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# Classification of vegetation in an open landscape using full-waveform airborne laser scanner data

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ABSTRACT

Airborne laser scanning (ALS) is increasingly being used for the mapping of vegetation, although the focus so far has been on woody vegetation, and ALS data have only rarely been used for the classification of grassland vegetation. In this study, we classified the vegetation of an open alkali landscape, characterized by two Natura 2000 habitat types: *Pannonic salt steppes and salt marshes* and *Pannonic loess steppic grasslands*. We generated 18 variables from an ALS dataset collected in the growing (leaf-on) season. Elevation is a key factor determining the patterns of vegetation types in the landscape, and hence 3 additional variables were based on a digital terrain model (DTM) generated from an ALS dataset collected in the dormant (leaf-off) season. We classified the vegetation into 24 classes based on these 21 variables, at a pixel size of 1 m. Two groups of variables with and without the DTM-based variables were used in a Random Forest classifier, to estimate the influence of elevation, on the accuracy of the classification. The resulting classes at Level 4, based on associations, were aggregated at three levels — Level 3 (11 classes), Level 2 (8 classes) and Level 1 (5 classes) — based on species pool, site conditions and structure, and the accuracies were assessed. The classes were also aggregated based on Natura 2000 habitat types to assess the accuracy of the classification, and its usefulness for the monitoring of habitat quality. The vegetation could be classified into dry grasslands, wetlands, weeds, woody species and man-made features, at Level 1, with an accuracy of 0.79 (Cohen's kappa coefficient, $\kappa$). The accuracies at Levels 2–4 and the classification based on the Natura 2000 habitat types were $\kappa$: 0.76, 0.61, 0.51 and 0.69, respectively. Levels 1 and 2 provide suitable information for nature conservationists and land managers, while Levels 3 and 4 are especially useful for ecologists, geologists and soil scientists as they provide high resolution data on species distribution, vegetation patterns, soil properties and on their correlations. Including the DTM-based variables increased the accuracy ($\kappa$) from 0.73 to 0.79 for Level 1. These findings show that the structural and spectral attributes of ALS echoes can be used for the classification of open landscapes, especially those where vegetation is influenced by elevation, such as coastal salt marshes, sand dunes, karst or alluvial areas; in these cases, ALS has a distinct advantage over other remotely sensed data.

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## 1. Introduction

Preserving and restoring our remaining natural heritage has become a global concern in the past decades, with increasing awareness about the loss of biodiversity and natural habitats, which have preserved their original species composition, structure and ecosystems functions (Barbault, 2013). Several factors, such as agricultural intensification, urbanization and climate change, contribute to the loss, fragmentation and degradation of natural habitats (Opdam and Wascher, 2004; Su et al., 2012; Vimal et al., 2012). Monitoring the effects of these factors on the remaining natural habitats is essential to understand ecological processes, thereby supporting informed decision-making. High-resolution and up-to-date vegetation maps are crucial tools for nature conservation due to the rapid human-induced changes in landscape composition. Mapping the distribution and extent of habitats is the first step toward understanding the conditions critical to their persistence (Hooftman and Bullock, 2012; Vanden Borre et al., 2011).

Multi-spectral satellite imagery, with resolutions ranging from 10 m to 1 km, has been extensively used for classifying and map-

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ping vegetation at the global and regional scales (Friedl et al., 2002; Han et al., 2004; Wessels et al., 2004). Airborne laser scanning (ALS) is an active remote sensing technique which is increasingly being used for the mapping of vegetation, alone or in conjunction with other remote sensing data, at fine spatial resolutions of up to a few meters (Alonzo et al., 2014; Hladik et al., 2013; Ke et al., 2010). ALS makes use of light detection and ranging (LiDAR) to estimate distances from the sensor to the target. Conventionally ALS was used for generating Digital Terrain Models (DTMs), due to its ability to collect information from the ground through gaps in tree canopies. An advantage of ALS over passive multi-spectral remote sensing in vegetation mapping is that the height of vegetation can be estimated based on the DTM (Blair et al., 1999).

Full-waveform ALS data, which have been in use since 2004, provide more information about the echoes, such as amplitude and echo width, compared to discrete-return ALS. These attributes of the echoes, together with scanning parameters such as range and incidence angles, can be used for calibration and thereby estimation of the reflectance of surfaces. Reflectance data are thus comparable across different flying heights and incidence angles, within a single flight as well as between different flights. The use of this information, which was largely discarded earlier, has opened up new possibilities for the classification and mapping of vegetation using ALS (Heinzel and Koch, 2011).

