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Heathland conservation status mapping through integration of hyperspectral mixture analysis and decision tree classifiers

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ABSTRACT

Monitoring the conservation status of natural habitats is an essential aspect of effective conservation management. Not only data on habitat occurrence are needed, but also detailed information on the structural and functional characteristics of the habitat patches is crucial for an adequate conservation status assessment. Classification of hyperspectral remote sensing images performs well in discriminating dominant land cover and vegetation classes, but the accuracy drops significantly for the classification of more subtle differences in conservation status that are related to structural characteristics. This study proposes a method to facilitate ecological conservation status assessment based on decision tree modeling of subpixel fraction estimates steered by ecological expert knowledge. In particular, it contributes to the spatially explicit assessment of an important structural aspect of dry heathland vegetation, namely the heather age structure, using Airborne Hyperspectral line-Scanner radiometer (AHS-160) data of the Kalmthoutse Heide in northern Belgium. We implemented a subpixel unmixing approach to identify the percentage of heather, sand and shadow in each heather pixel, and subsequently applied a decision tree classification to allocate each pixel to a certain age class. As such, our method provides a tool that contributes to the information required for an appropriate management and successful conservation of natural heathlands.

1. Introduction

Knowledge on the conservation status of natural areas is essential to guide site managers in their management decisions. Specific management actions may be needed to counteract observed effects of environmental pressures, while zones in excellent condition may benefit from a continuation of the existing management. Since species richness is closely linked to habitat structure, variation in the structure of the vegetation is needed to maintain high levels of biodiversity. This is especially true for heathland, which is a dwarf shrub dominated vegetation type predominantly growing on nutrient poor soils in coastal climates. In Western Europe, heathland occurrence is almost always caused by historical anthropogenic land use. In the past, European heathlands extended over several millions of hectares, but due to the cessation of traditional agricultural practices and changes in land use, the total heathland area has decreased significantly over the last 150 years (Odé et al., 2001; Webb, 1998). As a result, the remaining "islands" of heathland have become even more vulnerable to isolation, increased grass and tree encroachment, high levels of atmospheric deposition of pollutants, and occasional uncontrolled wildfires (Anderson, 1995; Webb, 1990). The loss and degradation of heathland has caused many fauna and flora species, closely associated with the habitat, to become rare and isolated (Desender et al., 2010; Piessens & Hermy, 2006). In order to preserve the historical, ecological and aesthetic conservation value of heathlands, European environmental policies have introduced a formal protection of heathland habitats under the Habitats Directive. Many heathland remnants were designated as Special Areas of Conservation (SAC), contributing to the coherent European ecological network of SACs, referred to as the Natura 2000 network (Anon, 1992). This EU-wide network, comprising all SACs designated by Member States under the Habitats Directive, aims at assuring the long-term survival of Europe's most valuable and threatened species and habitats. Within this framework, European Member States are obliged to report every 6 years on the conservation status of, amongst others, the heathland habitats on their national territory. As a result, an important challenge with the implementation of the Habitats Directive and the Natura 2000 network, lies in the design of accurate, simple and repeatable methods for habitat and species monitoring as a basis for reporting.

In areas with a favorable conservation status, heathlands show a complex structural variation, which is a prerequisite to provide a habitat for many rare and specialized plant and animal species. Important indicators of heathland quality are the amount of grass and tree encroachment, optimally being less than 10% (T'jollyn et al., 2009), the

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age structure of heather (*Calluna vulgaris*) which is preferably mixed, and the presence of typical species. To date, most conservation status assessments are based on field observations and/or aerial photo interpretation (Vanden Borre et al., 2011). This survey driven approach is however very labor-intensive and time-consuming, and hence not suitable to be repeated frequently. For example, for the Flemish region of Belgium (Flanders), one of the smaller sub-national administrative units in Europe, covering an area of approximately 13 500 km^2, it took more than 10 years of intensive fieldwork to realize the Biological Valuation Map (BVM), a uniform field-driven land cover and vegetation map at a scale of 1/10.000 (Vriens et al., 2011). Relying entirely on this map to comply with the European Natura 2000 legislation, would mean that it should be updated every 6 years, which is simply not possible with the current field methods. Next to labor-intensity, survey-driven approaches are further complicated by the limited accessibility of many protected areas (i.e., because of remoteness, difficult terrain, military use). Moreover, despite efforts to apply strict rules for field mapping, inter-observer errors remain an issue (e.g. Hearn et al., 2011). Remote sensing, in contrast, is considered as a valuable, accurate and repeatable tool to aid in the mapping and monitoring of habitat types and their conservation status assessment (Alexandridis et al., 2009; Bock et al., 2005; Cantarello & Newton, 2008; Förster et al., 2008; Frick et al., 2005; Gross et al., 2009; Mehner et al., 2004; Newton et al., 2009; Ramsey & Jensen, 1996; Roughgarden et al., 1991; Zomer et al., 2009). Researchers have already successfully used remote sensing for broad heathland mapping for more than 20 years (e.g., Wardley et al., 1987). More recently, Hooftman and Bullock (2012) presented a way to quantify the scale and pattern of habitat loss in heathlands by analyzing patterns of habitat changes over a large scale with remote sensing data. They thereby introduced the first step towards a more quantitative framework to support conservation planning decisions on a broad scale. While pixel-based remote sensing techniques have been used to map heathland cover successfully, they are at present sub-optimal or inappropriate for accurate, and complete conservation status assessment and monitoring of natural heathland habitats at a local scale, such as required in the European Natura 2000 context (Spanhove et al., 2012). This also explains why these in-depth conservation status assessment studies still are rarely exploited (Vanden Borre et al., 2011) and sometimes even questioned by ecologists. Or as McDermid et al. (2005) formulated: "The resource manager requires a variety of information products at a wide range of scales but is unsure of the capabilities of remote sensing and GIS".

