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Secondary succession of trees in the dune landscape of the 'Glinki' long-term research area – analysis with GIS

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Abstract. The aim of the study was to present the main characteristics of the 'Glinki' research area together with results of the first measurements on tree number, density, distribution and species composition carried out in 2011. The research was conducted in a free-of-forest management part of the Toruń military area which is located in one of the biggest inland dune fields of Europe. The 'Glinki' research area was established in 2011 and consists of two plots (together 26.3 ha), which are in close proximity to each other. After the last fire in 1991, secondary succession has been the main factor shaping vegetation on both plots. For every plot, the location of all trees of at least 1 m height (560 in plot I and 292 in plot II) was determined. These measurements were subjected to spatial analysis in ArcGIS 9.3 with special emphasis on the exposure of the dune slopes. The main tree species on both plots were Scots pine, *Pinus sylvestris*, and birch, *Betula pendula*, (82 % and 17 % of all trees respectively). Tree density 20 years after the last fire was very low (32 trees/ha), which mainly resulted from the lack of a sufficient source of seeds in the close vicinity of the plots during the first years after the fire. We also found that tree distribution was related to the main direction of seed inflow and land relief. Tree density was much higher on dune slopes with a northern exposure when compared to other slope exposures, which resulted from different site conditions on the different slopes.

Keywords: relief, slope aspect, Podzols, military area, spatial analysis

1. Introduction

Long-term research conducted on permanent plots is particularly valuable when it comes to the study on functioning of forest ecosystems and on the course of plant community succession (Faliński 2001; Falińska 2003). There is however only little long-term research on permanent plots. Some of the ones that were intended to last for decades were suspended after a few or dozen or so years (Faliński 2001). Most likely, this fact resulted from poor documentation of the examined plots' initial condition (e.g. imprecise border definition), which made it impossible to continue measurements for the following generations of researchers.

Areas excluded from forest management are optimum objects for running long-term research of natural ecological processes in forest ecosystems. Due to this fact, research of the above-mentioned type is being held on strictly protected areas (Linder 1998; Bernadzki et al. 1998) or on areas excluded from intensive utilisation on which natural disasters occurred (Hibbs 1983; Rykowski 2012). Military training grounds deforested in the past for military purposes are also valuable objects for long-term research on forest succession. Especially valuable are objects abandoned by the army and also peripheral parts of the exercise site of active military training grounds, which someti-mes are entirely excluded from the direct influence of the army and no forest husbandry is run there.

The overgrowth at the exercise site of the Toruń training ground has been observed for many years now by foresters, soldiers and scientists (Chojnacka et al. 2010). No wider research has been conducted however in order to recognise and document the course of this process. A similar situation appears in many training grounds in Poland, which results in the high potential of those objects for the research of natural ecological processes being almost entirely unused.

The aim of establishing the 'Glinki' permanent research area in the Toruń artillery training ground was to initiate long-

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term research on forest succession in conditions of poor sites of inland dunes. The aim of the following study is to present the main characteristics of an established area (history of the area, localisation, border location) and results (number of trees, tree density, species composition of trees and tree distribution) of the first inventory conducted in 2011. In the analysis of tree distribution, special attention was paid to the influence of dune slope aspects because this factor was found to be very important for the natural development and formation of phytocoenosis at the exercise site of the Toruń training ground (Jankowski 2010; Sewerniak et al. 2013).

2. Research object and characteristics of the established area

The research was conducted on the area of the Toruń artillery training ground located in the eastern part of Bydgoszcz Primeval Forest, within the Otłoczyn circle of the Gniewkowo Forest inspectorate. This training ground is located on one of the biggest fields of inland dunes in Europe. It is the only large-area military ground in Poland located in a landscape with a large accumulation of aeolian forms. As a result of the presence of numerous dunes, this area is characterised by a diversified relief, which makes it suitable for artillery shooting. The area of research is characterised by low precipitation with a long-term average 522.5 mm (Wójcik, Marciniak 2006).

The Toruń military ground is one of the biggest active training grounds in Poland. Its area amounts to around 12.4 thousand ha (Wasilewski 2004). The area of the training ground is divided into two functional zones. Its central part, with an area around 6 thousand ha, constitutes the so-called exercise site on which army actions are being held. This zone has been deforested in the past in order to expose the area for military purposes. At present, the exercise site is covered by heathlands and grassy areas in which Scots pine (*Pinus sylvestris*) and Silver Birch (*Betula pendula*) encroach by natural succession. In some places, pine and birch forest stands of natural origin can be also found, in which extensive forest management is run. The second functional zone of the training ground is the area overgrown by productive pine forest stands in which forest management is run by standard methods used in Polish forestry. This area constitutes the external buffer belt for military actions run in the inner, exercise site of the training ground.

