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

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a b s t r a c t

*Keywords:*

Satellite image analysis Earth observation data

Natural and semi-natural habitats European Habitats Directive

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](#_bookmark41) [et al.,](#_bookmark41) [2011).](#_bookmark41) 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

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## 1992, the HabDir has set the rules for developing a coherent eco- logical network in Europe, called Natura 2000 ([EC,](#_bookmark28) [1992).](#_bookmark28) 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 mem- ber 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](#_bookmark16) [et al.,](#_bookmark16) [2005).](#_bookmark16)

Remote sensing has become an essential tool for evaluating the implementation of environmental policies ([Mayer](#_bookmark79) [and](#_bookmark79) [Lopez,](#_bookmark79) [2011).](#_bookmark79) Together with standardized ground plots and regular in situ

## 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 (multi- spectral 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 habi- tats, 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](http://dx.doi.org/10.1016/j.jag.2014.11.005).

This paper provides a synthesis on what is currently feasi- ble in terms of (i) the ability of remote sensing to distinguish vegetation-based habitat categories both between and within sev- eral broad physiognomic types: forest, grassland, heathland, and wetland and (ii) the use of remote sensing for assessing the con- servation 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, deriv- ing 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 habi- tats’). 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). Addi- tionally, 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).](#_bookmark8)

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,](#_bookmark67) [1998).](#_bookmark67)

* 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 Euro-

pean 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](#_bookmark86) [et al.](#_bookmark86) [(2003),](#_bookmark86) there are two general approaches to the remote sensing of biodiversity: (i) direct map- ping of individual organisms, species assemblages or ecological communities from airborne or satellite sensors, and (ii) indi- rect sensing of biodiversity-related aspects using environmental parameters as proxies. Many species are conﬁned in their distribu- tion 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](#_bookmark92) [et al.,](#_bookmark92) [2004).](#_bookmark92) Alternative classiﬁ- cation systems such as the General Habitat Categories ([Bunce](#_bookmark19) [et al.,](#_bookmark19) [2008)](#_bookmark19) or the Terrestrial Ecosystem Mapping system ([Johansen](#_bookmark44) [et al.,](#_bookmark44) [2007),](#_bookmark44) as well as existing land use/cover schemes ([Tomaselli](#_bookmark85) [et al.,](#_bookmark85) [2013),](#_bookmark85) 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](#_bookmark36) [et al.,](#_bookmark36) [2010).](#_bookmark36) 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](#_bookmark88) [Borre](#_bookmark88) [et al.,](#_bookmark88) [2011).](#_bookmark88) 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).](#_bookmark7) Mapping of broad habitats types using remote sensing is a common practice from the perspective of land cover map- ping, and is generally done at a relatively coarse scale of analysis ([Wulder](#_bookmark99) [et al.,](#_bookmark99) [2004).](#_bookmark99) Global land cover mapping has been accom- plished using the MODIS satellite, at 500 m resolution ([Friedl](#_bookmark49) [et al.,](#_bookmark49) [2010),](#_bookmark49) while country and regional level land cover classiﬁcations have been accomplished using medium resolution sensors such as Landsat or SPOT ([Fuller](#_bookmark53) [et al.,](#_bookmark53) [1994;](#_bookmark53) [Tiede](#_bookmark53) [et al.,](#_bookmark53) [2010).](#_bookmark53) However, it is possible to delineate more detailed land cover boundaries using a higher spatial resolution ([Förster](#_bookmark38) [et al.,](#_bookmark38) [2010a,b),](#_bookmark38) or by including ancillary data or active sensors ([Kasischke](#_bookmark49) [et al.,](#_bookmark49) [1997;](#_bookmark49) [Dobson](#_bookmark49) [et al.,](#_bookmark49) [1992;](#_bookmark49) [Hatunen](#_bookmark49) [et al.,](#_bookmark49) [2008;](#_bookmark49) [Ali](#_bookmark49) [et al.,](#_bookmark49) [2013;](#_bookmark49) [Bargiel,](#_bookmark49) [2013).](#_bookmark49)

Another factor to consider is the complexity of landscape struc- ture. Overall, mapping in less complex habitat mosaics is relatively straightforward ([Lengyel](#_bookmark64) [et al.,](#_bookmark64) [2008),](#_bookmark64) but becomes more challeng- ing when landscapes are more heterogeneous and ﬁne-grained and the variation between habitats is more continuous ([Díaz](#_bookmark23) [Varela](#_bookmark23) [et al.,](#_bookmark23) [2008).](#_bookmark23) Also, the complexity of landscape structure differs between protected areas and their surroundings, and thus differ- ent 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](#_bookmark100) [and](#_bookmark100) [Sassin,](#_bookmark100) [2004;](#_bookmark100) [Verrelst](#_bookmark100) [et al.,](#_bookmark100) [2009;](#_bookmark100) [Rocchini](#_bookmark100) [et al.,](#_bookmark100) [2010).](#_bookmark100)

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 differentia- tion of the main forest cover types (deciduous, coniferous, mixed) is possible ([Wessels](#_bookmark94) [et al.,](#_bookmark94) [2004;](#_bookmark94) [Yu](#_bookmark94) [et al.,](#_bookmark94) [2004),](#_bookmark94) unless ancillary data is used ([Zhiliang](#_bookmark104) [and](#_bookmark104) [Evans,](#_bookmark104) [1994).](#_bookmark104) However, even with its higher resolution, single-date moderate resolution multispectral imagery alone is often not sufﬁcient for detailed forest type differentiation,

### Table 1

Evaluation of sensor’s suitability for the characterization of natural habitats (based on [Ichter](#_bookmark38) [et al.](#_bookmark38) [(2014)).](#_bookmark38) Various remote sensing techniques (sensors and resolution) are compared for mapping both between broad physiognomic types (Level 1) and within these types (Level 2). The degree of sensor suitability is indicated as follows:

