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Topographically-controlled site conditions drive vegetation pattern on inland dunes in Poland

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ABSTRACT

The inland dunes of Central Europe are commonly overplanted by Scots pine (*Pinus sylvestris*) monocultures in which the primary occurrence of the natural vegetation pattern is obliterated. We hypothesize that on naturally revegetated inland dunes the pattern is clear and driven by topographically-controlled site conditions. To test this hypothesis, we addressed the following research questions: (1) Does topography drive vegetation patterns on inland dunes and if so, what are main differences between vegetation in varying relief positions? (2) To what extent does topography involve the variability of microclimates and of soil properties, and how does the topographically-induced differentiation of these site conditions control vegetation patterns? We conducted interdisciplinary studies (applying floristic, pedological and microclimatic research techniques) on a naturally revegetated inland dune area situated on a military artillery training ground near Toruń, northern Poland. We investigated vegetation patterns with reference to three topographical position variants (north-facing slopes, south-facing slopes, and intra-dune depressions). We found distinct differences in vegetation characteristics covering the aforementioned topographical positions. This primarily concerned species composition of ground vegetation: *Calluna vulgaris* was dominant species on north-facing slopes, *Corynephorus canescens* on south-facing slopes, while *Calamagrostis epigejos* in intra-dune depressions. In comparison to dune slopes, the depressions were characterized by much higher biodiversity of vascular plant species. This followed the most favorable soil conditions for the existence of plants (higher moisture and nutrient pools) occurring in low topographical positions. However, tree succession was most advanced not in depressions, where the competitive impact of tall grasses on seedlings was recognized, but on north-facing slopes. Based on our results, we formulated some suggestions, which could be useful for both practical foresters to increase biodiversity of ecosystems and for practices that work on the fixation of dunes by restoring vegetation.

1. Introduction

Topography, in so far as it controls microclimates (Cantlon, 1953; Bennie et al., 2008) and soil properties (Seibert et al., 2007; Sewerniak and Jankowski, 2015), is considered to be an essential indirect variable affecting vegetation patterns (Guisan and Zimmermann, 2000). Despite the fact that land-relief is a well known agent affecting plant diversity patterns at local and landscape scale (Whittaker et al., 2001; Moeslund et al., 2013a), the effect of topography on vegetation has mainly been investigated with reference to large-scale landforms, and thus usually reported for mountainous areas (e.g. Grytnes, 2003; Černy et al., 2013; Monteiro et al., 2013). With regard to lowlands, the general importance of topography is less recognized and the mechanisms by which it exerts effects on local plant diversity are still not comprehensively understood (Moeslund et al., 2013c).

Most studies on the effects of topography on vegetation patterns in dune ecosystems were conducted with regard to coastal areas (Zoladeski, 1991; Piotrowska, 1988; Tilk et al., 2011). In these areas, vegetation patterns that follow environmental gradients were also investigated in relation to the distance to the seashore (Acosta et al., 2000; Forey et al., 2009). Much fewer studies were conducted with reference to inland dune fields even though they are common landforms in the European sand belt, which extends throughout the entire central, lowland part of the continent (Zeeberg, 1998). Regularities of vegetation patterns on inland dunes were primarily

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studied in reference to successional stages, which on sandy deposits are commonly linked to the time of sandy-ground fixation (Elgersma, 1998; Jankowski and Bednarek, 2000; Mierlo et al., 2000; Rahmonov and Oleś, 2010; Ujházy et al., 2011). The pattern of vegetation in relation to relief was only roughly described for these dunes (Jankowski, 2010; Sewerniak et al., 2011; Sewerniak and Jankowski, 2015). Moreover, the pattern has thus far not been investigated in detail for inland dunes in relation to the topographically-induced diversity of site conditions. This remains unfavored for biodiversity maintenance, because comprehensive understanding of the spatial pattern of vegetation and the mechanisms driving it is crucial for halting biodiversity loss (e.g. Willis and Whittaker, 2002; Kallimanis et al., 2007).

The inland dunes of Central Europe are dominated by dry, acidic soils which are poor in nutrients (Prusinkiewicz, 1969; Elgersma, 1998). Thus, they are not appropriate for agricultural purposes, and the dunes are almost entirely overplanted by even-aged sections of Scots pine (*Pinus sylvestris*) production monocultures. Most of them are characterized by high floristic uniformity with low biodiversity of understorey vegetation (Matuszkiewicz, 2001; Błońska et al., 2014), which has become even more distinct in recent decades (Matuszkiewicz, 2007) and can be stimulated by forest management practices (Stefańska-Krzaczek and Fałtynowicz, 2014). The decrease in forest biodiversity reveals, for example, the obscuring occurrence of ground vegetation mosaics in production monocultures in comparison to primeval forests occurring in comparable site conditions (Halme et al., 2013). Hence, naturally developed ecosystems (e.g. as a result of natural succession) are of greater importance for research on natural vegetation patterns (McCook, 1994; Faliński, 2003). As the great majority of inland dunes in Europe are overplanted by pine monocultures, the areas where vegetation develops on the dunes as a result of natural ecological processes are scarce. In Poland, the only large-scale site of such character is the Toruń artillery training ground, located in the northern part of the country.

