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A general framework to describe the alteration of natural tree species composition as an indicator of forest naturalness

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ABSTRACT

The alteration of natural tree species composition is defined as the deviation of the current tree species composition from that of the natural state. It can be used as a measure of human influence on forest vegetation, and thus as an indicator of the naturalness of forest vegetation. The aim of the study was to develop a standard procedure for estimating the alteration of natural tree species composition, to explain factors driving alteration and to examine its significance for susceptibility of forest stands to natural disturbances. The alteration of natural tree species composition was estimated for the Dinaric region (5556 km^2, Slovenia) by the Robič Index of Dissimilarity (*RID*), ranging from 0 (completely natural) to 100 (completely altered). The index was calculated on the compartment level (24 ha each on average) with data on current and potential natural forest vegetation. The influence of human activities on tree species alteration was examined by using topographic and accessibility variables. The susceptibility of forest stands to natural disturbances was analysed with data on sanitary felling. In the study area, the natural tree species composition of forest stands is moderately preserved; the average value of *RID* was 50.05, ranging from 1.76 to 100, and the coefficient of variation was 0.49. The alteration of the natural tree species composition of forest stands is primarily the result of forest management and past land use, conditioned either by topography or accessibility of forests. The degree of alteration of tree species composition decreased along the gradients of rockiness, inclination and elevation. A greater degree of alteration appeared on the slopes of intermediate and south facing aspects than on north facing slopes, and in areas that were closer to the forest edge. A higher level of alteration significantly increases the susceptibility of forest stands to natural disturbances. The procedure represents a novel approach in modelling the alteration (naturalness) of tree species composition of forest vegetation. It is applicable at different spatial scales and fosters an understanding of the patterns of tree species composition under the influence of human activity across forest landscapes.

1. Introduction

Human intervention of varying intensity has markedly modified forest vegetation, resulting in structural and compositional changes in forest stands. The deviation of the current tree species composition from that of the 'natural' state can be defined as the alteration of natural tree species composition. It is a measure of the direct human influence on forest vegetation. The concept of 'natural' in the context of the forest ecosystem, forest vegetation or forest stand has been frequently criticized as vague given that almost all forests have been influenced by humans. Nevertheless, the term 'natural' has been widely used in vegetation science to define anything that has not been, at least not evidently, created or influenced by humans, particularly by technology (Angermeier, 2000). Natural has also been understood as the way the system would function in the absence of humans (Anderson, 1991).

The comparison of the current state of forest ecosystems with their natural state is central to the concept of naturalness (Machado, 2004; McRoberts et al., 2012). Although the concept has been made operational through the application of structural, compositional and functional indicators of naturalness (e.g. Anderson, 1991; Brūmelis et al., 2011; Gibbons et al., 2008; Liira and Sepp, 2009), comprehensive evaluations of forest naturalness are scarce. Instead, a simplified assessment of naturalness has often been per-

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formed (e.g. Gimmi and Radeloff, 2013; Laarmann et al., 2009) using only a limited number of indicators, tree species composition being one of the most important. For instance, the naturalness of tree species composition was found as the most relevant and informative indicator for assessment of 'high nature value' forests – a concept strongly related to forest naturalness (EEA, 2014). An overview of naturalness studies (Winter, 2012) reached a similar conclusion.

The degree of alteration and naturalness of tree species composition are interrelated: the more altered the natural tree species composition, the lower the naturalness. The values of both indicators are not binary but should be understood as a continuum from completely altered (not natural) to completely natural (unaltered). To estimate both indicators for a given site, (1) the natural tree species of forest stands as an approximate reference value should be known, and (2) information on current tree species composition should be available.

The natural tree species composition of forest stands is strongly related to the concept of potential natural vegetation (PNV); for each PNV unit, a plant composition, and thus also natural tree species composition, is typical. The concept of PNV was introduced by the German phytosociologist Reinhold Tüxen, who defined it as the hypothetical vegetation that would develop without human influence. The PNV concept was later adjusted to account for persistent and irreversible anthropogenic changes in site conditions (Zerbe, 1998). The concept of PNV has often been criticized, mostly for its methodological inconsistency in constructing the PNV or for its disregard for the dynamics of vegetation communities (e.g. Chiarucci et al., 2010). Despite scepticism about the consistency of the PNV concept, PNV mapping has been widely applied in practice, especially in forestry, natural resource management, land use planning and nature conservation. PNV mapping in forestry has mainly been based on phytosociological relevés (surveys) of forest vegetation. PNV mapping has become well established in Central European phytosociology (Braun-Blanquet, 1964) as well as outside of Central Europe. PNV has often been used as an indicator of the environmental and ecological conditions of an area (Roberts, 2015; Somodi et al., 2012). Several studies used the PNV as a reference value for the restoration of terrestrial ecosystems or as a vegetation baseline in projecting climate change-induced shifts in natural vegetation (Brzeziecki et al., 1995; Wang et al., 2013). The reliability of PNV mapping has been substantially improved by combining phytosociological studies with environmental surveys. For instance, PNV modelling that uses spatially explicit environmental variables (e.g. soil, substrate, and climate) has already shown promise for mapping at the national, regional and local levels (e.g. Reger et al., 2014).