− = unsuitable, −/+ = more or less suitable, + = suitable, ++ = recommended.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Low spatial resolution and very high temporal resolution (e.g., MODIS, AVHRR) | Medium to high spatial/temporal resolution (e.g., Landsat, IRS, SPOT) | Very high spatial resolution (e.g., aerial photos IKONOS, QuickBird, GeoEye, WorldView-2, Pléiades) | Hyperspectral (e.g. HyMap, CASI,Hyperion) | Laser scanning (LiDAR) | Active microwave sensors (e.g. SAR) |
| *Level 1*. | ++ | ++ | ++ | ++ | ++ | + |
| Distinction | (only in landscapes | Multitemporal imagery | (besides open | (besides open | ([García](#_bookmark58) [et al.,](#_bookmark58) [2011)](#_bookmark58) | (besides open water) |
| between broad | with large | ([Fuller](#_bookmark53) [et al.,](#_bookmark53) [1994)](#_bookmark53) | water and bare | water and bare |  | ([Kasischke](#_bookmark49) [et al.,](#_bookmark49) |
| physiognomic | vegetation patches) | including ancillary data | soil) ([Förster](#_bookmark38) [et al.,](#_bookmark38) | soil) ([Xie](#_bookmark101) [et al.,](#_bookmark101) |  | [1997)](#_bookmark49) |
| types: grass, shrub, | ([Carrão](#_bookmark20) [et al.,](#_bookmark20) | ([Hatunen](#_bookmark69) [et al.,](#_bookmark69) [2008)](#_bookmark69) | [2010a,b)](#_bookmark38) | [2008)](#_bookmark101) |  |  |
| tree | [2008),](#_bookmark20) including |  |  |  |  |  |
|  | ancillary data |  |  |  |  |  |
|  | ([Friedl](#_bookmark49) [et al.,](#_bookmark49) [2010)](#_bookmark49) |  |  |  |  |  |
| *Level 2.* | −/+ | + | ++ | ++ | −/+ | −/+ |
| Distinction within | Deciduous/ | Broad types ([Foody](#_bookmark37) [and](#_bookmark37) | Tree species | ([Asner](#_bookmark32) [et al.,](#_bookmark32) [2008;](#_bookmark32) |  | Less efﬁcient than |
| the physiognomic | Coniferous/Mixed | [Hill,](#_bookmark37) [1996;](#_bookmark37) [Brown](#_bookmark37) [de](#_bookmark37) | classiﬁcation | [Dalponte](#_bookmark32) [et al.,](#_bookmark32) | Must be combined with | multispectral |
| type Forests | forest ([Fu](#_bookmark51) [et al.,](#_bookmark51) | [Colstoun,](#_bookmark37) [2003),](#_bookmark37) | ([Immitzer](#_bookmark39) [et al.,](#_bookmark39) | [2012;](#_bookmark32) [Fusilli](#_bookmark32) [et al.,](#_bookmark32) | multispec- | imagery for species |
|  | [2010;](#_bookmark51) [Yu](#_bookmark51) [et al.,](#_bookmark51) | dominant species using | [2012),](#_bookmark39) | [2007;](#_bookmark32) [Ghosh](#_bookmark32) [et al.,](#_bookmark32) | tral/hyperspectral | identiﬁcation |
|  | [2004),](#_bookmark51) ever- | multitemporal imagery | differentiation of | [2014)](#_bookmark32) | imagery for mapping | Radar-derived |
|  | green/deciduous, | ([Wolter](#_bookmark95) [et al.,](#_bookmark95) [1995)](#_bookmark95) | structure and age |  | forest species | information on |
|  | dense/fragmented |  | classes ([Johansen](#_bookmark44) |  |  | vegetation structure |
|  | ([Achard](#_bookmark24) [and](#_bookmark24) |  | [et al.,](#_bookmark44) [2007),](#_bookmark44) |  | ++ | is complementary to |
|  | [Estreguil,](#_bookmark24) [1995),](#_bookmark24) 25 |  | multitemporal |  | Assessment of forest | the information |
|  | classes with |  | ([Key](#_bookmark52) [et al.,](#_bookmark52) [2001)](#_bookmark52) |  | parameters (stand | provided by |
|  | ancillary data |  |  |  | density, height, crown | multispectral |
|  | ([Zhiliang](#_bookmark104) [and](#_bookmark104) |  |  |  | width, crown length) ([Li](#_bookmark65) | imaging ([Saatchi,](#_bookmark99) |
|  | [Evans,](#_bookmark104) [1994)](#_bookmark104) |  |  |  | [et al.,](#_bookmark65) [2013),](#_bookmark65) species | [1997),](#_bookmark99) only moderate |
|  |  |  |  |  | distributions ([Anderson](#_bookmark30) | accuracy with radar |
|  |  |  |  |  | [et al.,](#_bookmark30) [2008;](#_bookmark30) [Jones](#_bookmark30) [et al.,](#_bookmark30) | alone ([Maghsoudi](#_bookmark75) |
|  |  |  |  |  | [2010;](#_bookmark30) [Ghosh](#_bookmark30) [et al.,](#_bookmark30) [2014)](#_bookmark30) | [et al.,](#_bookmark75) [2013)](#_bookmark75) |
| *Level 2.*Distinction within | − | ++With multi-seasonal | +With | ++Detection of | −/+ ([Bork](#_bookmark18) [and](#_bookmark18) [Su,](#_bookmark18) [2007)](#_bookmark18) | +Separation between |
| the physiognomic |  | imagery: Distinction | multi-seasonal | ﬂoristic gradients |  | natural grasslands |
