional mapping techniques that assess grass encroachment in a limited number of abundance classes at the patch level. It therefore provides a better basis to monitor large areas for processes such as grass encroachment that largely determine the conservation status of Natura 2000 heathland areas. Timely, accurate and up-to-date spatial information on the encroachment of mosses, grasses, shrubs or trees (dominant species) can help conservation managers to take better decisions and to better evaluate the effect of taken measures. While discrepancies exist between the results of field-based vegetation surveys and the proposed remote sensing approach, we provide a discussion on the uncertainty of determining which of both methods is most accurate in relation to dominant species, which is in our case *Molinia caerulea*, and set forth several reasons why the remote sensing based approach might form a better basis for the monitoring of abundant species and patch evolution through time.

1. Introduction

Over the past decades, the increasing loss of biodiversity has become an issue of global concern. The European Union responded to this societal demand by initiating the creation of an ecological network of protected areas across its territory, covering valuable natural habitats and species of particular importance for the conservation of biological diversity. This network of sites has become known as the Natura 2000 network, and its legal background is found in the Council Directive 79/409/EEC on the Conservation of Wild Birds (the Birds Directive, 1979), and the Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (the Habitats Directive, 1992). EU member states are incorporating the provisions of both directives in their national legislation, and need to develop instruments and procedures to achieve the goals set forth by the Directives. This includes, amongst others, the designation and appropriate management of 'Special Areas for Conservation' (SACs), and the 6-yearly, extensive reporting on the conservation status of protected habitats and species. As such, the implementation of the Habitats Directive is currently one of the main concerns of European agencies and national and regional authorities responsible for nature conservation. While the designation of SACs has largely been completed, the design of appropriate monitoring methodologies still remains a huge challenge (Vanden Borre et al., 2011).

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The assessment of the conservation status of a habitat type is based on four parameters (European Commission, 2005; ETC/BD, 2006): (i) area, being the sum of the patch surfaces occupied by the habitat; (ii) range, being the region in which the habitat is likely to occur provided local conditions are suitable; (iii) specific structures and functions, encompassing indicators of habitat quality; and (iv) future prospects for the survival of the habitat in the member state's territory. For all these parameters, the conservation status needs to be determined as 'favourable', 'unfavourable-inadequate' or 'unfavourable-bad'. Criteria and thresholds for identifying the state of a certain parameter are provided by the European Commission (2005). From the experience of the first assessment on the conservation status of habitat types by the EU member states (ETC/BD, 2008), it became clear that the 'best available data' had many shortcomings, resulting in gaps and inconsistencies in the information provided to the EC (Evans, 2006). The inconsistency was caused by the differences between the EU member states in the interpretation of the "Explanatory Notes and Guidelines for reporting, assessment and monitoring" (ETC/BD, 2006) and in the applied methods for data collection and data analysis. This first assessment also pointed out that timely and accurate habitat monitoring is vital for assessing whether goals have been met. Comprehensive monitoring programmes that are able to meet these needs are, however, still largely missing in the EU member states. A huge challenge hence lies in developing appropriate monitoring schemes by the time of the next reporting period (the current reporting period is of 2007–2012, with reports due in 2013), in order to fill the existing information gaps and resolve the inconsistencies in information amongst member states. As financial resources are limited, the monitoring approaches need to be as cost effective and consistent as possible. Up till now, field observations have been the main source of information for the assessment of the conservation status of habitat types. As these are however both time-consuming and costly, monitoring responsibles are in search of new sources that can deliver information in a more cost-effective way (Vanden Borre et al., 2011).

