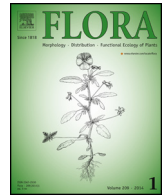




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Fine-scale vertical position as an indicator of vegetation in alkali grasslands – Case study based on remotely sensed data

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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.

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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 Bátorfi 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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(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 Körmöczy, 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 Pusztá (N 47°21' E 21°04'), a lowland alkali landscape, which is part of the Hortobágy National Park (East-Hungary). Ágota Pusztá 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 herdsman. 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 solonchaks 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 seatacae-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*

Table 1

Environmental characteristics of the studied associations (after Kelemen et al., 2013; Deák et al., 2014).

Main vegetation groups	Association	Number of polygons	Soil salt content	Water balance
Loess grasslands	<i>Cynodonti–Poetum angustifoliae</i>	23	Low	Dry/stable
Alkali steppes	<i>Artemisio santonici–Festucetum pseudovinae</i>	13	Moderate	Dry/astatic ^a
	<i>Achilleo seataceae–Festucetum pseudovinae</i>	61	Low	Dry/stable
Open alkali swards	<i>Camphorosmetum annuae</i>	14	High	Dry/astatic ^a
	<i>Puccinellietum limosae</i>	23	High	Dry/astatic ^a
	<i>Pholiuro pannonicum–Plantaginetum tenuiflorae</i>	18	High	Dry/astatic ^a
Alkali meadows	<i>Agrostio stoloniferae–Alopecuretum pratensis</i>	27	Low	Mesic/astatic ^b
	<i>Agrostio stoloniferae–Beckmannietum eruciformis</i>	14	Low-moderate	Mesic ^b

^a Rapid seasonal changes in water balance; usually wet in early spring, then getting dried before summer.^b Covered by water in spring, drying out till summer.

limosae; *Pholiuro pannonicum–Plantaginetum tenuiflorae* (hereafter *Camphorosmetum*, *Puccinellietum* and *Pholiuro–Plantaginetum*).

Alkali meadows

Alkali meadows are wet grasslands characterised by tall grass species. Generally they dry out in mid-summer and have a low to moderate salt content in the soil (Deák et al., 2014). They comprise two associations in the study site: *Agrostio stoloniferae–Alopecuretum pratensis* (hereafter *Agrostio–Alopecuretum*) and *Agrostio stoloniferae–Beckmannietum eruciformis* (hereafter *Agrostio–Beckmannietum*). Compared to *Agrostio–Alopecuretum*, *Agrostio–Beckmannietum* typically grows on more wet and alkali soils, which is indicated by several halophyte species and species of salt marshes, like *Cirsium brachycephalum*.

ALS data collection and pre-processing

The ALS data were acquired using a RIEGL LMS-Q680i full-waveform laser scanner mounted on a fixed wing aircraft in March 2012 in the framework of the ChangeHabitats2 EU FP7 project. The average point density was estimated as 25 pts/m², considering all types of echoes (first, intermediate, last). A fine-scale DTM was derived from the ALS point cloud with a grid size of 0.25 m × 0.25 m using the software SCOP++ (2008). Vertical accuracy of an ALS echo was determined to be less than 0.05 m.

Field data collection

Field data were collected in June 2013. Based on the DTM, we designated fifteen transects (150 m long, 30 m wide) along an elevation gradient from the highest elevated plateaux to the lowest-elevated areas. We mapped all typical associations (in total 193 polygons) in transects and measured their positions with a Trimble Geoexplorer 6000 differential GPS. We recorded the dominant species in each polygon and then assigned the polygons into association types (see Table 1) using the categories suggested by Borhidi et al. (2012). Data from the polygons recorded in the field were processed in ArcGIS 10.1; the areas of the polygons were standardised to the area of the smallest patch (4 m²) which yielded 64 DTM grids with discrete elevation data.

Data analysis

We compared the vertical positions of the main vegetation groups and the associations with a Kruskal–Wallis test (Zar, 1999). Then we calculated the pairwise comparisons with Mann–Whitney (M–W) test (Bonferroni adjusted) using SPSS 20.0. For the calculations we used averaged elevation data from each polygon.

Results

Main vegetation groups

Even though we detected a very limited range in the vertical position (121 cm) of the main vegetation groups, they were well separated along vertical positions ($N=193$; $df=3$; $p<0.001$) (Fig. 1A). Loess grasslands were characterised by the highest vertical position. Alkali steppes were situated below loess grasslands; they were well separated from each other by vertical position ($p<0.001$). Open alkali grasslands had an intermediate position between the alkali steppes and alkali meadows. Alkali meadows were situated in the lowest elevations, clearly separated from open alkali swards ($p<0.001$).

Association types

Although we found significant differences between the vertical positions of the studied associations ($N=193$; $df=7$; $p<0.001$) (Fig. 1B), the pairwise comparisons showed that not all association types were clearly separated by vertical positions. Based on their vertical position, the order of association types is as follows.

Stands of *Cynodonti–Poetum* were located at the highest positions; they formed a quite well-separated group, overlapping only with *Artemisio–Festucetum* stands.