| type Grasslands |  | between marshy | imagery: | ([Schmidtlein](#_bookmark100) [and](#_bookmark100) |  | and improved |
|  |  | grasslands (Molinia- or | Grassland types | [Sassin,](#_bookmark100) [2004),](#_bookmark100) |  | pastures (in Quad |
|  |  | Juncus-dominated), | with different | determination of |  | polarization) ([Price](#_bookmark91) |
|  |  | unimproved | levels of | homogenous cover |  | [et al.,](#_bookmark91) [2002b),](#_bookmark91) |
|  |  | (Festuca-dominated), | agricultural | types ([Irisarri](#_bookmark40) [et al.,](#_bookmark40) |  | mowing intensity via |
|  |  | semi-improved and | improvement | [2009)](#_bookmark40) |  | swath detection |
|  |  | improved ([Price](#_bookmark90) [et al.,](#_bookmark90) | ([Corbane](#_bookmark22) [et al.,](#_bookmark22) |  |  | ([Schuster](#_bookmark103) [et al.,](#_bookmark103) [2011)](#_bookmark103) |
|  |  | [2002a)](#_bookmark90) | [2013),](#_bookmark22) levels of |  |  |  |
|  |  |  | mowing intensity |  |  |  |
|  |  |  | ([Franke](#_bookmark48) [et al.,](#_bookmark48) [2012)](#_bookmark48) |  |  |  |
| *Level 2*. Distinction within the | − | ++With multi-seasonal | ++Seasonal | ++Distinction | −/+Only if types differ in | − |
| physiognomic type |  | imagery: Distinction | phenological | between: | structure or density |  |
| Heathlands |  | between heath types | variation can | dry and wet | ([Hellesen](#_bookmark72) [and](#_bookmark72) |  |
|  |  | (e.g. *Genista*, *Erica*, . . .) | discriminate the | heathland, | [Matikainen,](#_bookmark72) [2013)](#_bookmark72) |  |
|  |  | ([Lucas](#_bookmark71) [et al.,](#_bookmark71) [2007),](#_bookmark71) | evergreen | heathland types |  |  |
|  |  | four heath types, | *Calluna vulgaris* | (*Calluna*, *Molinia* |  |  |
|  |  | including ancillary data | from the deciduous | *Deschampsia*, *Erica*, |  |  |
|  |  | ([Morán-Ordón˜ ez](#_bookmark81) [et al.,](#_bookmark81) | *Vaccinium myrtillus* | etc.) and heather |  |  |
|  |  | [2012)](#_bookmark81) | ([Mac](#_bookmark76) [Arthur](#_bookmark76) [and](#_bookmark76) | age classes |  |  |
|  |  |  | [Malthus,](#_bookmark76) [2008)](#_bookmark76) | ([Thoonen](#_bookmark82) [et al.,](#_bookmark82) |  |  |
|  |  |  |  | [2013)](#_bookmark82) |  |  |
| *Level 2.* Distinction within the type | − | +Seasonal imagery | +Detection of | ++Distinction | −/+To be combined with | − |
| Wetlands |  | allows mapping the | riparian vegetation | between aquatic | multispectral imagery. |  |
| Note: Wetlands are |  | spatial extent of | species ([Belluco](#_bookmark12) | macrophyte | High precision |  |
| not a physiognomic |  | seasonally submerged | [et al.,](#_bookmark12) [2006),](#_bookmark12) | species (*Typha*, | LiDAR-derived digital |  |
| type per se but are |  | wetlands and some | shallow, | *Phragmites*, *Scirpus*) | terrain map is used to |  |
| various |  | vegetation species | submerged | ([Schmidt](#_bookmark102) [and](#_bookmark102) | build the relationship |  |
| physiognomic |  | ([Bock,](#_bookmark17) [2003;](#_bookmark17) | vegetation ([Dogan](#_bookmark26) | [Skidmore,](#_bookmark102) [2003;](#_bookmark102) | between wetland |  |
| types that have |  | [Davranche](#_bookmark17) [et al.,](#_bookmark17) [2010),](#_bookmark17) | [et al.,](#_bookmark26) [2009)](#_bookmark26) | [Rosso](#_bookmark102) [et al.,](#_bookmark102) [2005;](#_bookmark102) | vegetation species and |  |
| adapted to the |  | freshwater swamp |  | [Belluco](#_bookmark102) [et al.,](#_bookmark102) [2006;](#_bookmark102) | associated ground |  |
| continuous or |  | vegetation ([Harvey](#_bookmark68) [and](#_bookmark68) |  | [Jollineau](#_bookmark102) [and](#_bookmark102) | elevation. This may |  |
| temporary |  | [Hill,](#_bookmark68) [2001),](#_bookmark68) functional |  | [Howarth,](#_bookmark102) [2008)](#_bookmark102) | enhance the |  |
| presence of water |  | wetland types ([Mac](#_bookmark73) |  |  | understanding of the |  |
|  |  | [Alister](#_bookmark73) [and](#_bookmark73) [Mahaxay,](#_bookmark73) |  |  | characteristics of |  |
|  |  | [2009)](#_bookmark73) |  |  | different wetland |  |
|  |  |  |  |  | vegetation species |  |
|  |  |  |  |  | ([Prisloe](#_bookmark93) [et al.,](#_bookmark93) [2006)](#_bookmark93) |  |



