Ecological Indicators 46 (2014) 264–285

Contents lists available at ScienceDirect

Ecological Indicators

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

Hyperspectral modeling of ecological indicators – A new approach for monitoring former military training areas

Laura Luft[a,c,*], Carsten Neumann[b], Matthias Freude[d], Niels Blaum[c], Florian Jeltsch[c]

[a] Sielmann's Naturlandschaft Döberitzer Heide gGmbH, Athener Straße 2, 14641 Wustermark, Germany
[b] Helmholtz-Zentrum Potsdam-Deutsches GeoForschungsZentrum GFZ, Section 1.4, Telegrafenberg, 14473 Potsdam, Germany
[c] Institute for Biochemistry and Biology, Department of Plant Ecology and Nature Conservation, University of Potsdam, Maulbeerallee 2, 14469 Potsdam, Germany
[d] Landesamt für Umwelt, Gesundheit und Verbraucherschutz Brandenburg, Seeburger Chaussee 2, 14476 Potsdam, OT Groß Glienicke, Germany

ARTICLE INFO

Article history:
Received 29 August 2013
Received in revised form 16 June 2014
Accepted 18 June 2014

Keywords:
Ecological health
Fauna
Flora
Hyperspectral remote sensing
Military conversion
Natura 2000 monitoring

ABSTRACT

Military areas are valuable habitats and refuges for rare and endangered plants and animals. We developed a new approach applying innovative methods of hyperspectral remote sensing to bridge the existing gap between remote sensing technology and the demands of the nature conservation community. Remote sensing has already proven to be a valuable monitoring instrument. However, the approaches lack the consideration of the demands of applied nature conservation which includes the legal demands of the EU Habitat Directive. Following the idea of the Vital Signs Monitoring in the USA, we identified a subset of the highest priority monitoring indicators for our study area. We analyzed continuous spectral response curves and tested the measurability of $N = 19$ indicators on the basis of complexity levels aggregated from extensive vegetation assemblages. The spectral differentiability for the floristic as well as faunistic indicators revealed values up to 100% accuracy. We point out difficulties when it comes to distinguishing faunistic habitat requirements of several species adapted to dry open landscapes, which in this case results in OVERALL ACCURACY of 67, 87–95, and 35% in the error matrix. In summary, we provide an applicable and feasible method to facilitating monitoring military areas by hyperspectral remote sensing in the following.

1. Introduction

The unique value of former military areas for nature conservation is increasingly recognized (e.g. Quist et al., 2003; Havlick, 2011; Warren et al., 2007). In particular, the military use "protected" these areas for decades or even centuries from habitat fragmentation by e.g. infrastructure and settlements, and land conversion by e.g. agriculture (Carvell, 2002; Walker and Pywell, 2000; Warren et al., 2007). Consequently, many former military areas have been converted into nature reserves and are protected by the European Network Natura 2000 (European Commission, 2005a; Höntsch et al., 2008). Projects advancing co-operations between military and the nature conservation community are more and more supported by the European Commission (see e.g. European Commission, 2005b) and management plans for conversion areas explicitly include the application of monitoring activities to identify changes in vegetation parameters, species diversity as well as succession processes. However, monitoring military conversion areas is particularly challenging since considerable loads of explosive contaminants remaining at the surface or invisible in the ground often exclude the application of field monitoring methods (Havlick, 2011; Walker and Pywell, 2000).