The 'Glinki' research area was established in the western part of the training ground's exercise site. This area consists of two plots placed around 1 km from each other. Their areas, forest addresses and GPS coordinates of characteristic border points (in WGS system) are shown in Table 1. In order to find plots easily in the future, definite field objects (fire lanes, compartment lines and dirt roads; see Fig. 1) were preferred as borders of the plots.

Table 1. Area and data concerning location of the investigated plots

Plot no.	Area [ha]	Forest compartment	Coordinates of border points
I	14.87	206a	N52 56.121, E18 34.128 N52 55.833, E18 34.052 N52 55.867, E18 33.752 N52 56.086, E18 33.811 N52 56.076, E18 34.063
II	11.43	278a, 279a	N52 55.398, E18 34.066 N52 55.377, E18 34.281 N52 55.192, E18 34.224 N52 55.282, E18 33.819

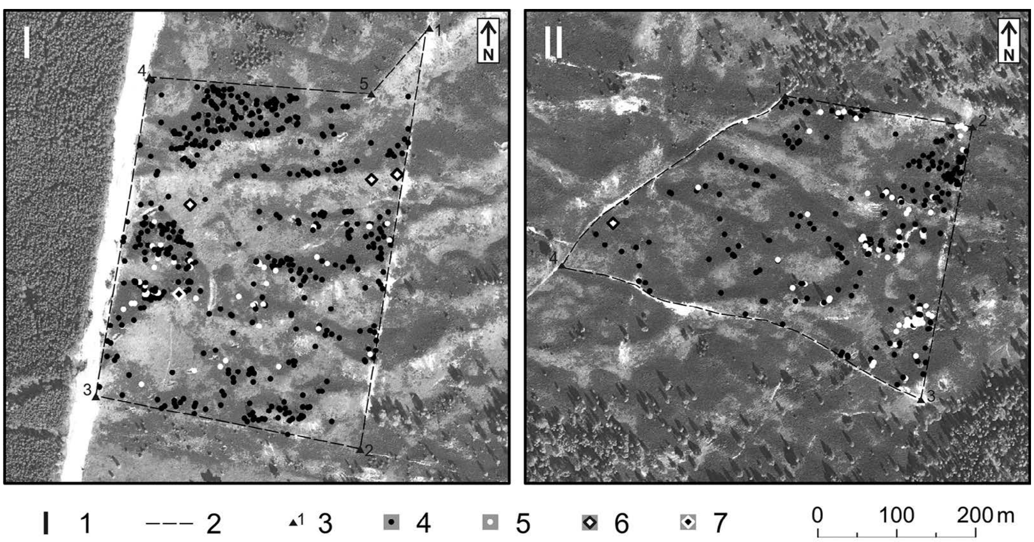

Figure 1. Location of the in-vestigated plots shown in aerial photos together with distribution of trees. Explanations: 1 – plot number, 2 – borders of the plots, 3 – the boundary points described in the Table 1, 4 – Scots pine, 5 – silver birch, 6 – European pear, 7 – European aspen

Both the examined plots are located on areas with many dunes characterised by a hilly landform. A small fragment of Vistula's IX terrace occurs in the southern part of plot no. I (Weckwerth 2010) at an altitude 70 m above sea level [amsl], which constitutes the lowest ordinate of the examined area. The highest point of plot no. I (98 m amsl) is the culmination of the dune located in its northeastern part. Plot no. II is located within several dunes joined together. The altitude of this plot is 73–88 m amsl. In the soil cover, Podzols dominate on both plots, which are often eroded to different depths because of destructive processes (mainly deflation) being activated after deforestation. On southern slopes, which are more susceptible to those processes, the wind blowing at the Podzols' upper part is intensive enough that they can be classified as Arenosols (Jankowski 2010; Sewerniak et al. 2013). On the 'Glinki' research area, in the form of small contours, intra-dune soils enriched in iron (Jankowski 2001, 2014), anthropogenically transformed soils and rusty soils on one fragment of the river terrace on plot no. I also occur.

A part of the exercise site on which the 'Glinki' research area was established, was deforested for military purposes (small tree groups of pines were left with a small quantity of birch in places) in the 50s of the 20th century. In the summer of 1989, on an area of several hundred hectares flora regenerating through natural succession was burnt. The last fire that took place on both analysed plots was the fire in the summer of 1991 when mainly grasses colonising open space were burnt. After both fires, only single trees survived on the area designed for research. In order to reduce the risk of another fire, the 'Glinki' research area was localised in a part of the training ground's exercise site placed peripheral to present-day military actions. The established area, after arrangements with the Gniewkowo Forest inspectorate and headquarters of the training ground, has the status of an official permanent research area of Department of Soil Science and Landscape Management of Nicolaus Copernicus University in Toruń.