Reflectance, in the case of full-waveform laser scanning, generally refers to backscatter coefficient, the area-normalized backscatter cross-section corrected for incidence angle. The backscatter cross section of a target is equal to the physical cross sectional area of an idealized isotropic target, which has the same intensity as the selected target; an isotropic target scatters light in all possible directions (Wagner, 2010; Wagner et al., 2006; Woodhouse, 2005). The illuminated area of the target can be approximated correctly only in the case of extended targets where the target surface is bigger than the footprint of the laser beam; footprint is the area illuminated by a single laser beam, which is dependent on the flying height, incident angle and target surface. In this case, the backscatter cross section of two targets with similar surface properties would be different if their illuminated areas are different, and hence the need to estimate backscatter coefficient, which is dependent only on surface properties. When there is more than one echo and the laser footprint only partly illuminates a surface, for example the leaves or branches of trees, the actual area corresponding to one echo is unknown. The estimated reflectance values for target surfaces with single echoes are therefore better approximations than those for distributed targets with multiple echoes (Roncat et al., 2014; Wagner et al., 2006). This should make reflectance from ALS more useful for grasslands than forests.

Classification of features using ALS was largely focused on urban areas and forests due to the significant advantages of ALS over passive multi-spectral imagery in terms of elevation data. This was useful for classifying buildings, trees, shrubs, grass and roads in urban areas (Brennan and Webster, 2006), delineating tree stands in forests and classifying trees to some extent based on structural and spectral attributes (Brandtberg, 2007; Heinzel and Koch, 2011; Li et al., 2013; Yao et al., 2012). Reflectance of surfaces in open landscapes can possibly be estimated and interpreted better than those in forests; open landscapes refer to areas characterized by herbaceous vegetation (i.e., grasslands, meadows, marshes) and a low cover of woody species. However the potential of using ALS for the classification of vegetation types in grasslands has been less explored.

Bork and Su (2007) classified rangeland vegetation into ten classes using five variables based on elevation from ALS, in a decision tree, with an accuracy of 52.3%. There were four classes of grassland (freshwater and saline meadows, fescue and mixed prairie grasslands), two classes of shrubland (Western snowberry and Silverberry) and two classes of forests (closed aspen and semi-open forests). However, the shrublands and fescue grasslands could not be well-classified. Korpela et al. (2009) classified the vegetation in boreal mires into 21 mire site types in forested, composite and treeless mires using 63 variables based on the elevation and intensity of discrete-return ALS data. The intensity data were not useful for differentiating vegetation types in the treeless mires, and they suggested that reflectance data from full-waveform ALS may be a better alternative. Zlinszky et al. (2014) performed a feasibility study on the use of airborne laser scanning for the classification of vegetation in grasslands, and noted that the most useful variables were based on vegetation height or texture. Improved classification accuracies for grasslands may result from using both spatial and spectral attributes from full-waveform ALS.

Terrain elevation can be an important determinant of vegetation patterns in grasslands similar to the altitudinal zonation in mountainous regions, although at a much smaller scale (Deák et al., 2015). ALS has been extensively used for generating high-resolution DTMs. Combining the spatial and spectral attributes from ALS for the classification of vegetation in open landscapes offers the possibility of mapping vegetation in grasslands extending over large areas, such as prairies in the US, steppes in Russia and Pusztas in the Pannonian region. Vegetation pattern of alkali landscapes shows a high correlation with the position of water table level and the level of salt accumulation, which are strongly correlated with micro-topography; vegetation types can thus be distinguished from each other based on only a few centimeter difference in elevation (Valkó et al., 2014). This results in a horizontal zonation in the landscape where loess grasslands and shortgrass alkali steppes are located at the highest elevations, open alkali grasslands are in the middle and alkali meadows, sedge and marshes are present in the lowest parts (Deák et al., 2014a).

*Pannonic salt steppes and salt marshes* and *Pannonic loess steppic grasslands*, which typically co-occur, belong to the most threatened Natura 2000 habitats. Natura 2000 is a European Union (EU)-wide network of nature protection areas designated to protect endangered habitats and species (Council Directive 92/43/EEC). As the existence of habitats and species of alkali landscapes are sensitive to changes in environmental conditions, it is essential to have up-to-date knowledge of the vegetation patterns of these landscapes. Changes in vegetation can indicate changes in the most essential environmental and management parameters such as changes in the level of the groundwater or the intensity of management. Detection of the changes is therefore a priority for nature conservation, as it can be a basis for management plans.

The aim of our study is to classify vegetation types of open alkali landscapes, especially those which belong to the Natura 2000 habitat categories: *Pannonic salt steppes and salt marshes* and *Pannonic loess steppic grasslands*. We use a full-waveform ALS dataset collected in leaf-on (growing) season, and a DTM, generated from an ALS dataset collected in leaf-off season, for this study. The first objective is to use variables derived from the ALS datasets to classify vegetation of an open alkali landscape in the Pannonian Puszta grasslands, and aggregate them at different levels. Since some of the vegetation associations in these grasslands are considered to have a strong correlation with elevation, the second objective is to estimate the influence of terrain elevation for the classification of the Puszta.

## 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 and the

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