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

Remote sensing for mapping natural habitats and their conservation status – New opportunities and challenges

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Satellite image analysis
Earth observation data
Natural and semi-natural habitats
European Habitats Directive

ABSTRACT

Safeguarding the diversity of natural and semi-natural habitats in Europe is one of the aims set out by the Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) and one of the targets of the European 2020 Biodiversity Strategy, and is to be accomplished by maintaining a favourable conservation status. To reach this aim a high-level understanding of the distribution and conditions of these habitats is needed. Remote sensing can considerably contribute to habitat mapping and their observation over time. Several European projects and a large number of scientific studies have addressed the issue of mapping and monitoring natural habitats via remote sensing and the deriving of indicators on their conservation status. The multitude of utilized remote sensing sensors and applied methods used in these studies, however, impede a common understanding of what is achievable with current state-of-the-art technologies. The aim of this paper is to provide a synthesis on what is currently feasible in terms of detection and monitoring of natural and semi-natural habitats with remote sensing. To focus this endeavour, we concentrate on those studies aimed at direct mapping of individual habitat types or discriminating between different types of habitats occurring in relatively large, spatially contiguous units. By this we uncover the potential of remote sensing to better understand the distribution of habitats and the assessment of their conservation status in Europe.

Introduction

Biological diversity underpins a variety of ecological functions as well as the services provided by ecosystems (Isbell et al., 2011). In recognition of this importance, the European Union adopted the Habitats Directive (92/43/EEC, short: HabDir) in order to halt the loss of biodiversity and its terrestrial and marine habitats. Since 1992, the HabDir has set the rules for developing a coherent ecological network in Europe, called Natura 2000 (EC, 1992). The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species as well as natural and semi-natural habitats.

To oversee its implementation, Article 17 of the HabDir imposes on EU member states an obligation to report in six-year intervals on the conservation status of the habitats of Community interest. In addition, the EU 2020 Biodiversity Strategy calls upon member states to digitally map and assess biodiversity and ecosystem services. Given their scope, these measures would greatly benefit from the development of more cost- and time-effective monitoring strategies (Bock et al., 2005).

Remote sensing has become an essential tool for evaluating the implementation of environmental policies (Mayer and Lopez, 2011). Together with standardized ground plots and regular in situ

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http://dx.doi.org/10.1016/j.jag.2014.11.005
0303-2434/

measurements, remote sensing is a powerful monitoring device as well. Today a broad variety and amount of data from different sensors is available, ranging from multi-resolution optical (multispectral and hyperspectral) imagery, to radar and LiDAR products. They all, in different aspects, offer useful information for mapping natural habitats and their status.

The potential for the use of current sensors in identifying habitats, obtaining information on their distribution and monitoring their conservation status is a prominent research topic. Several European and national projects (Supplementary Material Table S1) and a large number of scientific studies have addressed the issue of mapping natural habitats via remote sensing and the deriving of indicators on their conservation status.

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.jag.2014.11.005.

This paper provides a synthesis on what is currently feasible in terms of (i) the ability of remote sensing to distinguish vegetation-based habitat categories both between and within several broad physiognomic types: forest, grassland, heathland, and wetland and (ii) the use of remote sensing for assessing the conservation status of habitat types. This review focuses on techniques that aim to map and delineate distinct habitats as the public policy framework generally defines such discrete habitats. Still, deriving proxy indicators that represent structural ecological features and patterns in a continuous manner are used for assessing the conservation status (see 'Assessing the conservation status of habitats'). The review is based on a systematic literature search within the Web of Science for keywords related to nature conservation (e.g. 'Natura 2000') and specific habitat types in combination with remote sensing related terms (such as sensors or classifiers). Additionally, other sources, such as conference proceedings, known to the authors are considered. A number of issues related to the suitability of spectral, spatial and temporal resolutions of remote sensing data for habitat mapping are discussed before finally addressing the challenges and prospects in using remote sensing for mapping and monitoring habitats in Europe (Fig. 1).