3. Research methods

Field work, which included designing plot borders and determination of tree locations, was performed in the autumn of 2011. On both plots, all trees that were higher than 1.0 m were measured. Tree location was defined with the use of GPS receiver Garmin eTrex Vista HCx.

Geographic Information System (GIS) analysis, area calculation and cartographic work were carried out with the use of ArcGIS 9.3 software. The first stage of this work was to digitalise contour lines from a topographic map in a 1:10 000 scale. The altitude vector data obtained in such a way underwent interpolation with the use of the 'natural neighbor' method (Spatial Analyst tools were used). Digital Terrain Model obtained in such a way became the basis for further analysis. Areas of slopes were designed for the following aspects: northern (adopted azimuth value for the aspect: 315°–45°), eastern (45°–135°), southern (135°–225°) and western (225°–315°). Areas defined in that way (four result classes corresponding to individual slope aspects for each plot) were compared with the database, which consists of information about the GPS position of trees. In this manner, information about the number and density of trees growing within a specified slope aspect was obtained. In the analysis, terrain inclination higher than 5° was included. Slopes meeting the criterion of inclination were defined in ArcGIS 9.3 with the use of 3D Analyst tools.

4. Results

Number, density and species composition of trees

The presence of 852 trees (560 on plot no. I and 292 on plot no. II) of height 1 m or higher was stated on the examined area. Scots pine (700 trees) and Silver birch (147 trees) distinctly dominated among those trees. Besides those species noted were only five other trees (four European pears and one Common aspen). Pine dominated birch on both plots but it was more visible on plot no. I rather than on plot no. II (respectively, nine and two times more pines than birches; see Table 2).

Table 2. Number of trees and tree density

Plot no.	Number of trees			Tree density [pcs./ha]		
	Σ	pine	birch	Σ	pine	birch
I	560	503	53	38	34	4
II	292	197	94	25	17	8
I + II	852	700	147	32	27	6

Tree density stated on the 'Glinki' research area after 20 years after the last fire was low. It was 32 trees per hectare for the whole area. The value of this parameter on plot no. I was higher than on plot no. II (respectively, 38 and 25 trees/ha), which resulted from the difference in pine densities. Birch density developed inversely. It was two times higher on plot no. II than on plot no. I (Table 2). Due to the relatively small number of birch trees, this fact did not influence significantly the difference of all tree densities on both plots.

Distribution of trees in relation to relief

Tree distribution by species on the 'Glinki' research area is presented on Fig. 1. Significant differences in tree concentrations dependent on the slope aspect were stated (Fig. 2). Northern slopes on both plots, in comparison to all remaining aspects, were characterised by the largest number of trees and also the highest density (Table 3).

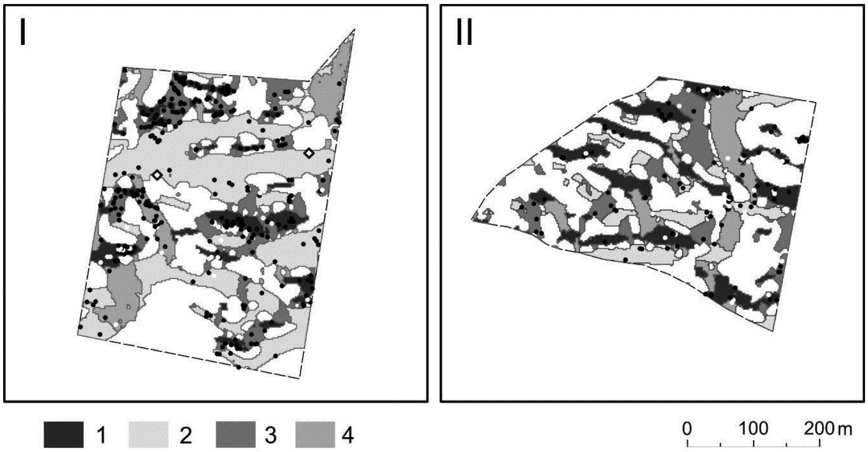

Figure 2. Location of dune slopes with position of trees occurring on the slopes. Explanations: 1 – northern slopes, 2 – southern slopes, 3 – western slopes, 4 – eastern slopes; other denotes as in the Fig. 1.