Remote sensing is regarded as a powerful tool for monitoring vegetation cover (e.g. Binner and Seitz, 2009; Frick, 2006; Förster and Frick, 2010). Still, there is a general discrepancy between the output of remote sensing data and the demands of monitoring experts (Vanden Borre et al., 2011). Vanden Borre et al. (2011) suggested a general misperception to be the main reason for this existing gap. On the one hand, ecologists and nature conservation agencies are mostly not able to interpret remote sensing data and lack expert knowledge in regard to new technologies. On the other hand, remote sensing scientists do not exactly know what kind of data are required by the nature conservation community and are

* Corresponding author at: Sielmann's Naturlandschaft Döberitzer Heide gGmbH, Athener Straße 2, 14641 Wustermark, Germany. Tel.: +49 1749690776.
E-mail addresses: lluft@uni-potsdam.de (L. Luft), carstenn@gfz-potsdam.de (C. Neumann), bdp@lugv.brandenburg.de (M. Freude), blaum@uni-potsdam.de (N. Blaum), jeltsch@uni-potsdam.de (F. Jeltsch).

http://dx.doi.org/10.1016/j.ecolind.2014.06.025
1470-160X/

therefore probably more interested in the technological development (Vanden Borre et al., 2011). Consequently, the offered data do not allow investigations at species or community level or e.g. evaluations of specific habitat requirements for selected species (see Bellis et al., 2008). Thus, in many cases, remote sensing projects remain in their initial phases and the demands of the applied nature conservation are not met (Vanden Borre et al., 2011).

To bridge the gap between remote sensing technology and the demands of the nature conservation community we developed a new approach applying innovative methods of hyperspectral remote sensing and statistical methods. Following the idea of the Vital Signs Monitoring in the USA, we identified a subset of the highest priority monitoring indicators (Vital Sings) that is characteristic for a focused area (Fancy et al., 2009). Furthermore we applied these methods to our study area, the Döberitzer Heide in Brandenburg, Germany, where it will help to monitor changes in the ecological status. The Vital Signs Monitoring is part of the US American Inventory and Monitoring Program, which aims to preserve the natural resources and wildlife of protected areas and to leave them unimpaired for future generations (Fancy et al., 2009). Existing approaches in the USA like the NPScape project and the PALMS project already aim to improve the use of remote sensing methods in concern of the Vital Signs Monitoring (see e.g. Goetz et al., 2011; Gross et al., 2009; Hansen et al., 2010). Yet, they mainly focus on Landsat data with a medium spatial resolution of 30 m and a low spectral resolution of 7 spectral bands, which to us seem inefficient for the purpose of monitoring on a smaller scale (Wang, 2012a). In order to overcome this we decided to focus on monitoring bio-indicators by hyperspectral sensor systems. Hereby, instead of defining separable entities in a classification approach, we analyzed continuous spectral response curves of concrete plant indicators and evaluated the spectral differentiability of variable complexity levels aggregated from extensive vegetation assemblages. For faunistic indicators, we selected vegetation parameters representing a favorable habitat quality and evaluated their possibility to be monitored by satellite data.

2. Approaches using remote sensing in monitoring concerns

Remote sensing methods are increasingly used for environmental monitoring (Aplin, 2005; Nagendra et al., 2013; Turner et al., 2003). Projects worldwide aim to improve the applicability of remote sensing imagery for specific nature conservation requirements (Mücher et al., 2013; Wang, 2012b; Weiers et al., 2004). Cooperations between remote sensing institutes and the nature conservation community like the “NPScape” project (by the US National Park Service and NASA) as well as projects by the Parks Canada Agency and the Canadian Space Agency demonstrate that the use of remote sensing data can facilitate monitoring and reduce the financial effort in National Parks (Gross et al., 2009). Especially Landsat data imagery has proven to be useful for monitoring natural resources (Kennedy et al., 2012; Leimgruber et al., 2005). Since they are easy (see US Geological Survey, 2013, http://landsat.usgs.gov/Landsat_Search_and_Download.php) and partly free available (see for example ESA, 2011, http://www.esa.int/Our_Activities/Observing_the_Earth/ESA_opens_Landsat_archives), consistent, cover the last decades as well as provide a good balance of spatial extent and grain (Woodcock et al., 2001; Xie et al., 2008), they are used to observe land-cover changes (see Wang et al., 2012; Woodcock et al., 2001), landscape dynamics (Schroeder et al., 2006; Kennedy et al., 2012; Zheng et al., 2006), as well as landslide and glaciers movements (Lu et al., 2012) or wildfire impacts (Michalek et al., 2000; Wang et al., 2012). Nevertheless, there seems to be a recent increasing use of hyperspectral data in combination with statistical analyses. HyMap or Hyperion images are used to monitor environmental changes in mining areas (Zhang et al., 2012) and classifications of habitat structures of semi-natural patches and grasslands in agricultural landscapes are conducted on the basis of TerraSAR-X Hugh Resolution Spotlight data (Bargiel, 2013). Camathias et al. (2013) proved the possibility to improving species richness models by using LiDAR spectral images and Mansour et al. (2012) showed how AISA Eagle data can help to assess rangeland degradations.

