Ecological Indicators 60 (2016) 906–920

Contents lists available at ScienceDirect

Ecological Indicators

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

Micro-topography driven vegetation patterns in open mosaic landscapes

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 25 June 2015
Accepted 17 August 2015

Keywords:
LIDAR
Grasslands
Topographic Position Index (TPI)
Topographic Wetness Index (TWI)
Hortobágy

ABSTRACT

Elevation models based on remotely sensed data, especially high-resolution Digital Terrain Models (DTMs) generated using airborne laser scanner (ALS) data, are increasingly being used for the analysis of plant diversity patterns in open landscapes. The vegetation pattern of alkali landscapes shows a high correlation with the position of water table and salt accumulation, which are strongly correlated with topographic variations occurring at a small spatial scale of a few decimetres (micro-topography). In this study we classified eight grassland associations in an alkali landscape based on a DTM generated from ALS data at a pixel size of 0.25 m, and 30 variables derived from the DTM, using an ensemble learning method (Random Forest). Our aim was to identify the micro-topographic variables which could be indicators of vegetation pattern in alkali landscapes. The associations range from *Cynodon* pastures (short dry grasslands on soil with low salt content) occupying the highest elevations to *Beckmannia* meadows (wet grasslands on soils with moderate salt content composed of tall grass species) at the lowest elevations, with an elevation difference of approximately 1.2 m between the two. Apart from slope, aspect and curvature, we used Topographic Wetness Index (TWI), and Topographic Position Indices (TPI) at various kernel sizes ranging from 50 cm to 500 m for the classification. The eight associations were also grouped into four aggregated categories — loess grasslands, alkali steppes, open alkali swards and alkali meadows — for further analysis. Vegetation of the studied alkali landscape could be classified into the eight associations with an accuracy of κ: 0.56, and into the four aggregated categories with an accuracy of κ: 0.77 using all the variables. Sequential backward and forward selections of variables were implemented to reduce the number of variables while maximising the accuracies, resulting in increased accuracies of κ: 0.72 and κ: 0.83 for the associations and aggregated categories using six and three variables respectively. TPI at different kernel sizes, previously used to explain vegetation distribution in mountainous areas, was found to be a better indicator of vegetation types than absolute elevations in lowlands where the elevation differences are more subtle. Two characteristic features of the study area — erosional channels and alkali steps — could also be delineated using micro-topographic variables. The results point to the possibility of large-area mapping and monitoring of grasslands where micro-topography is an indicator of vegetation, using only the elevation data from ALS.

1. Introduction

Grasslands harbour a large variety of plant and animal taxa, in addition to providing ecosystem services such as regulation of soil erosion, pollination and carbon sequestration (Egoh et al., 2011). Approximately 50% of the endemic plant species of Europe are associated with grasslands (Veen et al., 2009). European semi-natural grasslands hold a high biodiversity, and are closely linked to centuries-long agricultural practices (Dengler et al., 2014). Land use changes favouring intensive land use over traditional management techniques have resulted in habitat degradation, fragmentation and overall loss of biodiversity in European semi-natural grasslands (Valkó et al., 2011). Given the rapid loss of global biodiversity, it is essential to find efficient methods for the mapping and monitoring of grassland habitats, which can support the design and implementation of conservation measures (Lewis et al., 2014).

Vegetation patterns in open landscapes such as salt marshes, mires and alkali grasslands are often influenced by elevation and

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http://dx.doi.org/10.1016/j.ecolind.2015.08.030
1470-160X/

environmental factors determined by micro-topography (Deák et al., 2014a; Korpela et al., 2009; Moeslund et al., 2011, 2013b; Ward et al., 2013). Altitudinal zonation of vegetation typically occurs in mountainous regions (Ashton, 2003; Grytnes, 2003; Lomolino, 2001), which is more related to the environmental trends on the topographic gradients than any direct relationship between elevation and vegetation (Day and Monk, 1974). The principle of altitudinal zonation at the larger scales in mountainous regions seems to occur at a much smaller scale in grasslands (Deák et al., 2015; Kelemen et al., 2013).

Alkali landscapes of the Pannonian basin are one of the best-preserved over a large contiguous area, where several plant associations co-exist in a complex mosaic-like pattern (Eliáš et al., 2013). The vegetation pattern shows a high correlation with the position of water table level and the level of salt accumulation; these factors in turn are highly correlated with the topography (Valkó et al., 2014). In addition to these factors several micro-topographical features typical to alkali landscapes shape the distribution of these associations; the two most typical features are alkali steps (Appendix 1A) and erosional channels (Appendix 1B).