Despite the fact that fields of inland dunes are commonly reported as monotonous areas forming uniform site conditions (Prusinkiewicz, 1969; Elgersma, 1998), in our previous, preliminary studies, we found differences in the properties of soils and microclimates related to the slope aspect on the dunes (Sewerniak et al., 2011; Sewerniak and Jankowski, 2015). Moreover, in intra-dune depressions, the humus, Al and Fe-enriched soils (Entic Podzols) have recently been revealed and described, which distinctly differs from the soils covering dune slopes (Jankowski, 2001, 2014). These findings encouraged us to expand our studies on topographically-induced regularity of microclimatic and soil variables and to link it to vegetation pattern. We hypothesized that when vegetation develops by natural succession, topographically-controlled differences in environmental variables clearly drive vegetation patterns, even in such a seemingly monotonous landscape as inland dunes. By conducting this research on naturally revegetated inland dunes with reference to three topographical positions (north-facing slopes, south-facing slopes, intra-dune depressions) we addressed the following specific study questions:

(1) Does topography drive vegetation patterns on inland dunes and if so, what are main differences between vegetation in the studied relief positions?
(2) To what extent does topography involve the variability of microclimates and of soil properties, and how does the topographically-induced differentiation of these site conditions control vegetation patterns?

As we presumed, our research would gain new data on the variation of site conditions and potential plant biodiversity on inland dunes. We believed that our findings would enable us to suggest implications for management which could increase biodiversity and ecological stability of production pine ecosystems in European inland dune areas. This would be expected because *Pinus sylvestris* monocultures planted on huge areas in Central Europe were commonly indicated as being susceptible to numerous hazards (e.g. Kenk and Guehne, 2001) and the necessity to increase their resistance (i.a. by increasing biodiversity) was commonly highlighted (Zerbe, 2002; Spiecker, 2003).

2. Materials and methods

2.1. Study area

The study area is located in the Toruń Basin (northern Poland) which is situated within the European sand belt (Zeeberg, 1998). The investigated area forms one of the biggest inland dune fields both in Poland and in the whole of Europe. The mineral material of the studied dunes is very homogeneous, concerning both the texture (fine-medium sand) and the mineralogical composition in which a distinct predominance of quartz occurs (85–99%, Jankowski, 2010). The dominant soils for the studied dune field are sandy, acidic and nutritionally poor Podzols and Albic Arenosols. Among these, numerous but small areas of soils enriched in humus and iron occur (Entic Podzols), which are situated in intra-dune depressions (Jankowski, 2001, 2014). The Toruń Basin is characterized by a transitional type of climate, somewhere between oceanic and continental. The mean annual temperature is 7.9 °C (the hottest month is July: 18.1 °C and the coldest is January: −2.2 °C) and the average annual precipitation is 522.5 mm, with July as the wettest month. The mean yearly length of the growing season is 218 days. On average, the season starts on 1st April and ends on 4th November (Wójcik and Marciniak, 2006).

The research was conducted in the eastern part of the Toruń Basin, in an artillery training ground located south of Toruń (52°55′N, 18°36′E; Fig. 1). Since the 19th Century, the inner part of the area was gradually deforested for military purposes, and since then this part has been almost entirely excluded from forest management. Therefore, for many decades fires and natural

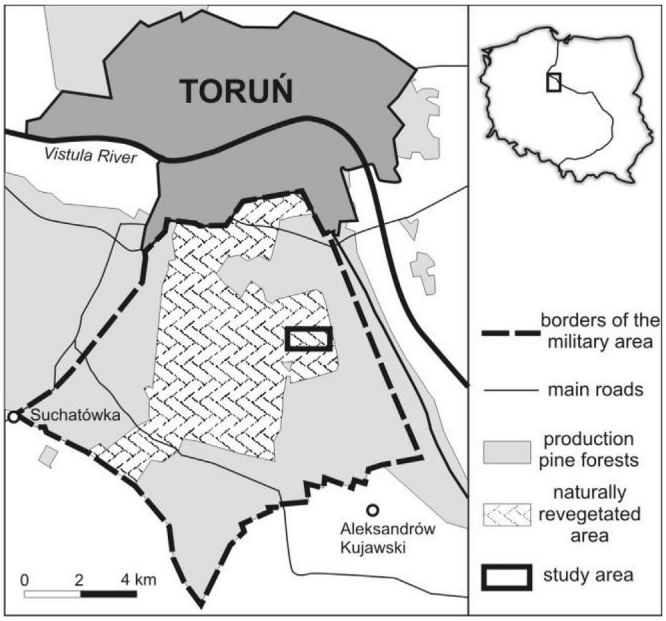

Fig. 1. Location of the study area.