Remote sensing observations can complement and add to field observations as they deliver a synoptic view and offer the opportunity to provide consistent information in time and space (Battrick, 2005, 2006; Groom et al., 2006; Nagendra, 2001; Nagendra and Rocchini, 2008; Vanden Borre et al., 2011). For the purpose of habitat monitoring, remote sensing methods and especially hyperspectral techniques are promising, but existing remote sensing data and classification methods fall short in several aspects: (i) airborne hyperspectral data are suitable (Hufkens et al., 2010; Schaepman et al., 2009; Ustin et al., 2004), but coverage is still limited; (ii) existing methods have not addressed the issue of habitat structure and functioning, which is a key factor for assessing habitat quality; and (iii) most existing remote sensing methodologies have not been tested vigorously for operational purposes. Opportunities for space-based remote sensing in habitat and biodiversity monitoring at the regional level have been reviewed by (Duro et al., 2007) and (Gillespie et al., 2008). These studies show that remotely sensed monitoring of detailed habitat quality information remains a challenging application, as this requires sensors and methods which can deal with complex transitional zones present in natural vegetation. Hyperspectral sensors offer finer spectral measurements than multispectral instruments, with often hundreds of spectral bands of narrow width being recorded, allowing a near continuous spectrum to be reconstructed for each pixel. This presents opportunities for more precise identification of biochemical and biophysical properties of the vegetation compared to when broadband multispectral sensors are used. New spaceborne hyperspectral sensors are on their way, in parallel to the existing very high spatial resolution (VHSR) multispectral sensors such as Worldview-II and (with a spatial resolution of 2 m for the 8 multispectral bands and 0.5 m for the panchromatic band). For example, Italy's ASI space agency plans to launch PRISMA, a medium-resolution hyperspectral imaging mission with about 235 channels in the visible, NIR and SWIR wavelength regions, by the end of 2013. The German Aerospace Centre (DLR) and the German Research Centre for Geosciences (GFZ) are planning to launch the EnMAP hyperspectral satellite in 2015 to map the Earth's surface in over 250 narrow wavebands. And in 2015 or 2016, NASA plans to launch the HyspIRI mission, which will acquire medium-resolution imagery across 210 spectral bands. Thus, the combination of high resolution multispectral and medium resolution hyperspectral spaceborne data are going to become increasingly available by the end of the decade and, in an endeavour of forward-planning, we will evaluate the use of high resolution hyperspectral data for habitat and vegetation monitoring, as this is anticipated to become a hot topic for the remote sensing and conservation community in the coming years.

As stated by Burnett and Blaschke (2003), natural complexity can be best explored using spatial analysis tools based on concepts of ecosystems or landscapes as process continuums, that can be partially decomposed into objects or patches. Object-based image analysis (OBIA), often referring to object-based image segmentation, classification concepts and tools, has been proposed as a strong toolset to identify, delineate, describe and label the required patches in a consistent way (Blaschke, 2010; Burnett and Blaschke, 2003). Nevertheless, OBIA techniques are in our opinion still less suitable for the assessment of continuous gradients related to structural and functional processes. Some other techniques have however been shown promising. Schmidtlein et al. (2007) for example combined ordination measures derived from floristic field data with spectral data from HyMap hyperspectral imagery to derive continuous maps which represent abrupt transitions between habitats as well as gradual transitions and within habitat heterogeneity. Another approach for continuous vegetation mapping is the use of spectral mixture analysis (SMA). In SMA, the reflectance of a single pixel is considered to be a mixture of endmembers, each with a specific spectrum, and each relating to a vegetation or species class present in the pixel. Because the same endmember can be used to analyze a time sequence, SMA has the capability to estimate changes in abundance (Li et al., 2005; Rosso et al., 2005). Hestir et al. (2008) also showed the potential of SMA to estimate the spatial distribution and abundance of invasive species and vegetation. Thus, SMA has great values for monitoring aspects related to habitat structure and function (e.g., grass encroachment), because changes in patterns can be detected and quantified.

This study assesses the integrated use of linear spectral mixture analysis and segmentation techniques on high resolution hyperspectral imagery to evaluate the structure of a heathland ecosystem under pressure, with emphasis on the specific problem of grass encroachment. The proposed approach was applied on hyperspectral AHS-160 imagery, to investigate the appropriateness of the method to characterize the spatial coverage and configuration of relevant heathland vegetation types. The results are compared with traditional vegetation mapping methods as hitherto implemented in the study area. SMA in combination with segmentation techniques is examined as a possible method that takes advantage of the high-dimensional spectral information content of imaging spectroscopy data to discriminate continuous processes, such as grass encroachment in vegetation patches in complex ecosystems. In the discussion, we specifically focus on the opportunities for remote sensing to complement the traditional vegetation field surveys.