Artemisio–Festucetum stands overlapped with stands of *Cynodonti–Poetum* above, and *Achilleo–Festucetum* and *Camphorosmetum* below. *Achilleo–Festucetum* stands had a rather wide elevation range (110 cm) in their vertical position, thus they covered almost the whole gradient. This type overlapped with *Artemisio–Festucetum* stands above and also with the stands of all of the open alkali grassland associations below. *Achilleo–Festucetum* was significantly separated from the *Cynodonti–Poetum* ($p<0.001$) and from both alkali meadow associations ($p<0.001$ for each).

Camphorosmetum stands overlapped with both the stands of alkali steppe associations above and with all other open alkali grassland associations below. *Camphorosmetum* stands differed significantly from the *Cynodonti–Poetum* stands ($p=0.015$) and stands of both alkali meadow associations ($p=0.001$ for each). *Puccinellietum* stands differed significantly from stands of *Cynodonti–Poetum* ($p=0.001$) and *Artemisio–Festucetum* above ($p=0.017$), and both alkali meadow associations below (*Agrostio–Alopecuretum* $p=0.021$; *Agrostio–Beckmannietum* $p=0.018$). *Pholiuro–Plantaginetum* stands overlapped with almost all of the studied associations, except for *Cynodonti–Poetum* ($p<0.001$) and *Artemisio–Festucetum* ($p=0.001$) stands.

Stands of *Agrostio–Alopecuretum* were well separated from all other associations except for the *Pholiuro–Plantaginetum* and *Agrostio–Beckmannietum* stands. Stands of *Agrostio–Beckmannietum* were situated at the lowest position. They were well separated from all other associations

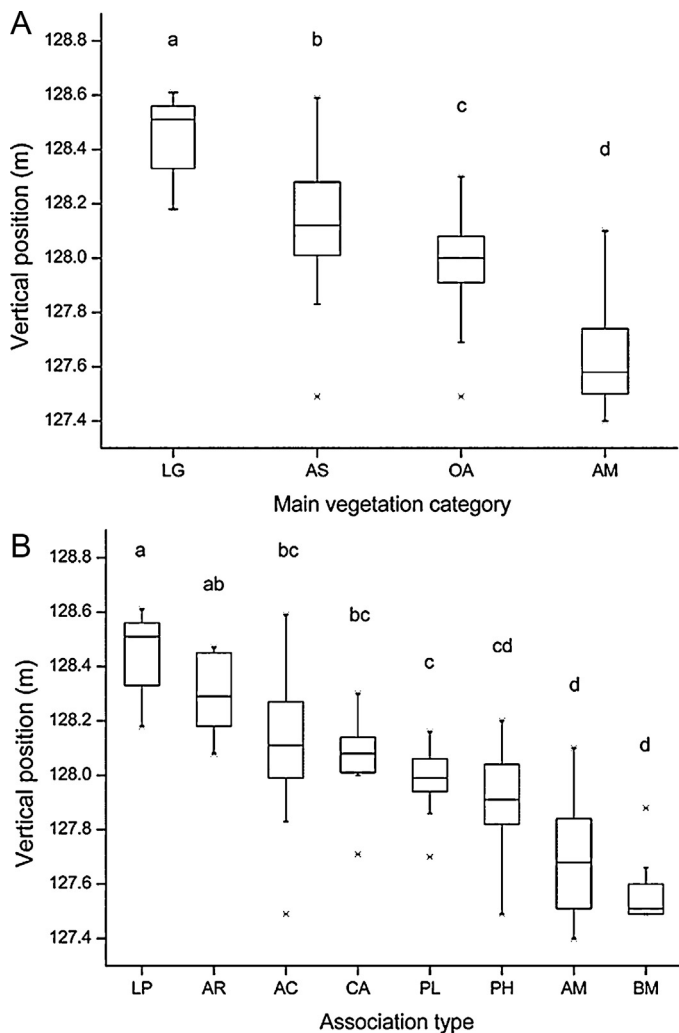


Fig. 1. (A) Elevation of main vegetation groups. (B) Elevation of the studied association types. Boxes indicate the 25–75 percentiles, lines are the medians, and the asterisks are the outliers. Significant differences between the different groups are indicated by different letters (Mann–Whitney test, $p < 0.05$). Abbreviations of the main vegetation groups: LG – loess grassland; AS – alkali steppes; OA – open alkali grassland; AM – alkali meadows; Abbreviations of the associations: CP – *Cynodonti–Poetum*; AF – *Achilleo–Festucetum*; AR – *Artemisio–Festucetum*; CA – *Camphorosmetum annuae*; PP – *Pholiuro–Plantaginetum*; PL – *Puccinellietum limosae*; AA – *Agrostio–Alopecuretum*; AB – *Agrostio–Beckmannietum*.

except for the *Pholiuro–Plantaginetum* and *Agrostio–Alopecuretum* stands.