**Fig. 1.** Overall structure of this review article.

## due to the lack of spectral separability between forest subtypes ([Foody](#_bookmark37) [and](#_bookmark37) [Hill,](#_bookmark37) [1996).](#_bookmark37) This type of differentiation is only possible through the inclusion of ancillary data such as terrain ([Woodcock](#_bookmark98) [et al.,](#_bookmark98) [1994)](#_bookmark98) or the use of a time series ([Wolter](#_bookmark95) [et al.,](#_bookmark95) [1995;](#_bookmark95) [Grignetti](#_bookmark95) [et al.,](#_bookmark95) [1997).](#_bookmark95) However, this level of analysis is ultimately limited by the respective spatial resolution of the sensor being used.

More detailed analyses have been performed using high spatial resolution sensors. This scale of analysis allows for the inclusion of image texture, which has proven to vary signiﬁcantly between tree species and age classes at the canopy level ([Johansen](#_bookmark44) [et al.,](#_bookmark44) [2007;](#_bookmark44) [Immitzer](#_bookmark44) [et al.,](#_bookmark44) [2012).](#_bookmark44) The use of a time series with high spatial resolution data helps distinguish between individual trees, through the use of phenological characteristics such as leaf development and senescence ([Key](#_bookmark52) [et al.,](#_bookmark52) [2001).](#_bookmark52)

The use of hyperspectral imagery allows for an even greater level of detail, enabling the distinction of tree types based on reﬂectance in response to pigment, nutrient, and structural dif- ferences between species ([Asner](#_bookmark32) [et al.,](#_bookmark32) [2008).](#_bookmark32) However, this is greatly inﬂuenced by spatial resolution, as a balance must be found between the within-class variability of VHR imagery (through features such as branches, shadow, and undergrowth) and the between-class spectral mixing of low resolution imagery ([Nagendra,](#_bookmark85) [2001;](#_bookmark85) [Underwood](#_bookmark85) [et al.,](#_bookmark85) [2007;](#_bookmark85) [Nagendra](#_bookmark85) [and](#_bookmark85) [Rocchini,](#_bookmark85) [2008).](#_bookmark85) Spectral unmixing is possible for lower resolution sensors but is limited by the respective sensitivity of the sensor ([Fusilli](#_bookmark55) [et al.,](#_bookmark55) [2007).](#_bookmark55)

One strategy to tackle this variability is the use of object-based image analysis (OBIA). This is typically done through the combi- nation of spectral behaviour and texture, either from the details available through high spatial resolution imagery ([Johansen](#_bookmark44) [et al.,](#_bookmark44) [2007;](#_bookmark44) [Strasser](#_bookmark44) [et al.,](#_bookmark44) [2014)](#_bookmark44) or through the inclusion of data from active sensors such as LiDAR ([Jones](#_bookmark47) [et al.,](#_bookmark47) [2010;](#_bookmark47) [Ghosh](#_bookmark47) [et al.,](#_bookmark47) [2014)](#_bookmark47) or SAR ([Wolter](#_bookmark97) [and](#_bookmark97) [Townsend,](#_bookmark97) [2011).](#_bookmark97) However, active sensors alone have generally proven less successful at making distinctions ﬁner than forest stand-level ([Ranson](#_bookmark96) [and](#_bookmark96) [Sun,](#_bookmark96) [1994;](#_bookmark96) [Saatchi,](#_bookmark96) [1997;](#_bookmark96) [Li](#_bookmark96) [et al.,](#_bookmark96) [2013).](#_bookmark96)

Independent from the sensor category, the detection of forest habitat is nearly always limited to the detection of tree species and related habitat composition. However, this may problematic for those forest habitat categories which differ by their understory

vegetation, such as *Stellario-Carpinetum* and *Galio-Carpinetum* which are both oak-hornbeam forest types. These limitations could be reduced by using additional geo-data, such as soil data ([Förster](#_bookmark41) [and](#_bookmark41) [Kleinschmit,](#_bookmark41) [2014),](#_bookmark41) but relying solely on remote sensing data limits the capacity to distinguish these habitats.

*Distinction of grassland habitats*

In contrast to forests, grassland species are detectable primarily as assemblages, and may occur in complex mixtures within habi- tats. Thus, direct remote sensing approaches are generally limited to the detection of relatively homogenous grassland habitat types ([Irisarri](#_bookmark40) [et al.,](#_bookmark40) [2009).](#_bookmark40) Instead, indirect approaches have been found to be successful, such as those that use environmental gradients ([Fuller](#_bookmark53) [et al.,](#_bookmark53) [1994)](#_bookmark53) or usage intensity for mowed semi-natural grasslands ([Schuster](#_bookmark103) [et al.,](#_bookmark103) [2011).](#_bookmark103)

Moderate spatial resolution sensors such as Landsat Thematic Mapper (TM) and Landsat-7 Enhanced Thematic Mapper (ETM+) were used by [Lucas](#_bookmark71) [et al.](#_bookmark71) [(2007)](#_bookmark71) and [Price](#_bookmark90) [et al.](#_bookmark90) [(2002a)](#_bookmark90) for the classiﬁcation of grasslands. However, this has only allowed for a broad level of class distinction in terms of level of improvement such as unimproved vs. semi-improved grasslands.

Higher spatial resolution imagery, using an object-based approach with ancillary data such as elevation and soil type, has proven successful in differentiating between a few dominant grassland species ([Laliberte](#_bookmark59) [et al.,](#_bookmark59) [2007),](#_bookmark59) although other grassland habitats are more difﬁcult to distinguish ([Corbane](#_bookmark22) [et al.,](#_bookmark22) [2013).](#_bookmark22) For relatively homogeneous grasslands, the use of a spectral–temporal library (instead of training areas) with multitemporal HR data has been shown to accurately differentiate grassland types; still, object-based classiﬁcation methods have been shown to perform better for more heterogeneous grassland types ([Förster](#_bookmark45) [et al.,](#_bookmark45) [2012).](#_bookmark45) Dominant grassland species have also been distinguished using high-order derivatives of hyperspectral imagery ([Yamano](#_bookmark100) [et al.,](#_bookmark100) [2003).](#_bookmark100) However, such imagery may be better applied to determine ﬂoristic gradients, proven to be more useful in habitat identiﬁ- cation than single species classiﬁcations ([Schmidtlein](#_bookmark100) [and](#_bookmark100) [Sassin,](#_bookmark100) [2004).](#_bookmark100) Given this, the necessity of hyperspectral imagery has been debated, as recent research has shown that the spectrum from vis- ible to short-wave infrared is the most signiﬁcant for detecting wet

and dry grassland ﬂoristic gradients ([Feilhauer](#_bookmark34) [et al.,](#_bookmark34) [2013).](#_bookmark34)

Active sensors alone have had little success in differentiating un-managed grassland types, in particular for structurally homoge- nous grasslands ([Hill](#_bookmark74) [et al.,](#_bookmark74) [1999;](#_bookmark74) [Price](#_bookmark74) [et al.,](#_bookmark74) [2002b;](#_bookmark74) [Bork](#_bookmark74) [and](#_bookmark74) [Su,](#_bookmark74) [2007),](#_bookmark74) although moderate success may be possible with a high-resolution time series ([Metz](#_bookmark80) [et al.,](#_bookmark80) [2012).](#_bookmark80) Additionally, multi- temporal active systems are useful in detecting indirect indicators, such as the number of swaths per year, in the case of semi-natural grasslands managed by mowing ([Schuster](#_bookmark103) [et al.,](#_bookmark103) [2011).](#_bookmark103) Further- more, derived topographical and textural features have been shown to improve upon grassland classiﬁcations when combined with spectral data ([Bork](#_bookmark18) [and](#_bookmark18) [Su,](#_bookmark18) [2007).](#_bookmark18)