According to Stabach et al. (2012), the value of remotely sensed data concerning faunistic monitoring is increasing as well. Habitat conditions and grazing effects of large mammals (e.g. reindeer or horses) are monitored (Colpaert et al., 2003) and even habitat suitability for faunal species like *Pygoscelis* penguins (Cimino et al., 2012) or Greater Rheas (*Rhea americana*) (Bellis et al., 2008) or floral species as *Bromeliaceae* (Judith et al., 2013) can be estimated.

However, the gap between remote sensing techniques and applied nature conservation can only be bridged if the applied methods take the legal requirements for nature conservation and the practical work of nature conservation agencies into account. The cornerstone of the European nature conservation policy is the Natura 2000 network which is formed by the Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (the Habitats Directive, European Commission, 2005a) and the Council Directive 79/409/EEC on the Conservation of Wild Birds (the Birds Directive, European Commission, 2009). Together with the areas designated under the Habitats Directive as Sites of Community Importance (SCI), the Special Protection Areas (SPAs) designated under the Birds Directive constitute the Natura 2000 network, covering valuable species and natural habitats to face the increasing loss of biodiversity. Nevertheless, we still lack remote sensing methods supporting the conservation status assessment of protected species and habitats, which is legally demanded by the Habitat Directive in a six-year-cycle (Spanhove et al., 2012; Vanden Borre et al., 2011). Mücher et al. (2013) suggest a historical gap between the remote sensing and nature conservation community to be the reason for this delay (see also Spanhove et al., 2012; Vanden Borre et al., 2011). Vanden Borre et al. (2011) confirm the general will of monitoring experts to use remote sensing data, but point out a trade-off between its value for monitoring and the arising costs at the same time. Only a few approaches (see e.g. Mücher et al., 2013; Neumann et al., 2010; Förster et al., 2008) pushed the improvement of monitoring methods for Natura 2000 areas by remote sensing at the basis of defining indicators forward. Spanhove et al. (2012) tested the ability of fine-scale quality indicators, estimated by hyperspectral sensors, to assess the conservation status of habitats preserved by the Habitats Directive (in the following called FFH-habitats). They confirm that the combination of remote sensing methods and advanced statistical modeling techniques can be useful to generate indicators giving information on the habitat quality. This was also tested by Mücher et al. (2013), who used hyperspectral imagery to assess habitat quality at a heathland site in the Netherlands. A Natura 2000 habitat type assessment was realized for forest sides on the basis of indicator approaches (Cantarello and Newton, 2008). On our study area Döberitzer Heide in Germany, the projects SARA’04 (2003–2005) and SARA_EnMAP (2007–2009) aimed to improve environmental monitoring methods to evaluate vegetation classes conforming to land use and FFH-habitat types by high resolution data from Quickbird satellite and simulation data of EnMAP-satellite, which will be send to the orbit in 2017. From 2009 to 2012, the CARE-X project used multitemporal and multisensoral satellite data (Rapid Eye and TerraSAR-X-Satellite) to improve FFH-monitoring at the level of biogeographical areas (Frick, 2011).