Alkali steps, features with sudden cliff-like steep slopes, are created by the erosion of the topsoil layer (A horizon) of the solonetz soil. The erosion is generally initiated by some mechanical disturbance, mainly caused by the trampling of herbivores and in some cases by the pressure of wheels, and further carried forward by the flow of surface water. The erosion results in sharp differences in the elevation, generally in the range of 20–30 cm. The length of these features usually ranges from a few metres to more than 20 m in length. As there is a significant contrast between the abiotic parameters (e.g. humus, salt content and water balance) of the upper and lower part of the alkali steps they always form sharp borders between different vegetation types. Due to the special environmental conditions alkali steps hold a narrow, but very specific vegetation characterised by species (such as *Kochia prostrata* and *Artemisia santonica*) adapted to moderate salt content and drought (Molnár and Borhidi, 2003).

The eroded soil is transported from the alkali steps to the alkali marshes by the other characteristic feature of this landscape — erosional channels; they are shallow and narrow features, usually 10–20 cm deep and 30–50 cm wide, with low vegetation cover. Erosional channels are characterised by a wet muddy surface in the spring which completely dries out for midsummer followed by a moderate salt accumulation. Accordingly vegetation of erosional channels harbours several specialist species (such as *Pholiurus pannonicus*, *Plantago tenuiflora* and *Myosurus minimus*) which are restricted only to these micro-topographical features (Dítě et al., 2010; Molnár and Borhidi, 2003).

Both alkali steps and erosional channels are therefore good indicators for the presence of rare specialist species. On the one hand, these formations indicate good ecosystem functioning (surface water movement). On the other hand they are indicators of the pristine character of alkali landscapes, as their formation requires centuries with no transformation of the landscape (no settlements, ploughing or afforestation).

Due to the fine scale heterogeneity of alkali landscapes their conventional habitat mapping is very time- and labour consuming especially for extended areas. Remote sensing offers the possibility of large-area mapping and monitoring of habitats, which is nearly impossible with field data collection alone. Airborne laser scanning (ALS) is an active remote sensing technique which makes use of light detection and ranging (LiDAR) to estimate distances from the sensor to the target. ALS is increasingly being used for generating high-resolution Digital Terrain Models (DTMs) due to its ability to collect information from the ground through gaps in vegetation. These data can be used as an exploratory tool for understanding ecological processes co-varying with elevation.

Table 1
Vegetation associations and categories, in the approximate order in which they occur. Pannonic loess steppic grasslands usually occupy the highest elevation.

Order	Associations	Aggregated categories	Order
1	*Cynodonti-Poëtum*	Loess grasslands	1
2	*Achilleo-Festucetum*	Alkali steppes	2
3	*Artemisio-Festucetum*		
4	*Camphorosmetum annuae*	Open alkali swards	3
5	*Pholiuro-Plantaginetum*		
6	*Puccinellion limosae*		
7	*Agrostio-Alopecuretum*	Alkali meadows	4
8	*Agrostio-Beckmannietum*		

Deák et al. (2013) used a high-resolution DTM generated from ALS in a decision tree classifier and found that some of the associations in these alkali landscapes could be separated based on elevation alone. Statistical analyses also showed the existence of a correlation between elevation and vegetation in these grasslands (Deák et al., 2014a). Alexander et al. (2015) used 45 variables derived from elevation, reflectance, echo width and the number of echoes from two ALS datasets to classify vegetation, and found that terrain elevation was the single-most important variable for classification, especially when the classes were aggregated.

Previous studies have shown that elevation and its derivatives, such as slope, aspect and curvature, serve as proxies for soil depth, nutrient status and water status (Lassueur et al., 2006). Micro-topography in alkali grasslands may influence the vegetation patterns at different scales due to its correlation with salt accumulation zone and ground water table. The aim of our study was to map eight typical vegetation associations and two unique topographic features in an alkali landscape based only on DTM generated using ALS elevation data, and its derivatives. The specific objectives were (i) to classify vegetation using DTM and its derivatives in a Random Forest classifier; (ii) to identify variables which could be drivers for vegetation; and (iii) to delineate alkali steps and erosional channels using micro-topographic variables.

2. Methodology

2.1. Study area

The study area is located in Ágota Puszta (E 47°21′14″; N 21°05′04″) which is a part of the Hortobágy National Park in Hungary. The Hortobágy National Park was founded to preserve the largest continuous semi-natural inland alkali landscape of Europe. An area of 1 km × 2 km, which contained all the associations of interest, was selected for the study (Fig. 1). Terrain elevation in the site ranged from 124 m to 130 m above sea level (Fig. 2), with the vegetation associations of interest occurring within an elevation range of approximately 1.2 m from loess grasslands in the highest position, to wet meadows occupying the lower elevations.

2.2. Datasets

2.2.1. Field data

Field data were collected in May–June 2013, along 15 transects in elevation gradients — five transects each in three plots — in the study area (Fig. 2). Polygons with homogeneous vegetation, with respect to associations, were mapped using a Trimble GeoExplorer 6000 differential GPS. The polygons were assigned to eight association types (Table 1) based on the categories described by Borhidi et al. (2012). These associations were also grouped into four aggregated vegetation categories: loess grasslands, alkali steppes, open alkali swards and alkali meadows. These categories represent the higher phytosociological orders of the vegetation associations