Within this paper, the following definitions are used:

- Natural habitats are "terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural" (HabDir).
- Biotopes are "the smallest geographical unit of the biosphere or of a habitat that can be delimited by convenient boundaries and is characterized by its biota" (Lincoln, 1998).
- The term 'remote sensing' as used in this context comprises advanced, computer-assisted analytical tools for information extraction from satellite or airborne imagery. Thus, we exclude the purely visual interpretation of analogue or digital images.
- Spatial resolution is defined using the thresholds set by the European Space Agency (ESA) very high spatial resolution (VHR) >3 m; high resolution (HR) 3–30 m; medium resolution 30–300 m; low resolution <300 m.

Remote sensing capabilities for mapping natural habitats

According to Turner et al. (2003), there are two general approaches to the remote sensing of biodiversity: (i) direct mapping of individual organisms, species assemblages or ecological communities from airborne or satellite sensors, and (ii) indirect sensing of biodiversity-related aspects using environmental parameters as proxies. Many species are confined in their distribution to specific habitats such as woodland, grassland, or sea grass beds that can be directly identified with remote sensing data.

In general, a perfect correspondence of conventional biotope types and spectrally derived vegetation cover is rarely possible, due to the practice of manually delineating biotope types from aerial photos and field surveys (Weiers et al., 2004). Alternative classification systems such as the General Habitat Categories (Bunce et al., 2008) or the Terrestrial Ecosystem Mapping system (Johansen et al., 2007), as well as existing land use/cover schemes (Tomaselli et al., 2013), have been evaluated in order to more successfully employ Earth observation (EO) data in the classification and monitoring of habitats. However, any such system is dependent on reliable remote sensing-based methods including advanced pre-processing techniques (Baraldi et al., 2010). This section considers the ability of these methods to physiognomically distinguish between habitat types at different scales, and then addresses the capacity of remote sensing data to assess the conservation status of these habitats using the example of forest types.

Habitat mapping using remote sensing technology

In recent years, advances have been reported in the use of remote sensing technology for the mapping and the assessment of habitats in Europe (Vanden Borre et al., 2011). This applies to different broad habitat types (forests, grasslands, wetlands, etc.) and different scales of observations as fine as sub-habitat level (see Table 1). Mapping of broad habitats types using remote sensing is a common practice from the perspective of land cover mapping, and is generally done at a relatively coarse scale of analysis (Wulder et al., 2004). Global land cover mapping has been accomplished using the MODIS satellite, at 500 m resolution (Friedl et al., 2010), while country and regional level land cover classifications have been accomplished using medium resolution sensors such as Landsat or SPOT (Fuller et al., 1994; Tiede et al., 2010). However, it is possible to delineate more detailed land cover boundaries using a higher spatial resolution (Förster et al., 2010a,b), or by including ancillary data or active sensors (Kasischke et al., 1997; Dobson et al., 1992; Hatunen et al., 2008; Ali et al., 2013; Bargiel, 2013).

Another factor to consider is the complexity of landscape structure. Overall, mapping in less complex habitat mosaics is relatively straightforward (Lengyel et al., 2008), but becomes more challenging when landscapes are more heterogeneous and fine-grained and the variation between habitats is more continuous (Díaz Varela et al., 2008). Also, the complexity of landscape structure differs between protected areas and their surroundings, and thus different approaches to mapping need to be considered. As landscapes become more heterogeneous and the numbers of classes increase, direct mapping of the distribution of all major habitat types based on remotely sensed information becomes more challenging. In this case alternative indirect approaches are to be taken into account, such as modelling the relationship between species distribution patterns and remotely sensed data (Schmidtlein and Sassin, 2004; Verrelst et al., 2009; Rocchini et al., 2010).

The following sub-sections will address the abilities of remote sensing to distinguish vegetation categories, using several broad physiognomic types as examples: forest, grassland, heathland, and wetland. The examples provided, while not exhaustive, should illustrate what is currently possible. In general, the efficiency of different spatial and spectral resolutions will be discussed, as well as the use of active sensors and ancillary data.

Distinction of forest habitats

The differentiation of forest habitats is possible with a variety of image resolutions and data types, depending on the level of detail required. With low spatial resolution data only rough differentiation of the main forest cover types (deciduous, coniferous, mixed) is possible (Wessels et al., 2004; Yu et al., 2004), unless ancillary data is used (Zhiliang and Evans, 1994). However, even with its higher resolution, single-date moderate resolution multispectral imagery alone is often not sufficient for detailed forest type differentiation,