*Distinction of heathland habitats*

Generally, heathland habitats are characterized by a mixture of ericaceous dwarf shrub species (e.g. *Calluna vulgaris*), grass- land species and open soil. Since all three components can be reliably spectrally distinguished, these habitats are rather straight- forward to detect and to monitor. However, if the differentiation is between subtypes, such as wet and dry heathland types, these vegetation classes have been shown to have poor spectral sep- arability using moderate resolution imagery ([Díaz](#_bookmark23) [Varela](#_bookmark23) [et al.,](#_bookmark23) [2008).](#_bookmark23) Better results have been obtained with the use of a habitat model, where data such as elevation and precipitation were included ([Morán-Ordón˜ ez et al., 2012](#_bookmark81)). Another successful approach was able to differentiate several heathland types through an object-based segmentation based on cadastral data, effectively incorporating anthropogenic boundaries into the classiﬁcation pro- cess ([Lucas](#_bookmark71) [et al.,](#_bookmark71) [2007).](#_bookmark71)

In general, OBIA has successfully been applied to high spatial resolution imagery in identifying dominant heather areas ([Förster](#_bookmark40) [et al.,](#_bookmark40) [2008;](#_bookmark40) [Mac](#_bookmark40) [Arthur](#_bookmark40) [and](#_bookmark40) [Malthus,](#_bookmark40) [2008).](#_bookmark40) In combination with other indicator species, this can be used to differentiate between heathland habitats ([Förster](#_bookmark40) [et al.,](#_bookmark40) [2008).](#_bookmark40) However, this approach is limited by the inability of remote sensing to detect in detail the full indicators used to determine heathland habitat types. Simi- lar, more detailed approaches have been done using hyperspectral imagery ([Thoonen](#_bookmark82) [et al.,](#_bookmark82) [2013),](#_bookmark82) where kernel-based reclassiﬁca- tion was used to transform the resultant land cover classes into heathland habitats.

Few speciﬁc studies have been performed regarding the use of active sensors in detecting heathland habitats. For example, the use of LiDAR to distinguish between tree, shrub, and grassland forms ([Hellesen](#_bookmark72) [and](#_bookmark72) [Matikainen,](#_bookmark72) [2013)](#_bookmark72) enables the differentiation of heathland habitats, if combined with spectral data. High resolu- tion multi-channel SAR has been shown to have similar capabilities ([Bargiel,](#_bookmark13) [2013).](#_bookmark13)

*Distinction of wetland habitats*

Wetland vegetation is characterized by high spatial and spec- tral variability, and is inﬂuenced by soil moisture, atmospheric moisture, and the respective hydrological properties of the wet- land type. This makes traditional vegetation mapping approaches based on the mid-to-near infrared range difﬁcult, due to the rela- tively higher absorption of this wavelength by water ([Adam](#_bookmark25) [et al.,](#_bookmark25) [2009).](#_bookmark25) Nevertheless, medium resolution imagery such as Landsat has been used to classify broad wetland habitat types ([Mac](#_bookmark73) [Alister](#_bookmark73) [and](#_bookmark73) [Mahaxay,](#_bookmark73) [2009).](#_bookmark73) Additionally, the use of ancillary data such as soil type, combined with multispectral imagery, can be used to help differentiate spectrally similar classes ([Bock,](#_bookmark17) [2003).](#_bookmark17) In terms of mapping dominant species, high spatial resolution imagery was successful ([Everitt](#_bookmark33) [et al.,](#_bookmark33) [2004;](#_bookmark33) [Belluco](#_bookmark33) [et al.,](#_bookmark33) [2006),](#_bookmark33) including submerged vegetation types ([Dogan](#_bookmark26) [et al.,](#_bookmark26) [2009).](#_bookmark26) Thus, it is con- sidered to be more suitable than hyperspectral imagery ([Belluco](#_bookmark12) [et al.,](#_bookmark12) [2006).](#_bookmark12) Additionally, LiDAR has been used alone to perform genus-level wetland classiﬁcation ([Zlinszky](#_bookmark105) [et al.,](#_bookmark105) [2012),](#_bookmark105) as well as

in combination with VHR imagery for object-based classiﬁcation ([Prisloe](#_bookmark93) [et al.,](#_bookmark93) [2006).](#_bookmark93)

Still, for a more detailed differentiation between wetland habitat types, hyperspectral imagery has proven more useful at a sufﬁ- ciently high spatial resolution ([Adam](#_bookmark25) [et al.,](#_bookmark25) [2009).](#_bookmark25) For example, [Schmidt](#_bookmark102) [and](#_bookmark102) [Skidmore](#_bookmark102) [(2003)](#_bookmark102) indicated that it is possible to dis- tinguish between 27 types of salt marsh vegetation using spectral signatures. However, it is still difﬁcult to distinguish between sub- merged vegetation types, due to factors such as water turbidity, depth, and bottom reﬂectance ([Jollineau](#_bookmark46) [and](#_bookmark46) [Howarth,](#_bookmark46) [2008).](#_bookmark46)

*Assessing the conservation status of habitats*

Even more challenging than detecting the correct species, vege- tation community or habitat, yet of high relevance for conservation managers, is the detection of information about the conservation status of habitat types ([Mücher](#_bookmark83) [et al.,](#_bookmark83) [2013).](#_bookmark83) Since this informa- tion is not always directly linked to a certain habitat class, effective and salient indicators are required. National quality parameters for monitoring the conservation status are deﬁned by differ- ent European states, such as Austria ([Ellmauer,](#_bookmark29) [2005),](#_bookmark29) Belgium ([T’Jollyn](#_bookmark80) [et al.,](#_bookmark80) [2009),](#_bookmark80) France ([Conservatoire des Espaces Naturels,](#_bookmark21) Languedoc-Roussillon, 2012), Denmark ([Søgaard](#_bookmark75) [et al.,](#_bookmark75) [2007)](#_bookmark75) and Germany ([Balzer](#_bookmark35) [et al.,](#_bookmark35) [2008).](#_bookmark35) In most cases, the conservation status is assessed by habitat structures (e.g. horizontal and vertical varia- tion, age structure), presence of typical species (mostly ﬂora) in the habitat, abiotic factors (e.g. ﬂooding) and pressures on or distur- bances of the habitat type (e.g. eutrophication indicators, invasive species).

