SYLWAN 166 (7): 444-461, July 2022
https://doi.org/10.26202/sylwan.2022042
Journal homepage: https://sylwan-journal.pl

ORIGINAL PAPER

A century-long change in vegetation in Zdrojowa Góra interdunal depression, Niepust range, Kampinos National Park (central Poland)

Piotr T. Zaniewski[(1)]✉, Ewa Zaniewska[(2)], Anna Kębłowska[(3)], Łukasz Kwaśny[(4)]

[(1)] Department of Forest Botany, Institute of Forest Sciences, Warsaw University of Life Sciences, Nowoursynowska 159, 02-776 Warsaw, Poland

[(2)] Department of Environmental Protection and Dendrology, Institute of Horticultural Sciences, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787 Warszawa, Poland

[(3)] Science and Nature Monitoring Division, Kampinos National Park, ul. Tetmajera 38, 05-080 Izabelin, Poland

[(4)] Independent Department of Geomatics and Spatial Management, Institute of Forest Sciences, Warsaw University of Life Sciences, Nowoursynowska 159, 02-776 Warsaw, Poland

ABSTRACT

Long-term studies can provide a better understanding of vegetation dynamics. However, the shortage of older datasets means such studies remain uncommon. An exception is the work by Professor Roman Kobendza, who in the 1920s prepared a high-quality sketch of vegetation of the Zdrojowa Góra interdunal depression in Kampinos National Park (KNP), central Poland. He identified 11 plant communities, consisting mainly of open mire, bog, sedge, and meadow vegetation, and drew six 1-m elevation isolines. In the 1920s the area was a wet pasture. Nowadays, the site is abandoned and covered by shrub and forest vegetation arising from secondary succession. The aim of this study was to describe the present state of the vegetation and interpret its past dynamics. The historical spatial vegetation data was georeferenced primarily using microtopography derived from a high-resolution Digital Elevation Model. Fieldwork was carried out in 2022, ca. 100 years after the inventory made by Kobendza, including aerial photogrammetry, ground vegetation sampling, and mapping with a high-resolution orthophotomap. Changes in habitat were assessed using environmental indicators values. Significant shifts in vegetation were observed since the original survey, 100-years previously. Non-forest communities were replaced by scrub and forest vegetation. The study area was dominated by *Frangula alnus* and *Betula pubescens*. Two plant associations were identified: optimal and terminal phases of buckthorn scrub (*Frangulo-Rubetum plicati*) and the initial phase of mixed oak-pine forest (*Querco-Pinetum*). Secondary succession process was interpreted. Based on ecological indicator values, there were registered decreases in light and moisture and an increase in fertility. These results confirm trends of environmental changes taking place in ecosystems at KNP. The study shows that microtopography can be successfully used during geoprocessing of historic surface vegetation data.

✉e-mail: piotr_zaniewski@sggw.edu.pl

Received: 25 July 2022; Revised: 30 September 2022; Accepted: 30 September 2022; Available online: 5 November 2022

KEY WORDS

agricultural abandonment, ecological indicator values, ecological succession, forest, *Frangulo-Rubetum plicati*, *Querco-Pinetum*, wetlands

Introduction

LONG-TERM STUDIES ON VEGETATION CHANGE. Long-term vegetation studies bring valuable information about plant species dynamics and help improve the understanding of community change and its reaction to changing environment (Faliński, 1990; Wildi *et al.*, 2004; Kowalska, 2012). One of the most commonly used approaches to resurveying historical vegetation data uses the Braun-Blanquet method with vegetation plots (*e.g.*, Evangelista *et al.*, 2016; Czortek *et al.*, 2018). There is a large amount of such data already available in the literature (Dengler *et al.*, 2011). In forests, information on tree species parameters is also used (*e.g.*, Brzeziecki *et al.*, 2020a). Resurveying historical vegetation plots has become popular despite some challenges, including uncertainty about plot location (Chytrý *et al.*, 2014; Kopecký and Macek, 2015; Kapfer *et al.*, 2017). The use of vegetation spatial data requires the application of more advanced procedures (Wildi *et al.*, 2004; Pancer-Koteja *et al.*, 2009; Kowalska, 2012).