Current tree species composition is commonly estimated in forest inventories and is defined by the presence of tree species (by individual or by group) and their abundance, which may be expressed in absolute values (e.g. volume, basal area, number of trees or coverage of tree species) or in relative terms with the proportion of tree species in the total abundance of trees measured with the above-mentioned parameters. Only trees that exceed threshold values, usually defined by a certain diameter at breast height, are sampled to estimate forest stand characteristics over a certain area. In national forest inventories in European countries, the threshold diameter at breast height lies mainly between 5 cm and 12 cm (Tomppo et al., 2010).

The alteration in natural tree species composition of forest stands may be driven by diverse human-induced influences, among which (1) forest management and (2) past land use are often cited as the most important. Forest management has led to substantial alteration of natural tree species composition of forest stands in many countries; economically relevant native tree species have been favoured and non-native tree species introduced to improve economic efficiency of forest management (Boucher et al., 2009). The magnitude of alteration of tree species composition has been largely dependent on the silviculture systems applied. The systems that are based on clear cutting and planting have caused immense changes to native tree species composition, even resulting in single species dominated forest stands in sites where mixed forests would potentially grow. In Europe, extensive Norway spruce (*Picea abies*) stands are a typical example. A high degree of alteration of natural tree species composition has had both ecologically and economically undesirable consequences, such as the failure of natural regeneration or greater susceptibility of forest stands to natural disturbances (Milad et al., 2011; Seidl et al., 2016). In contrast, continuous cover silvicultural systems, which are based on natural regeneration and mimicking natural stand dynamics, resulted in more preserved tree species composition and structure of forest stands than in forests where plantation management is practiced, and thus the greater resilience of forest stands to a changing environment (O'Hara, 2014). In reality, elements of different silvicultural systems are applied across the forest landscape, which results in a pattern of stands with different degrees of tree species alteration.

Land-use changes and past and current forest use, such as pasture and littering, have left a lasting impact on forest ecosystems (Munteanu et al., 2015). In many regions, forest area is increasing due to the abandonment of agricultural land. The tree species composition of early successional stages differs significantly from that of mature forest vegetation. Changes in tree species composition are expected to be greater in areas under stronger human influence, such as the surroundings of settlements, or in forest sites that were more appropriate for agricultural use due to the topographic conditions. It has therefore been suggested that forest naturalness should be assessed using spatial information on settlements, infrastructure and land use (Kapos et al., 2000).

Although there have been some studies on forest ecosystem naturalness (e.g. Uotila et al., 2002) and on the influence of forest management intensity on community composition (e.g. Gossner et al., 2014), research on the alteration of natural tree species composition in managed forests at a landscape scale is rare. The primary reason for this could be the huge gap between the well-developed theoretical framework for assessing naturalness of forest vegetation (Winter, 2012) and the lack of a spatially explicit procedure for estimating naturalness at various spatial scales using data on PNV and forest inventories (Chirici et al., 2011). Recent studies have mainly analysed the alteration of tree species composition on a national or international scale using broader categories of forest naturalness, such as primary forests, semi-natural forests and plantations (FAO, 2015; Forest Europe, 2015). Other studies addressed the naturalness of tree species composition only for a group of species, such as the presence or absence of dominant native tree species (EEA, 2014) or the presence of native versus non-native tree species. This study thus aimed to (1) develop a standard procedure for estimating the alteration of natural tree species composition in forest landscapes, (2) explain the main forces driving natural tree species composition alteration, and (3) examine whether the alteration of forest stand composition significantly influences forest landscape processes, applying susceptibility to natural disturbances as an example. We hypothesised that (1) the increased proportion of Norway spruce as an indicator of forest management regime, and the area of early successional stages as an indicator of past land use, significantly increase the alteration of tree species composition, (2) land accessibility and suitability for agricultural use are the best predictors of tree species composition alteration, and (3) alteration in tree species composition increases the susceptibility of forest stands to natural disturbances.