[Table 2](#_bookmark9) gives an example of how to assess the conservation sta- tus for forests according to the German monitoring guidelines at the same evaluation scale as [Table 2.](#_bookmark9) For a variety of the given conserva- tion parameters, such as ‘percentage of characteristic tree species’, it is possible to derive the respective status by means of remote sensing. Besides VHR data, the use of LiDAR data at different res- olutions (pulses/m2) seems crucial to derive speciﬁc parameters related to forestry. Especially for the detection of surface changes through erosion and different forest development stages, this type of data is clearly required. The assessment of conservation sta- tus was proved in several studies (see [Table 2).](#_bookmark9) However, not all relevant parameters can be detected, e.g. ‘habitat trees’, very old and degraded living microhabitat-bearing trees with hollows for nesting.

The assessment of certain conservation status parameters is likewise possible for other habitat types. Heathlands have been studied extensively in this respect ([Frick,](#_bookmark50) [2007;](#_bookmark50) [Delalieux](#_bookmark50) [et al.,](#_bookmark50) [2012;](#_bookmark50) [Spanhove](#_bookmark50) [et al.,](#_bookmark50) [2012;](#_bookmark50) [Mücher](#_bookmark50) [et al.,](#_bookmark50) [2013).](#_bookmark50) For grasslands, recent advances have been made in monitoring grassland use intensity ([Schuster](#_bookmark103) [et al.,](#_bookmark103) [2011;](#_bookmark103) [Franke](#_bookmark103) [et al.,](#_bookmark103) [2012)](#_bookmark103) and shrub encroachment ([Langanke](#_bookmark61) [et al.,](#_bookmark61) [2007;](#_bookmark61) [Förster](#_bookmark61) [et al.,](#_bookmark61) [2014).](#_bookmark61) Other indicators remain a challenge, especially since most of them are based on the detection of single species or species groups. Solu- tions may be found in alternative, remote sensing based indicators that correlate well with ﬁeld-based indicators of habitat conserva- tion status, and thus could be used as proxies ([Vanden](#_bookmark88) [Borre](#_bookmark88) [et al.,](#_bookmark88) [2011;](#_bookmark88) [Strasser](#_bookmark88) [et al.,](#_bookmark88) [2014).](#_bookmark88) Also, more effort should be put into developing a coherent and operational method which produces in a single workﬂow most or all relevant parameters to assess the conservation status within the Natura 2000 network.

**Challenges and opportunities in using remote sensing for mapping and monitoring habitats in Europe**

The presented study on habitat mapping ([Table 1)](#_bookmark7) show how remote sensing can contribute substantially to the mapping and

### Table 2

Suitable methods for detecting conservation status of forest. Parameters correspond to the German monitoring guidelines of Burkhardt (2004) – (++ = suited; + = applicable;

− = not applicable).

Policy-based assessment parameters

Parameters acquired by remote sensing

Conditions/constraints Method Resolution dependent feasibility

References

Spectral Temporal Spatial Ancillary data

and LiDAR

Medium to high spatial (e.g. Spot5)

Very high spatial (QuickBird)

### Detection of habitat

Main forest

NIR-band Vegetation ≤15 m DEM

GIS-based

++ + [Förster](#_bookmark42) [et al.](#_bookmark42)

### extent and change of habitats

types or tree species

period

Forestry Site Map

Further soil maps

modelling in combination with classiﬁcation

[(2005)](#_bookmark42)

### Forest composition parameters

*Habitat structures* [Maltamo](#_bookmark78) [et al.](#_bookmark78)

[(2005)](#_bookmark78)

Number of forest

Tree heights

Vegetation <5 m LiDAR Analysis of

− ++

development stages (e.g. for 9110: >3; 2;

less than 2)

Structural characteristics

period

height related to age classes Object-based analysis

Number of habitat trees (e.g. for 9110: ≥6; ≥3;

– − −

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| <3 per ha) |  |  |  |  |  |  |  |  |  |
| Number of dead trees Canopy gap(e.g. for 9110: >3; >1; mapping | NIR-band | Winterimage | <1 m | LiDAR | Support VectorMachines | − | + | [Nuske](#_bookmark86) [et al.](#_bookmark86)[(2009)](#_bookmark86) |
| ≤1 per ha) Deadwood |  |  |  |  | Manual |  |  | [Leiterer](#_bookmark62) [et al.](#_bookmark62) |
| detection |  |  |  |  | delineation |  |  | [(2013)](#_bookmark62) |
| *Availability of typical Species in the Habitat* |  |  |  |  |  |  |  |  |
| Percentage of characteristic tree | Tree species | NIR-band | Vegetation ≤1 m period | DEMForestry Site | Integrated classiﬁcation | − | ++ | [Förster](#_bookmark40) [et al.](#_bookmark40) [(2008)](#_bookmark40) |
| species (e.g. ≥90%; |  |  |  | Map | approach (e.g. |  |  | [Simonson](#_bookmark76) [et al.](#_bookmark76) |
| ≥80%; ≥70% of beech |  |  | LiDAR | Fuzzy Logic) |  |  | [(2013)](#_bookmark76) |
| for habitat type 9110 | ) |  |  |  |  |  |  | [Korpela](#_bookmark56) [et al.](#_bookmark56) |
|  |  |  |  |  |  |  |  | [(2010)](#_bookmark56) |
| Quality of understory layers | Tests for single species (e.g. |  | ≤1 m | LiDAR | LiDARintensities | − | (+) | [Korpela](#_bookmark57) [(2008)](#_bookmark57) [Korpela](#_bookmark54) [et al.](#_bookmark54) |
|  | Lichen) |  |  |  |  |  |  | [(2009)](#_bookmark54) |
| Faunal quality*Disturbances of the* | – |  |  |  |  | − | − |  |
| *habitat type*Disturbances of soil and Gully mapping hydrology (e.g.erosion) |  |  | LiDAR | LiDAR last pulse | − | + | [James](#_bookmark43) [et al.](#_bookmark43) [(2007)](#_bookmark43) |
| Disturbances of forest Tree species structure (e.g. changes Successional | NIR-band | Vegetation ≤1 m period | DEMForestry Site | Object-based and | − | ++ | [Hajek](#_bookmark66) [(2008)](#_bookmark66) |
| in relief, inﬂuence of | stages of forest |  |  | Map | knowledge- |  |  |  |
| neighbouring |  |  |  | LiDAR | based |  |  |  |
| vegetation) |  |  |  |  | classiﬁcation |  |  |  |
| Disturbances caused by Fragmentation forest fragmentation indices |  | Vegetation ≤15 m period | Existing Land Cover Maps | Landscape metrics | ++ | ++ | [Mairota](#_bookmark77) [et al.](#_bookmark77) [(2013)](#_bookmark77) |
| (e.g. road building)) |  |  |  |  |  |  |  |  |