THE USE OF PHYTOSOCIOLOGICAL SPATIAL DATA IN VEGETATION DYNAMICS ASSESSMENT. Resurveying historical spatial vegetation data is usually based on aerial photographs and satellite imagery (Kleinod *et al.*, 2005; Tyburski, 2017; Kapusta *et al.*, 2018), analyses of topographical maps (Szymura *et al.*, 2018), or field mapping of plant communities (Cannone *et al.*, 2007; Wozniak *et al.*, 2009; Kowalska, 2011; Krause *et al.*, 2011). Historical phytosociological maps are most valuable because they provide more accurate identification and better interpretations compared to the analysis of topographic maps or aerial photographs (Kowalska, 2012). However, the use of phytosociological maps in vegetation dynamics studies often requires appropriate data pre-processing, which depends on the features of each dataset. Nowadays, such studies are usually carried out with Geographical Information System (GIS) software, due to the need for data georeferencing and digitalisation (*e.g.*, Pancer-Koteja *et al.*, 2009; Kowalska, 2012). These procedures are preceded by scanning of phytosociological maps, which requires high-quality equipment for scanning large sheets.

Accurate analysis of vegetation change can be hampered by inaccuracies that arise during digitization and calibration, misinterpretation of vegetation units, and imprecise delimitation of unit boundaries (Kowalska, 2012). Georeferencing historical datasets requires good-quality control points, *i.e.*, locations whose coordinates can be determined without significant error, such as roads, buildings, or narrow gorges (Pancer-Koteja *et al.*, 2009). However, some datasets may not include stable terrain features. Thus, their georeferencing requires additional procedures, such as overlaying maps with other cartographic datasets to increase the probability of locating specific vegetation points or patches (Kowalska, 2012).

Comparing historical with new datasets can also entail additional difficulties due to different interpretations of vegetation types resulting from changes in syntaxonomy. In such cases, the generalization of vegetation units is needed (Pancer-Koteja *et al.*, 2009; Kowalska, 2012). Such a procedure is not complicated, as it uses a hierarchical system of syntaxa. However, the accuracy of sequential vegetation map comparisons also depends on the size of vegetation patches. Overlapping small objects can result in higher errors due to their imprecise locations (Pancer-Koteja *et al.*, 2009).

The oldest phytosociological maps in Poland were prepared in the first half of the 20th century (Faliński, 1990). Some of the oldest datasets are original maps and sketches of vegetation prepared by Kobendza in today's Kampinos National Park, located in central Poland (Kobendza, 1930).

Aim. The original sketch by Kobendza (1930) provides valuable information on the diversity and spatial arrangement of plant communities of the Zdrojowa Góra interdunal depression ca. 100 years ago. The opportunity to resurvey the mapped area and compare it with present vegetation led us to formulate the following aims for this study: (i) identify the current diversity and distribution of plant communities of the Zdrojowa Góra interdunal depression, (ii) compare the states of vegetation at the same location after 100 years, and (iii) determine the main ecological drivers of observed vegetation change and dynamic processes occurring in this ecosystem.

