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Original Articles

Sub-metric analisis of vegetation structure in bog-heathland mosaics using very high resolution rpas imagery

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ABSTRACT

This work presents a methodology based on Remotely Piloted Aircraft Systems (RPAS) RGB imagery for the analysis and characterization of the structure and condition of complex habitat mosaics of high conservation value in mountain wetlands. Structure from Motion (SfM) image reconstruction techniques were applied on a collection of RGB photographs to derive ultra-high resolution (2,5 cm) digital surface models and ortho-mosaics. Geographical object-based image analysis (GEOBIA) was used for the automatic discrimination of vegetation types for habitat condition assessment via multi-scale object-oriented classifications integrating machine-learning classification techniques with other decision rules. In particular, four vegetation classes were assessed, namely woody vegetation (scrub plants higher than 10 cm), bog herbaceous vegetation, non-bog herbaceous vegetation (as part of wet heathland vegetation mosaics) and areas with scarce or no vegetation (rocky habitats and areas of bare ground). The outputs of the classification were validated against field data of detailed vegetation coverage survey. Results allowed us the automatic and accurate discrimination of habitat types with different management demands, e.g. wet heaths against bogs, as well as the diagnosis of structural characteristics critical for their conservation, such as the ratio of cover herbaceous/woody species or the presence of erosion features.

1. Introduction

Upland heathland and bog mosaics, frequently termed under the general denomination of moorlands, are an example of wetland habitats with complex dynamics both spatially and temporally. Such complexity is in many cases increased due their dependence on land management, and particularly due their pastoralist use, including practices like grazing, burning, cutting and sodding (Barclay-Estrup and Gimingham, 1969; Bullock and Pakeman, 1997; Gimingham, 1975). Their conservation condition relies on a delicate balance in their management regimes, particularly on the livestock grazing intensity and the regulation of woody biomass, and environmental factors (Bokdam and Gleichman, 2000; Bokdam et al., 2002; Izco et al., 2006; Muñoz et al., 2014; Fagúndez, 2016). These habitats are particularly sensitive to the interaction of drivers operating at different spatial scales, such as local land use dynamics and the global scenario of climate change (Holden et al., 2007). A gradient of management regimes along with heterogeneity in topography, water table, soils, or even atmospheric deposition, often configure a complex mosaic of vegetation patches with diverse vegetation structure and species composition. These patches might vary in extent from metric and sub-metric area to hundreds of hectares with either sharp transitions or gradual and broad ecotones depending on the environmental spatial dynamics. Hence, sustainable management of such mountain wetlands of high conservation value, included in the Annex I of the European Union Council Directive 92/43/EEC (Habitat Directive) as priority habitats, requires a deep knowledge of their characteristics and dynamics with a level of detail enough to capture small scale particularities.

The development of effective and efficient methods for the monitoring of high biodiversity value and vulnerable habitats is a key issue for setting up effective conservation measures. In particular, the Article 11 of the above mentioned European Union Habitat Directive imposes to all the EU Member States the evaluation and monitoring of habitats and species important for biodiversity and listed in the Annexes II, IV and V. In addition, according Article 17, the EU Member States have to report periodically (every 6 years) the conservation status of the

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Directive Habitats of Interest with special reference to the status and trends of species populations or habitats and for providing information on main pressures and threats. Even though the conservation status should be reported in a given format, Member States are free to use different means and methods for data collection, as long as the resulting data proves useful for the reporting under Article 17. Besides, and in a broader scope, the EU 2020 Biodiversity Strategy requires Member States to map and assess biodiversity and their associated ecosystem services. Hence, these measures confirm the need of developing more cost- and time-effective monitoring strategies, being remote sensing a particularly suited data source for this purpose (Bock et al., 2005; Corbane et al., 2015; Vanden Borre et al., 2011). Legal requirements for the reporting on habitat condition include an inventory of the extent and location of the habitat types, structure and functions, as well as range and future prospects.

Remote sensing has shown advantages over traditional mapping techniques based exclusively on field surveys, namely the exhaustive and systematic covering of the territory, periodical data acquisition and the possibility of recording spectral information in different regions of the electromagnetic spectrum (Chuvieco, 2002; Zonneveld, 1988). In this sense, habitat mapping could be addressed with reasonable accuracy using medium and high resolution optical multispectal remote sensing imagery (Petrou et al., 2015; Vanden Borre et al., 2011). Yet, both the internal structure and functions of the habitat frequently demand data sources with a higher spatial and spectral resolution (Delalieux et al., 2012; Haest et al., 2010; Hufkens et al., 2010; Mücher et al., 2013Spanhove et al., 2012) and/or other data sources, such as 3D point clouds (Hellesen and Matikainen, 2013; Simonson et al., 2013; Vierling et al., 2008; Zlinszky et al., 2015). Within this context, the effective conservation of complex patterned habitat mosaics as wet heaths and bogs, demand accurate, detailed and spatial explicit information on their vegetation structure for supporting the adequate design of management plans and conservation measures. This information should also be generated in such a way to enable an easy integration of both the landscape scale, i.e. taking into account the composition and configuration of the landscape mosaic, and the habitat scale, with reference to the internal structure of the vegetation at each habitat patch.