Table 3. Total area of slopes of different aspect and tree density in relation to slope aspect

Plot no.	Summary slope area [ha] of aspect				Number of trees of all species per 1 ha			
	N	S	W	E	N	S	W	E
I	1.23	4.64	1.61	1.38	117.3	13.2	61.3	34.7
II	1.92	1.19	1.25	1.30	33.8	13.4	16.8	19.7
I + II	3.16	5.83	2.86	2.69	66.5	13.4	41.9	27.9

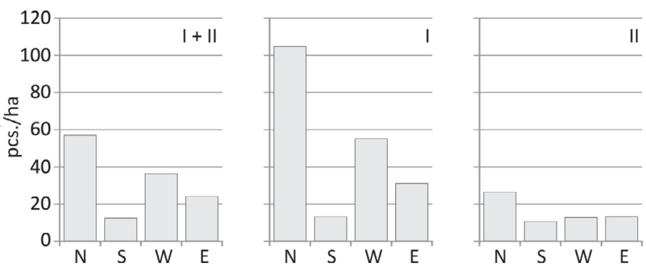

Figure 3. Density of pine in relation to slope aspect (Roman numerals indicate no. of a plot)

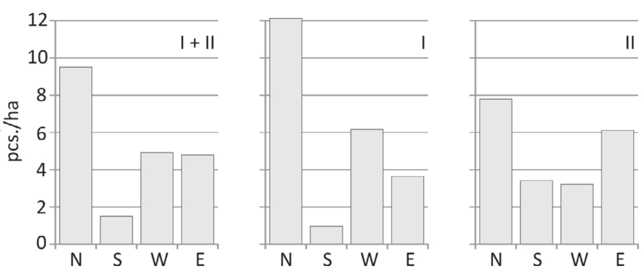

Figure 4. Density of birch in relation to slope aspect (Roman numerals indicate no. of a plot)

Differences in tree density in relation to slope aspects were very clear in the case of both dominant tree species on the 'Glinki' research area which was especially relevant to two contrasting in terms of insolation aspects (northern and southern; Figs 3 and 4). It is worth noting however that differences in densities of both species between those aspects were higher on plot no. I than on plot no. II. Pine density on plot no. I was almost 9 times higher on northern than on southern slopes (respectively, 105.2 and 12.3 trees/ha) and birch density was even 13 times higher (12.1 and 0.9 trees/ha). In the case of plot no. II, density differences were much smaller. Pine density on northern slopes was 2.6 times higher than on southern slopes (26.0 and 10.0 trees/ha) and density of birches was 2.3 times higher (7.8 and 3.4 trees/ha). Differences in pine and birch densities between western and eastern aspects were much smaller. On plot no. I, a higher density of trees was stated on western slopes and on plot no. II it was stated on eastern slopes (Figs 3 and 4). On the fragment of the river terrace on plot no. I, the tree density was 25 trees per hectare.

5. Discussion

In reference to the terminology proposed by Faliński (1986), back in 2011, the 'Glinki' research area represented an optimum stage of re-creative secondary succession in coniferous forest series. The dominant role of pine and birch in the recolonisation of this area after a fire is not surprising because those species are pioneers. Their renewal in natural conditions is often connected with the occurrence of disasters (Brzeziecki 2000). A continental fresh pine forest *Peucedano-Pinetum* is mainly a potential flora of poor habitats occurring on the dune fields of Bydgoszcz Forest (Chojnacka et al. 2010; Gugnacka-Fiedor, Adamska 2010). The increase in pine dominance over birch at the terminal stage of succession should be expected. Due to low trophism of habitats, it may be assumed that the diversity of tree species entering the 'Glinki' area will be lower in the future than on areas established in conditions of more fertile habitats (Hibbs 1983; Bernadzki et al. 1998). Oak–hornbeam forest species are most likely to appear on the southern part of plot no. I on contours of rusty soils that are characterised by hi-gher trophism than Podzols. The evolution of forest stands on rusty soils towards oak–hornbeam forests seems to be just theoretical due to the 'Glinki' location far from forest stands being a potential source of diasporas of oak–horn-beam forest species and also due to a large number of deer on the training ground area (about 35–40 specimens/1000 ha).