Materials and methods

Study site. Kampinos National Park (KNP) is the second largest national park in Poland. It is in the centre of the country and adjacent to its capital, Warsaw. The park was declared a 'Puszcza Kampinoska' Biosphere Reserve in 2000 and received Natura 2000 status (site PLC140001) in 2004 (Andrzejewska *et al*., 2010). It is the largest park in an area of forest that is constantly increasing due to afforestation, regeneration, and natural succession processes. The Zdrojowa Góra dune complex (WGS84: 52°19.3' N; 22°44.6' E) is located in the north-western corner of the Niepust area, in the south-eastern part of KNP, near Pociecha and Truskaw villages (Herz, 2022). At the beginning of the 20th century, the dune complex bordered farmland, mainly extensive areas of pasture belonging to Truskaw village (Kobendza, 1930), adjacent to state forests, and the private forest complex of Gać Zaborowska village. The whole complex of wet pastures was the largest area of *Nardus* grasslands in the entire Kampinos Forest (Kobendza, 1930). This pasture was purchased in 1977 and placed under strict protection in 1980 (Zespół, 1977; Ferchmin, 2010; Otręba *et al*., 2010). In 1988, about 70 ha of the area was affected by wildfire and left to allow spontaneous secondary succession to take place. Strict protection lasted till 1997 (Otręba *et al*., 2010) and then changed to active protection. This transition enabled active conservation, especially by mowing the meadows (Ferchmin, 2010). In addition, trees and shrubs were removed from about 10 ha of heathland xeric grasslands and inland dunes during 2010-2015 (Pepłowska-Marczak, 2016). Recently, tree and shrub removal has continued within additional parts of the Niepust area.

Historical sketch of vegetation of the interdunal depression in KNP. Kampinos National Park was established in 1959, but regular geobotanical studies of the area were first done at the beginning of the 19th Century (Andrzejewska *et al*., 2010). Interdunal depressions are a significant natural peculiarity diversifying the dune landscape within the park. The unique sketch of vegetation in the interdunal depression of the dune complex was prepared by Kobendza (1930) as a part of his inventory of Kampinos Forest vegetation carried out in 1922-1924. Although the sketch lacked a scale and north arrow, the work is of high quality. Kobendza distinguished 11 communities belonging to five phytosociological classes and carefully mapped their distribution. The sketch identified many small vegetation patches. In addition, Kobendza drew the original six 1-meter elevation isolines. These factors indicate the high precision and originality of mapping of the sketch, which allowed the dataset to be georeferenced. The sketch was supplemented by Kobendza with comments made in the main text. The site was characterized as highly wet despite being approximately 1.8 meters higher than adjacent pastures. Area of open water persisted in the middle of the wetland, usually for durations of several months but up to a full year. Wetland vegetation surrounded the area of open water and was gradually replaced by *Nardus stricta* L. along the edges of the depression (Kobendza, 1930). Local dune ridges were afforested with pine in about 1962. The cessation of grazing most probably occurred with the purchase of the area by KNP in 1977 (Ferchmin, 2010; Otręba *et al.*, 2010). The interdunal depression was not afforested but allowed to undergo spontaneous succession. Today, the site is in subcompartment 334n of the Lipków Range in KNP. The dune complex is now called Zdrojowa Góra (Herz, 2022).

Preliminary fieldwork and data preparation. The shape of the interdunal depression and precisely drawn relative elevations (isolines) are identifiable physical characteristics of the site. The presence of a spring northeast of the site and the general description of the area (*i.e.*, the location of pasture to the east, the 1.8 m denivelation between the bottom of the depression and the elevation of agricultural land, the adjoining of the site to a particular forest area) allowed the exact location of Kobendza's research area to be identified. Preliminary fieldwork was conducted in early spring 2022. Kobendza's sketch features were compared with present vegetation borders. Some relationships between local microtopography, past location of standing water, and vegetation types were recognizable, in particular: the lowest elevation of the central-northern part of the interdunal depression (representing the location of standing water in 1922-1924), a small area of higher elevation located in the central-northeast of the site (containing a plant community that included pine), and a small depression in the southeast (formerly a distinct patch of *Carex lasiocarpa* Ehrh.). The border between present-day wetland communities with *Molinia caerulea* (L.) Moench and semixeric communities was documented using GPS. The same procedure was applied to locations of nearby small dune ridges and two dune passes (one southern and one eastern), which corresponded well to their positions on Kobendza's sketch. A photogrammetric flight was carried out (DJI Phantom RTK) to obtain image data over the interdunal depression. The flight was carried out at an altitude of 120 m above ground level, and yielded a high-resolution orthophotomap in natural colours prepared using DroneDeploy software with field pixel size of 5 cm.