Remote sensing applications for very high or ultra-high resolution habitat assessment are in most cases focused on the discrimination of habitat patches including in some cases subcategories of degradation (e.g. grass or tree/scrub encroachment, erosion) of a given habitat (Gonçalves et al., 2016). Some examples on heathland habitats rely in complex classifications based on costly very high resolution (2.4 m) hyperspectral airborne imagery either using spectral unmixing (Delalieux et al., 2012; Mücher et al., 2013; Spanhove et al., 2012) or fuzzy classification probabilities (Hufkens et al., 2010) in order to ascertain subpixel characteristics of the heathlands. Others are based on multitemporal high resolution Airborne Laser Scanner datasets for the supervised classification of vegetation types and conservation indicators (Zlinszky et al., 2015).

The Remotely Piloted Aircraft Systems (RPAS) emerge as a flexible and cost effective alternative for remote sensing environmental survey with an unprecedented spatial resolution. They combine the advantages of the traditional remote sensing exhaustive mapping and the level of detail reached by fieldwork, filling in the scale gap between field-based observations and full-scale airborne or satellite observations (Lucieer et al., 2014). In fact, the civil applications of RPAS, such as high-resolution image acquisition, have emerged as an attractive option for agriculture, forestry and environmental monitoring, offering advantages such as cost savings, endurance, flexibility and resolution (Anderson and Gaston, 2013; Díaz-Varela et al., 2015; Laliberte et al., 2010a,b; Michez et al., 2016; Salamí et al., 2014). In particular, the combination of RPAS imagery with methods based on Structure from Motion (SfM) consumer grade RGB camera photo-reconstruction, enable the generation of digital surface models (DSM) and orthophotograph mosaics with high spatial and temporal resolution at a relatively low cost of acquisition and processing. This technology is particularly suitable for detailed environmental monitoring due its simplicity, low weight and low cost of the sensors required for SfM image reconstruction. Recent developments of miniaturized and low-cost inertial sensors, GPS devices and embedded computers implemented in RPAs and ultra-high or hyper-spatial resolution (Michez et al., 2016; Turner et al., 2014) offer new opportunities for monitoring.

In the light of the above-mentioned concerns, in the present work we aimed at the development and validation of a spatial explicit methodology for the characterization of the vegetation structure and habitat condition assessment at a detailed scale (2.5-centimetre resolution) in a complex patterned mosaic of wet heathland and bog mosaic, using ultra high resolution imagery acquired by RGB consumer grade cameras on board of RPAS.

More precisely, we integrated SfM image reconstruction techniques to derive digital surface models and ortho-mosaics and GIS and geographical object-based image analysis (GEOBIA) for the automatic estimation of the discrimination and coverage estimation of vegetation types in habitat condition assessment. Four vegetation classes were assessed, namely woody vegetation (scrub plants higher than 10 cm), bog herbaceous vegetation, non-bog herbaceous vegetation (as part of wet heathland vegetation mosaics) and areas with scarce or no vegetation (rocky habitats and areas of bare ground). The methodology was validated by comparing the classification results against quadrat-based detailed vegetation coverage reference data.

2. Material and methods

2.1. Study area

Study area spans an area of 22 ha located in the western slope of the main hill range of the Xistral Mountains (Northern Mountains of Galicia, NW Spain) (Fig. 1), with altitudes ranging from 771 to 901 m a.s.l. The environmental importance of the overall setting of these mountains has been recognised so that a significant part of its surface is included in the Natura 2000 Network as “Serra do Xistral” Special Area of Conservation (SAC) and in the UNESCO Biosphere Reserve “Terras do Miño”, holding the southernmost active blanket bogs of the Atlantic Biogeographical Region.

Climatic conditions in the study area are predominantly oceanic, with high precipitations well distributed throughout the year as rainfall and fogs, and with a gradient from mild to cold temperatures. The Regional potential vegetation is oak or mixed deciduous forests, but wind-exposed hyper-humid slopes at higher altitudes were hardly tree-colonised; rather, they were covered by wet heaths and bogs. Environmental constraints caused the dominance of extensive land uses in a significant part of this mountain system. Free livestock grazing takes place in upland wet heathlands and bogs, where grazing pressure and land use regimes define their structure and floristic composition (Cillero et al., 2016; Díaz Varela et al., 2008; Izco Sevillano et al., 2001). The most important recent landscape transformations in Xistral Mountains are afforestation, establishment of artificial grasslands and wind farms (Calvo-Iglesias et al., 2006; Calvo Iglesias et al., 2007; Diaz-Varela et al., 2007).

The dominant vegetation in the study area are a complex mosaic of acidic mires (blanket and raised bogs) and wet heathlands. Blanket bogs are a dense grassland formation dominated by sedges, being these mountains the southernmost European limit of the distribution of the habitat. The most frequent species are common cotton sedge (*Eriophorum angustifolium*) and the endemic species of the Iberian NW *Carex durieuii*, along with the grass *Molinia caerulea*. The presence of *Eriophorum angustifolium* and the endemic *Carex durieuii* makes these environments also singular in the South Atlantic context in comparison with the Blanket bogs of Ireland and Scotland, (Izco Sevillano et al., 2001; Rodríguez Guitián et al., 2009). Raised bogs are characterized by an important