Conventional satellite and airborne hyperspectral optical remote sensing classification methods indeed suffer from important limitations for detailed habitat conservation status mapping (Spanhove et al., 2012). A major drawback is the limited degree of detail that can be monitored. Lucas et al. (2007) were able to map most homogeneous habitats with an accuracy of over 80% using rule-based classification, but the accuracy dropped with increasing complexity and for less well-defined habitats. Similarly, a more detailed study on heathland habitats performed by Haest et al. (2010) illustrated that conservation status indicators related to dominant vegetation species (e.g. *Molinia* encroachment) can be mapped successfully using pixel-based classification methods on hyperspectral AHS imagery. However, for more specific indicators associated to species related vegetation structures (such as *Calluna* heath age classes), difficulties arise and classification accuracies drop. The key issue relates to the procedure itself, in which it is assumed that each pixel is exclusively occupied by just one feature (Fisher, 1997). Because of the specific age-related vertical and horizontal spatial characteristics of heath (see Section 2.2), the incorporation of subpixel classification or unmixing in the remote sensing analysis may therefore be the right tool to move beyond the pixel-based limitations for habitat conservation status assessment, thereby exploiting these inherent characteristics.

The current study, which is an extension of the work performed by Haest et al. (2010), aims at improving the assessment of the conservation status of dry heathland habitats by clarifying the relation between *Calluna* age classes and subpixel fraction estimates for sand, shadow and *Calluna*. To this end, a three-step algorithm was developed. First, a conventional supervised classification of the whole study area was performed, allowing the selection of heather-dominated pixels. Second, for each heather pixel, the subpixel composition of sand, shadow and *Calluna* was calculated using a Multiple Endmember Spectral Mixture Analysis (MESMA) (Roberts et al., 1998). Finally, a decision tree classification of the unmixing results was performed to reveal details about the structural characteristics of different heather age classes and hence allowing to turn it into a map product for conservation management planning.

2. Materials and methods

2.1. Study area

The Kalmthoutse Heide (51° 24′ 0″ N, 4° 25′ 0″ E) is situated 25 km north of Antwerp (Flanders, Belgium), next to the Dutch border. The central heath part of almost 1000 ha is one of the largest remaining heathlands in Flanders containing a mixture of wet and dry heath, inland sand dunes and water bodies (De Blust & Slootmaekers, 1997). It is the core of the 2000 ha protected complex heath and forest landscape of the *Kalmthoutse Heide* nature reserve and the 6000 ha Dutch-Flemish cross-border nature park '*De Zoom–Kalmthoutse Heide*'.

De Kalmthoutse Heide is recognized as a heathland of international importance under the Ramsar convention, and is, together with the neighbouring heath, pools and forests in The Netherlands, designated as a special Bird and Habitat Protection Site under the European Nature Directives (De Blust, 2007). Natura 2000 habitat types that are well represented are: dry sand heaths with *Calluna* and *Genista* (Habitats Directive Annex I code: 2310), inland dunes with open *Corynephorus* and *Agrostis* grasslands (2330), northern Atlantic wet heaths with *Erica tetralix* (4010), European dry heaths (4030), depressions on peat substrates of the *Rhynchosporion* (7150), natural dystrophic lakes and ponds (3160), and old acidophilous oak woods with *Quercus robur* on sandy plains (9190).

Appropriate management of this heathland area is needed to counteract the impacts of acidification, eutrophication and dessication (Diemont & Oude Voshaar, 1994). Due to the cessation of traditional land use and the substantial increase of atmospheric deposition, nutrients accumulate in the heath (Terry et al., 2004). As a consequence, purple moorgrass (*Molinia caerulea* (L.) Moench) has spread rapidly and has become dominant in the dwarf shrub vegetation (Aerts & Heil, 1993), resulting in a loss of suitable habitat for a large number of animals.

2.2. Heather life cycle

In western Europe, heather (*Calluna vulgaris* (L.) Hull) is a dominant species in dry heathlands. Its life cycle (Fig. 1) can be divided into four more or less distinctive stages: a (i) pioneer, (ii) building, (iii) mature and (iv) degeneration phase (Barclay-Estrup & Gimingham, 1969; Watt, 1955). The pioneer phase consists of low plants, recently established or in their early growth. Through the building and the mature phase, the plants grow higher and branches become densely foliated. Depending on the nutrient availability, heights of about 60 cm, rarely up to 1 m, can be attained (Watt, 1955). In the degeneration phase (from 15 years of age onwards in the Low Countries; Weeda et al., 1988), the branches start to defoliate, the stems spread apart and the plant finally dies off. As a result of the opening of the bush, light reaches the bare soil and litter underneath, stimulating the growth of mosses and lichens and eventually the colonization by new seedlings of heather. So, heather morphology strongly differs between development stages, with each phase creating different microclimatic conditions and microhabitats which provide shelter or food to different