Historical map georeferencing and preparation of the sampling scheme. The sketch of the interdunal depression made by Kobendza (1930) was digitized to permit georeferencing. To do so, a high-resolution (1 m grid cell and 0.15 m mean height error) Digital Elevation Model of the site obtained from Geoportal (GUGiK, 2022) was first used to produce elevation isolines. Control points were then created based on vegetation patches connected with microtopography of the interdunal depression and dune passes and ridges, estimated based on the original isolines drawn by Kobendza. The GPS points of the border between humid and semixeric habitats identified in the field were used as an additional spatial data source. Fifteen highly likely control points were used in sketch calibration. The root mean square error (RMSE) of the affine function was 9.62 m, but the alignment was inadequate. This indicated that the sketch prepared by Kobendza was not fully carthometric. To address this issue a spline function was used in its transformation. This greatly enhanced the visual alignment of the sketch content, which we believe improved the average accuracy to less than about 5 m. Vegetation patches were vectorised and their areas calculated. Due to changes in syntaxonomic approach, the vegetation types identified were generalised in order to compare changes in their area over time (cf. Pancer-Koteja *et al.*, 2009; Kowalska, 2012). The highest syntaxonomic level of vegetation units (class) was applied. A regular grid of 19 sample plot locations (25 m distance from one other) was prepared. Georeferencing and preparation of the sampling scheme were conducted in QGIS 3 software (QGIS Development Team, 2022). Maps were drawn with ArcGIS 10.8.

Sampling and remapping of the vegetation of the interdunal depression. Fieldwork was conducted in the middle of May 2022. Vegetation was sampled using the relevé method (Braun-Blanquet, 1928) with 50 m^2 samples distributed evenly in a 25 m grid. The Barkman *et al.* (1964) scale was used in the survey to obtain narrower cover intervals. The narrower scale decreases data uncertainty as noted by Podani (2006). Cover was used as a measure of species abundance (Barkman *et al.*, 1964; Dengler *et al.*, 2008). Sampling covered the entire interdunal depression and the nearby dune slopes. This better represented the vegetation of the interdunal depression border zone. Nineteen vegetation samples were obtained altogether. Vegetation mapping was based on phytosociological sampling and field mapping using GPS and the paper version of the high-resolution orthophotomap on a scale of 1:500.

Statistical and numerical analyses. Vegetation data was arithmetically transformed using the means of the cover intervals (Tüxen and Ellenberg, 1937). In further analyses, species cover of the upper and lower tree layers were summed, as were woody species of the shrub and herb layers. Vegetation data were then square-root transformed to reduce the importance of species domination. The Ward classification and PCoA ordination of vegetation data with the Bray-Curtis measure were conducted to identify vegetation patterns in the study area. The phytosociological classification of communities reflecting the groups of relevés obtained was based on Matuszkiewicz (2008) and Matuszkiewicz *et al.* (2012).

Nine sampling points were located within the inner part of the interdunal depression mapped by Kobendza (1930). These were used to compare habitat conditions in 1922-24 and 2022 based on ecological indicator values (EIV) of light (L), moisture (F), and fertility (N) (Ellenberg and Leuschner, 2010). EIVs of dominant species of the communities described by Kobendza were used. The arithmetic mean of EIVs of additional species was calculated where two dominant species in a community were present or when the location of a sampling point bordered more than one vegetation patch; the use of arithmetic mean is recommended by Chytrý *et al.* (2018). The present EIVs of vegetation were calculated for herb and bryophyte layers within the same sampling locations used in the Kobendza sketch. Historical and present-day datasets were compared using a non-parametric Wilcoxon two-sample paired signed rank test. Numerical and statistical analyses were conducted with PAST 4 software (Hammer *et al.*, 2001).