## monitoring of biodiversity and to meeting the requirements of environmental policies and transnational strategies. Surprisingly, the use of remote sensing for accurate, detailed and com- plete conservation status assessment and monitoring of natural habitats, such as required in the European Natura 2000 con- text, is still rarely exploited in practice ([Vanden](#_bookmark88) [Borre](#_bookmark88) [et al.,](#_bookmark88) [2011).](#_bookmark88)

As shown in this paper, several studies were successful in map- ping and monitoring habitats at the site level. But only few studies in Europe have persuasively used remote sensing techniques for habitat mapping at the regional and national levels ([Lucas](#_bookmark70) [et al.,](#_bookmark70) [2011).](#_bookmark70) It seems that the technology remains a ‘blunt tool’ ([Plummer,](#_bookmark89) [2000)](#_bookmark89) requiring a signiﬁcant amount of multidisciplinary research

and joint understanding in order to reach its full potential. The major obstacles for coming up with standardized scientiﬁc mon- itoring methodologies for habitat monitoring are presented in the following paragraphs.

Overall, the immense versatility of remote sensing techniques and products has led to numerous potential approaches, but all of them are to a great extent affected by a series of potential ﬂaws ([Grillo](#_bookmark63) [and](#_bookmark63) [Venora,](#_bookmark63) [2011):](#_bookmark63)

1. the large variability in the quality of input variables in terms of their semantic, thematic and geometrical accuracy;
2. the possible variability of the spectral, spatial and temporal resolutions of the input datasets used across different studies;
3. the (non-) availability of remote sensing data and ancillary data, with standardized metadata formats and pre-processing protocols, which are a prerequisite for the transferability of the methods between the sites;
4. the (non-)availability of ground truth data in a suitable for- mat for remote sensing applications (which differs from purely vegetation-based ﬁeld mapping).

An additional obstacle is that, despite the tremendous progress in the applications of remote sensing to habitat mapping, many data types discussed here (hyperspectral, LiDAR and Radar) might currently be beyond the capabilities of most researchers and biodi- versity practitioners. Furthermore, the costs for imagery and other geospatial data products are still fairly high with an overall trend to decline due to market competition. The trend is supported by recent release of free VHR imagery (e.g. USGS released Orbview-3 data in January 2012[1)](#_bookmark10) or the upcoming ESA Sentinel series of satellites ([Berger](#_bookmark14) [et al.,](#_bookmark14) [2012).](#_bookmark14) The availability of free geospatial data (e.g. the Open Street Map initiative[2](#_bookmark11) and open-source image processing and GIS software and tools (e.g. Orfeo Toolbox, Quantum GIS, GRASS, R, etc.) is also contributing to the democratization of remote sensing and to the decline in the costs of the image processing packages. Still, an even greater challenge for ecologists and conservation biol- ogists is the technical expertise required to handle imagery and other data products ([Turner](#_bookmark86) [et al.,](#_bookmark86) [2003).](#_bookmark86)

Nowadays, new software tools make remote-sensing data more accessible. The OBIA framework is facilitating this task by try- ing to model how humans interpret aerial or satellite imagery ([Blaschke,](#_bookmark15) [2010).](#_bookmark15) Automated image segmentation, in the context of OBIA approaches, can help reducing the amount of time spent in digitization a common practice in many nature conservation agencies, given the rules to delineate the boundaries are transfer- able. The automated generation of boundaries ideally applied to well calibrated input imagery, can be adapted to the target scale, considering minimum mapping unit requirements or generaliza- tion issues ([Lang](#_bookmark60) [et al.,](#_bookmark60) [2009).](#_bookmark60) In addition, OBIA can be used to address the hierarchical structure inherent to spectrally hetero- geneous, composite habitat classes while lower level segments provide the building blocks as relational object features in a pro- cess called class modelling ([Tiede](#_bookmark84) [et al.,](#_bookmark84) [2010).](#_bookmark84) While the image segmentation process may sometimes confuse apparent objects in the image (such as shadows) with real-world objects, it can gener- ally be seen as more consistent (in terms of objectivity) and precise (in terms of edge demarcation in raster images) than manual dig- itization ([Kampouraki](#_bookmark48) [et al.,](#_bookmark48) [2008).](#_bookmark48) OBIA gains further usability by integrating real-world cartographic objects, such as the cadastral boundaries used by [Tiede](#_bookmark84) [et al.](#_bookmark84) [(2010)](#_bookmark84) or other ancillary data such as soil type ([Laliberte](#_bookmark59) [et al.,](#_bookmark59) [2007).](#_bookmark59)

The missing direct relationship between habitats and land cover classes ([Groom](#_bookmark64) [et al.,](#_bookmark64) [2006)](#_bookmark64) poses further challenges to standard- ized monitoring methodologies. With the use of expert knowledge, it has been demonstrated with varying success how different land cover classiﬁcation systems can be translated into habitat classiﬁ- cation systems such as EUNIS or General Habitat Categories (GHC) ([Tomaselli](#_bookmark85) [et al.,](#_bookmark85) [2013;](#_bookmark85) [Adamo](#_bookmark85) [et al.,](#_bookmark85) [2014)](#_bookmark85) via the Food and Agri- cultural Organization land cover classiﬁcation system (LCCS). This type of approach, once operational, would support the standard- ization necessary to compare data temporally and spatially across the EU.