The 'Glinki' research area, in the period from the occurrence of the last fire to the time of measurement (20 years), was characterised by low tree density. It was much lower than in other natural seedings on areas where a disaster occurred (Dobrowolska 2007, 2008; Sewerniak 2010). This can be explained by the large number of deer on the Toruń training ground, fast spread of grass and heather on extensively burnt areas, which have competed for tree seedlings, and most of all by the lack of sufficient source of tree diasporas in the close neighborhood of the 'Glinki' area. Even though plot no. I is located in the close vicinity of a production pine stand (placed to the west of the plot), which was only 21 years old in the year of the last fire. This stand may have a significant impact on the occurrence of seeding when it is 30–40 years old because at that age pines growing in closed canopy start to produce seeds (Obmiński 1970). Eight years older pine monoculture growing in the compartment 207a placed to the northwest of plot no. I had a bigger role in seed sowing, which was reflected in a relatively high tree density in this part of the plot (Fig. 1). The direction of seed dispersion influenced also the tree distribution on plot no. II. A relatively large number of trees in its eastern part (Fig. 1) result from the fact that near the plot's eastern border, trees that survived the fire are located (mainly birches) and at that time, they had been around for 25 years. It also explains the lesser dominance of pine over birch on plot no. II than on plot no. I (Table 2). The dominant direction of seed inflow different in the case of both plots may explain the opposite density of pines and birches for eastern and western slopes on the examined plots (on plot no. I, higher for both species on western slopes and on plot no. II, higher on eastern slopes; see Figs 3 and 4).

Another, besides the direction of seed inflow, important factor influencing the tree distribution on the 'Glinki' research area is slope aspect. The influence of this factor on phytocoenosis features was observed also in the production forests of Bydgoszcz Forest (Sewerniak et al. 2011, 2012), seaside dunes (Piotrowska 1988) and also on areas formed from material other than aeolian sand (Cantlon 1953; Różański, Szwagrzyk 1987; Socha 2008). Besides, microrelief was indicated as a factor influencing the course of forest succession on wet meadows (Falińska 2003). Habitat conditions play a crucial part in ecological processes determining the flora spatial organisation (Faliński 2001), and different microclimates are being created due to the differences in inflow of solar energy on slopes of different aspects (Cantlon 1953; Sewerniak et al. 2011). Taking the above-mentioned factors into consideration, differences in tree density that were revealed for other slope aspects can be linked to the occurrence of varying relief site conditions. A higher density observed for northern than for southern slopes (Table 3, Figs 3 and 4) may be explained by the more favourable site conditions (referring both to moisture and contents of nutrients) occurring on shady slopes of Toruń training ground's dunes (Sewerniak et al. 2011, 2013). A significant influence of relief on tree distribution is reflected in the more distinct difference in the density between northern and southern slopes on plot no. I than on plot no. II (Table 3, Figs 3 and 4). Plot no. I is characterised by a height amplitude 13 m greater than plot no. II. This favours the occurrence of strongly visible slopes and, as a result, more distinct differences in site conditions on contrasting aspects.

Another factor influencing tree distribution on the examined area is ground vegetation. It is however a more indirect factor because it is conditioned by landform. On dunes of the training ground's exercise site a regular, microrelief conditioned, flora system can be observed, which appears also on the 'Glinki' research area. Northern slopes are covered most often by heather (*Calluna vulgaris*) and southern slopes by grass (Jankowski 2010; Sewerniak et al. 2013) – mainly grey hair-grass (*Corynephorus canescens*), sheep's fescue (*Festuca ovina*) and wood small-reed (*Calamagrostis epigejos*) which strongly compete for tree seedlings. The influence of ground flora on the distribution of young trees was observed by Ciurzycki (2004), who in a study conducted on mountain meadows stated more occurrences of spruce seedlings in groups of blueberries than in phytocoenosis of tufted hair grass. This author did not state however a relation between the number of seedlings and slope aspects.

6. Summary

The permanent 'Glinki' research area represented in 2011 an optimum stage of re-creative secondary succession in coniferous forest series. The tree density 20 years after the last fire was low (32 trees/ha) with a clear predominance of Scots pine (82% of all trees) and a relatively high share of Silver birch (17%). Other species growing on the examined area (European pears and Common aspen) were represented by some specimens only.

Crucial factors determining the distribution of trees in the examined area were the direction of seed inflow and relief. On both the examined plots of the 'Glinki' area, the highest density of trees appearing spontaneously after the fire (both pines and birches) was stated on slopes of the northern aspect. It suggests that, on inland dunes of Central Europe this slope aspect offers the best conditions for secondary succession of forests. The least favourable conditions are the ones occurring on southern dune slopes, which is confirmed by the lowest tree density revealed for this slope aspect.

The diversity of tree density in relation to slope aspects could be explained first of all by differences in site conditions and by differences in a type of ground vegetation occurring on slopes of different aspects. A detailed recognition of those relations requires further research.

Conflict of interest

None declared.

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Author's contribution

P.S. – research concept, execution of fieldwork, interpretation of results, literature review, manuscript preparation; Ł.M. – comparison of data, spatial analysis of results.

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