Flora 209 (2014) 693–697

Contents lists available at ScienceDirect

Flora

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

Fine-scale vertical position as an indicator of vegetation in alkali grasslands – Case study based on remotely sensed data

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ARTICLE INFO

Article history:
Received 19 May 2014
Received in revised form 9 September 2014
Accepted 12 September 2014
Edited by Brigitta Erschbamer
Available online 2 October 2014

Keywords:
Vegetation zonation
Airborne laser scanning
Saline grassland
Festucion pseudovinae
Natura 2000
Digital terrain model

ABSTRACT

Vertical position is an important driver of vegetation zonation at multiple scales, via determining abiotic environmental parameters, such as climate, soil properties and water balance. In inland alkali landscapes, elevation is a key factor for understanding patterns of salt accumulation and water table which is therefore considered a good indicator of alkali vegetation types. Remote sensing techniques offer viable solutions for linking elevation data to vegetation patterns by providing an elevation model of extended areas. Our goal was to test the relationships between fine-scale differences in vertical position and vegetation patterns in inland alkali landscapes by vegetation data collected in the field and elevation data generated using airborne laser scanning (ALS). We studied whether vertical position influences vegetation patterns at the level of main vegetation groups (based on alliances) or even at the level of associations. Our study sites were situated in a lowland alkali landscape in Hortobágy National Park (East-Hungary). We grouped the associations into four main vegetation groups: loess grasslands, alkali steppes, open alkali swards and alkali meadows. Even though we detected a very limited range (121 cm) in the vertical position of the main vegetation groups, they were well separated by their vertical positions. At the level of associations, a more detailed elevation-based distinction was also possible in many cases. The revealed elevation–vegetation correlations show that high-resolution mapping based on ALS remote sensing techniques is an ideal solution in complex lowland areas, such as alkali landscapes. Our findings suggest that in other types of lowland landscapes, characterised by elevation differences, the applied method might hold a great potential as a supporting tool for vegetation mapping.

Introduction

Linking vegetation patterns to abiotic environmental parameters has been a core topic in vegetation ecology for centuries (Watt, 1947). Elevation above sea level is an important driver of vegetation zonation at multiple scales (Lundholm, 2009). In case of large elevation gradients, the relationship between vegetation zonation and elevation is well-described, e.g. in mountain areas (Krömer et al., 2013; Ostendorf et al., 1999). In these areas elevation is a primary determinant of meso-climate, thus it is a good predictor of the potential vegetation type. In lowland regions elevation gradients occur typically on smaller scales, mainly connected to small-scale differences in water table, salinity, soil texture or nutrient availability (see e.g. Wesche et al., 2005). For instance, several lowland landscapes, such as inland sand dunes, karst or alluvial areas are characterised by heterogeneous structure, where small-scale differences in elevation can affect vegetation patterns (see Bátori et al., 2009; Moeslund et al., 2013a; Török et al., 2009). Salt-affected habitat complexes in lowland areas are ideal systems for studying elevation–vegetation correlations. These areas are characterised by a high level of small-scale elevation heterogeneity, which corresponds to different levels of abiotic stress, i.e. salt content and water availability (Wanner et al., 2014). In former studies elevation differences within the tidal range were found to be a major predictor of vegetation zonation in coastal salt-affected associations

Abbreviations: ALS, airborne laser scanning; DTM, digital terrain model; RS, remote sensing.

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http://dx.doi.org/10.1016/j.flora.2014.09.005
0367-2530/

(Minden et al., 2012; Zedler et al., 1999). In inland salt-affected landscapes the relationship between elevation and vegetation has been rarely studied.

Inland alkali grasslands are typical in continental climate, at sites with at least moderate salt concentration in the soil and dynamic changes in water regime (Deák et al., 2014; Eliáš et al., 2013; Valkó et al., 2014). Alkali landscapes of the Pannonian biogeographical region represent the most continuous salt-affected landscape in continental Europe with an extension of more than 210,000 ha (Šefferova Stanova et al., 2008). These landscapes hold an extremely high habitat diversity with numerous associations which form a very complex and heterogeneous mosaic structure even at a very fine-scale (Dítě et al., 2010a; Eliáš et al., 2013; Török et al., 2012) (Appendix A).

Species pool and spatial patterns of various grassland associations are driven by two main stress factors: salt- and water stress (Eliáš et al., 2013; Török et al., 2012; Zalatnai and Körmöczi, 2004). Therefore the amount and distribution of alkali salts in the soil together with the groundwater level determine vegetation patterns through environmental filtering (Molnár and Borhidi, 2003; Szombathová et al., 2008; Valkó et al., 2014). Based on this relationship Tóth and Kertész (1996) suggested using vegetation types for predicting soil parameters, such as pH, electrical conductivity and sodium activity. In areas located within a few metres of vertical distance from a water table, fine-scale elevation differences markedly affect local patterns in soil moisture (Moeslund et al., 2013a,b). Thus, elevation is a key factor for understanding salt accumulation patterns and water table level in inland alkali landscapes; for instance Zalatnai et al. (2007) suggested that the position along an elevation gradient was the most important factor affecting soil properties. Other studies proved that groundwater level and salinity significantly correlate with small-scale elevation differences in ground surface (Blaskó et al., 2006; Valkó et al., 2014). Based on vegetation-soil and soil-elevation relationships, it has been widely accepted that vegetation patterns show a distinct correlation with elevation in inland alkali landscapes, which was in line with numerous field observations (Molnár and Borhidi, 2003; Török et al., 2012; Appendix B). Similar small-scale elevation–vegetation correlations were confirmed by measurements in seashore landscapes (Moeslund et al., 2011; Ward et al., 2013). However, in inland alkali landscapes, systematic field measurements confirming the correlation between elevation and vegetation types along entire zonation gradients are still lacking.