Another obstacle for the standardization of monitoring method- ologies is the absence of studies on the typical surface area range in which most patches of a given habitat occur ([Vanden](#_bookmark88) [Borre](#_bookmark88) [et al.,](#_bookmark88)

1 [http://www.usgs.gov/newsroom/article pf.asp?ID=3070](http://www.usgs.gov/newsroom/article_pf.asp?ID=3070).

2 <http://www.openstreetmap.org/>.

## [2011).](#_bookmark88) Characterization of the intrinsic scales of natural habitats is necessary for their spatial identiﬁcation with remote sensing tech- niques (and even in the ﬁeld). For instance, the following issues have been reported on the problems of mapping the habitats listed in Annex I of the HabDir ([Evans,](#_bookmark31) [2006):](#_bookmark31)

1. many habitats as part of a dynamic system co-occur in a mosaic pattern which makes their systematic discrimination and the assessment of their extent difﬁcult;
2. Annex I includes habitats that may occur at scales or in associa- tions that preclude satisfactory delineation and categorisation ([The](#_bookmark81) [Heritage](#_bookmark81) [Council,](#_bookmark81) [2005);](#_bookmark81)
3. many of them are based on the descriptive informa- tion available to the CORINE Biotopes project. Only where phytosociological descriptions were available for vegeta- tion communities, these were incorporated into the habitat descriptions, so some of the habitat descriptions bear little resemblance to the local variants of the habitats.

[Vanden](#_bookmark88) [Borre](#_bookmark88) [et al.](#_bookmark88) [(2011)](#_bookmark88) argue that even if a standardized typology becomes available for Europe, it is unlikely that such a typology could also become the standard legend for all remote sensing derived habitat maps in the short term. Linkages between remote sensing and in situ habitat observation require intensive efforts to bridge the mutual understanding against different back- grounds and speciﬁc interests. To support those linkages, [Adamo](#_bookmark27) [et al.](#_bookmark27) [(2014)](#_bookmark27) propose a framework for the use of LCCS and EO data to automatically generate GHC maps, which could be used to improve the spatial focus of ﬁeld campaigns. The ﬁeld data could then be used to reﬁne the GHC mapping efforts. On a practical level, the Working Group 7 of the Group on Earth Observations Biodiversity Observation Network (GEO BON) is striving to set-up a platform that aims at bridging in situ observations of biodiver- sity with satellite remote sensing by networking super-sites and related observation networks ([Suzuki](#_bookmark79) [et al.,](#_bookmark79) [2010).](#_bookmark79) Such strate- gies need to be integrated into a common information framework, encompassing relationships at different scales.

**Concluding remarks: towards (new) solutions?**

If we are to stem the on-going and escalating loss of biodiver- sity, we need to understand its spatial distribution, expressed by habitats and species, and to identify hotspots of high conserva- tion need. This review article demonstrated that remote sensing is undoubtedly a powerful complementary source of information on biodiversity, when included with ﬁeld surveys or inventories. It is a relatively inexpensive means for deriving complete spatial cov- erage of environmental information over large areas in a consistent manner and with regular updating possibilities.

Despite all the recent advances in remote sensing techniques and the launch of new sensors, there is still limited, but increasing evidence of the use of these tools by ecologists and conservation biologists in their routine tasks and for reporting on habitat con- servation status in the framework of the HabDir. To even more overcome cultural or communication-related barriers, there are further steps to be taken it seems:

* 1. The use of a common language to ﬁll communication gaps between those who deliver information and those who use it: This can be fostered through the use of a platform or facility for sharing ideas, data and information (similar to the GEO BON platform or the geodata platforms generated by the projects MS.MONINA and BIO SOS).
	2. The provision of remote sensing derived information tailored to the needs of those in charge of the management of natural sites: This can be accomplished through cooperation between

remote sensing experts and ﬁeld researchers providing expert knowledge ([Adamo](#_bookmark27) [et al.,](#_bookmark27) [2014).](#_bookmark27)

* 1. The format in which information produces to get incorpo- rated into existing spatial data infrastructures: This applies to appropriate metadata and deﬁnition of thematic features, information on accuracy and conﬁdence of the datasets, appropriately scaled representation, semantic and geometric generalization, etc.
	2. The information products to enable updates: The current practice of generating maps relies on a combination of infor- mation derived from different remote sensing sensors as well as the occasional incorporation of ancillary data, which make updating complex and costly.
	3. Remote sensing research to be more tailored to policy support,

e.g. the Aichi Biodiversity Targets ([Secades](#_bookmark104) [et al.,](#_bookmark104) [2013):](#_bookmark104) Prod- ucts should be packaged and communicated appropriately for a better impact on policy and practices, including services deliv- ering products with spatially explicit change analyses and alerts in ‘near real time’.

Conclusively, to make full advantage of remote sensing, stake- holders including remote sensing experts, ecologists, conservation biologists, policy makers, protected area managers, conserva- tion consultants, etc. need to collaborate in interdisciplinary and transdisciplinary manner. As recommended by [Pettorelli](#_bookmark87) [et al.](#_bookmark87) [(2014),](#_bookmark87) integrative approaches with pro-active knowledge trans- fer between the remote sensing and ecological communities are needed to make remote sensing information products a real asset.

**Acknowledgements**

This work has been carried out in the framework of the FP7 SPACE project MS.MONINA (Multi-scale Service for Moni- toring Natura 2000 Habitats of European Community Interest). The research leading to these results has received funding from the European Community‘s Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 263479. The authors are grateful to numerous constructive comments from anonymous reviewers and the handling Guest Editor.

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