Discussion

We found that the main vegetation groups (loess grasslands, alkali steppes, open alkali swards and alkali meadows) of alkali landscapes can be clearly separated by fine-scale differences in their vertical position. This clear distinction is probably caused by the differences in the environmental conditions of the main vegetation groups (Borhidi et al., 2012). Loess grasslands are exposed to drought stress, but not affected by salt-stress and nutrient-deficiency. In contrast alkali steppes are exposed to moderate levels of drought and salt-stress; open alkali swards are exposed to high levels of drought and salinity; while alkali meadows are characterised by no drought and only moderate salt stress (Deák et al., 2014; Kelemen et al., 2013). Thus, these marked differences in abiotic stress factors – especially topographically controlled soil

moisture and salinity (Moeslund et al., 2013a,b) – likely resulted in the clear separation of main vegetation groups.

At the level of association types, a more detailed elevation-based distinction was also possible in many cases. Based on the DTM we revealed a fine-scale vertical vegetation gradient.

We found that *Cynodonti–Poetum* was situated on the top part of the gradient. They were typically situated on the highly elevated plateaux, which probably provided optimal conditions (nutrient-rich chernozem soil, low salt content and dry conditions) for loess grassland species, such as *Euphorbia cyparissias*, *Festuca rupicola* and *Galium verum* (Kelemen et al., 2013).

Below *Cynodonti–Poetum*, *Artemisio–Festucetum* was situated, overlapping with the *Cynodonti–Poetum*, *Achilleo–Festucetum* and even with open alkali swards in its vertical extent. *Achilleo–Festucetum* had the widest range of vertical position in our study site, likely because this association is characterised by moderate soil fertility and/or moderate salinity, which conditions are likely provided in different elevation zones (Kelemen et al., 2013). Accordingly its species pool includes some generalist species, shared with neighbouring associations, such as *Achillea* spp. and *Plantago lanceolata* with *Cynodonti–Poetum*, *Achillea* spp., *Festuca pseudovina* and *Podospermum canum* with *Artemisio–Festucetum*. Presence of generalist species and wide distribution of this association can be linked to the hypothesis of Molnár and Borhidi (2003) on the secondary origin of this association. They assume that several stands of *Achilleo–Festucetum* have originated from other associations typical to alkali landscapes (Molnár and Borhidi, 2003); which resulted in a species pool comprising generalist species.

Associations of the open alkali swards, such as *Camphorosmetum*, *Puccinellietum* and *Pholiuro–Plantaginetum* had a very similar vertical position in an intermediate position between alkali steppes and alkali meadows. These three associations are characterised by high salt-content on the soil surface, high groundwater table but dry soil surface after springtime (Dítě et al., 2010b; Valkó et al., 2014). These special environmental conditions are restricted to a narrow elevation zone, which was confirmed by the vertical position of *Camphorosmetum* and *Puccinellietum*. *Pholiuro–Plantaginetum* showed similarity to alkali meadows in their vertical position, even it was not indicated by the dominant species, which is probably due to intense silt accumulation processes typical both in *Pholiuro–Plantaginetum* and alkali meadows (Borhidi et al., 2012; Deák et al., 2014).

Alkali meadows were present in the lowest positions and were clearly separated from all other associations, except for the *Pholiuro–Plantaginetum*. *Agrostio–Alopecuretum* which had a wider range in vertical position compared to *Agrostio–Beckmannietum*. *Agrostio–Beckmannietum* is typical on mesic habitats with moderate or intense salt accumulation (Deák et al., 2014), indicated by the presence of *Beckmannia eruciformis* and *Glyceria fluitans*; these conditions are probably restricted to a limited elevation zone. In contrast, *Agrostio–Alopecuretum* stands are typical in astatic habitats with only moderate level of salt accumulation (Deák et al., 2014) which conditions are likely provided in a wider range of vertical position.

Our results clearly demonstrated that the main vegetation groups and associations of alkali landscapes are positioned along a vertical elevation gradient of even a couple of decimetres. These differences likely correspond to environmental gradients (soil type, salt accumulation and water balance) which are strongly correlated to elevation patterns (Tóth and Kertész, 1996; Tóth, 2010). At the association level the vertical elevation gradient could be detected, but vertical position of certain associations overlapped. Overlaps were typically found between associations characterised by similar environmental conditions.

We proved that the distribution of alkali vegetation types can be extracted from remotely sensed elevation data. We found that

in these landscapes, even within a range of only 1 m, main vegetation groups and association types can be separated based on their vertical position. Our findings also support the idea that in other types of lowland landscapes (see e.g. Moeslund et al., 2011; Ward et al., 2013), characterised by even larger elevation differences, the applied method might hold a great potential as a supporting tool for vegetation mapping. Elevation–vegetation correlations provide a good basis for practical application of ALS data in vegetation mapping of complex lowland landscapes, such as inland alkali habitats, large alluvial plains or vegetation mosaics of fens and dry grasslands. High resolution vegetation mapping in such heterogeneous landscapes is a challenging task for nature conservation managers given the complexity and fine-scale mosaic structure of the vegetation. Our results suggest that the application of DTM can considerably increase the accuracy and efficiency of vegetation mapping campaigns in landscapes with a heterogeneous configuration of habitats.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.flora.2014.09.005>.

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