Airborne laser scanning (ALS) became a widely available and therefore increasingly used tool in ecological studies, as it can provide reliable data on structural attributes of extended areas (Lefsky et al., 2002). ALS is an active remote sensing technique which can be used without the utilisation of sunlight and therefore it is highly insensitive to weather conditions. This emits short pulses of (usually infrared) light from airborne platforms, typically fixed-wing aircrafts or helicopters. The distances to target surfaces can subsequently be computed by measuring the time the pulse takes to travel from scanner to target and back (Wehr and Lohr, 1999). ALS has proven to be a useful tool for collecting information from the ground surface and generating digital terrain models (DTM) in open ecosystems with low amounts of biomass and vegetation cover. Therefore, for linking elevation data with vegetation patterns ALS offers a viable solution (Ward et al., 2013).

Our goal was to test the correlation between fine-scale differences in vertical position and vegetation patterns in inland alkali landscapes by vegetation data collected in the field and elevation data generated from airborne laser scanned data. We studied whether the vertical position influences vegetation patterns at the level of main vegetation groups or even at the level of associations.

Materials and methods

Study site

Our study site is situated in Ágota Puszta (N 47°21′ E 21°04′), a lowland alkali landscape, which is part of the Hortobágy National Park (East-Hungary). Ágota Puszta is characterised by a complex mosaic of alkali and loess vegetation. Smaller patches of non-alkali wetlands (marshes with *Typha* spp. and *Glyceria maxima*) and scattered woody vegetation (oak plantations and smaller patches of invasive woody species, such as *Eleagnus angustifolia* and *Fraxinus pennsylvanica*) are present as well, mainly connected to old riverbeds. Grasslands of the study area are managed uniformly by moderate (1.2 livestock unit/hectare/year) cattle grazing herded by herdsmen. The area is characterised by a continental climate with a mean annual temperature of 9.5 °C and mean annual precipitation of 550 mm (Török et al., 2012). The total elevation range within the study site (1 km × 2 km) is as low as 1.8 m (128.7–126.9 m a.s.l.) from the lowest elevations to the top of the plateaux.

Studied associations and main vegetation groups

We studied eight grassland associations, typical to alkali and chernozem soils, which are present in our study sites. Typical species and environmental characteristics of the studied associations are listed in Table 1. We justified the assignment of polygons to association types based on the constancy of the dominant species defined by a cover >5% (Appendix C, see also Borhidi et al., 2012). For further analyses we grouped the associations into four main vegetation groups The grouping refers to larger phytosociological units (Borhidi et al., 2012), i.e. alliances as follows: (i) Loess grasslands: alliance *Festucion valesiacae*; (ii) Alkali steppes: alliance *Festucion pseudovinae*; (iii) Open alkali swards: alliances *Puccinellion limosae* and *Salicornion prostratae*; (iv) Alkali meadows: alliance *Beckmannion eruciformis*.

Loess grasslands

This group comprises only one association: *Cynodonti–Poetum angustifoliae* (hereafter mentioned as *Cynodonti–Poetum*). Loess grasslands are short grasslands on chernozem soils, characterised by a high diversity of monocot and forb species (Borhidi et al., 2012). Due to the high fertility of their soil, weedy species are often typical in loess grasslands.

Alkali steppes

Alkali steppes are short, dry grasslands formed on solonetz soils with moderate humus content and low to moderate salt accumulation in the deeper soil layers (Török et al., 2012). In our study site two associations were present: *Achilleo seataceae–Festucetum pseudovinae* (hereafter *Achilleo–Festucetum*) and *Artemisio santonici–Festucetum pseudovinae* (hereafter *Artemisio–Festucetum*). The species pool of *Achilleo–Festucetum* steppes shows similarity to loess grasslands; *Artemisio–Festucetum* steppes show a definite alkali character indicated by several salt-tolerant species.

Open alkali swards

The most strongly salt-affected associations can be found in this group. Open alkali swards are generally covered by water in springtime, and salt accumulates in the upper soil layer or even on the soil surface. Due to the high salt content of the soil open alkali swards have a low vegetation cover (5–30%) and a species-poor vegetation mainly built by halophyte species (Török et al., 2012). They comprise three associations: *Camphorosmetum annuae*; *Puccinellietum*