Results

Five groups of contemporary relevés were distinguished using Ward's classification (Fig. 1). They represented the following communities:

A – semixeric pine forest *Leucobryo-Pinetum* with domination by *Pinus sylvestris* L. in the tree stand, *Deschampsia flexuosa* L. in the herb layer, and *Pleurozium schreberi* (Willd. ex Brid.) Mitt. in the bryophyte layer, occurring on dune ridges, not registered within the interdunal depression,

B – semixeric oak-pine forest *Querco-Pinetum typicum* with domination by *Pinus sylvestris* in the tree stand, *Frangula alnus* Mill. in the shrub layer, the dominance of species from *Vaccinio-Piceetea* class (*e.g.*, *Pleurozium schreberi*), and admixture of species from *Querco-Fagetea* class (*e.g.*, *Melica nutans* L. and *Stellaria holostea* L.) in the herb and bryophyte layers, located on the edges of the interdunal depression and dune slopes,

C – wet initial oak-pine forest *Querco-Pinetum molinietosum* with domination by *Betula pubescens* Ehrh. and admixture of *Pinus sylvestris* in the tree layer, domination of *Frangula alnus* in the shrub layer, co-dominance of *Molinia caerulea*, *Pteridium aquilinum* (L.) Kuhn and *Vaccinium myrtillus* L. with a small admixture of species from

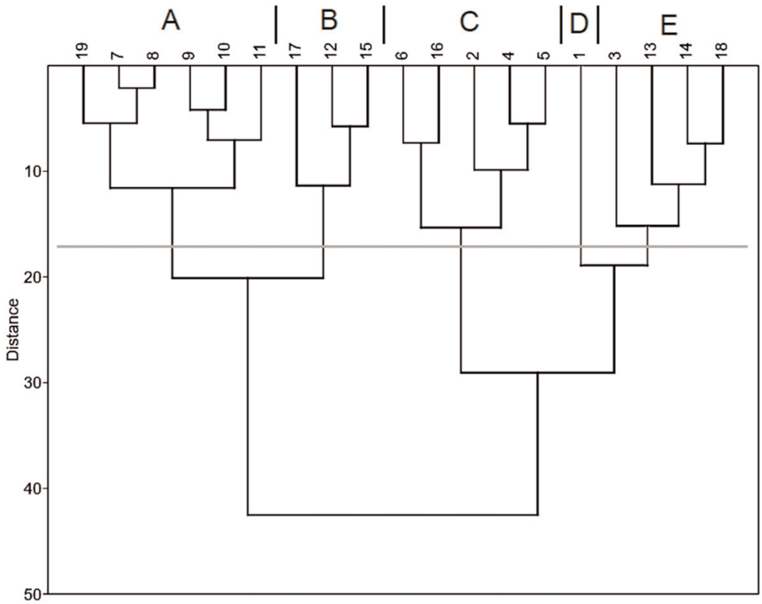

Fig. 1.
Ward's classification of phytosociological data obtained in 2022
A – *Leucobryo-Pinetum*, B – *Querco-Pinetum typicum*, C – *Querco-Pinetum molinietosum*, D – *Querco-Pinetum molinietosum* with *Carex acutiformis*, E – *Frangulo-Rubetum plicati*

Querco-Fagetea class (*e.g.*, *Corylus avellana* L., *Melica nutans*, *Polygonatum multiflorum* (L.) All.), occurring in large parts of the entire interdunal depression; this group of relevés was diverse and represented communities of varying moisture and successional stages (Table 1),

D – wet initial oak-pine forest *Querco-Pinetum molinietosum*, similar to group C but with admixture of *Carex acutiformis* Ehrh., located in the deepest part of the interdunal depression (Table 1),

E – wet buckthorn scrub community *Frangulo-Rubetum plicati*, dominated by *Frangula alnus* in the shrub layer, partially with the tree layer dominated by *Betula pendula* Roth, with diverse herb and bryophyte layers, often with *e.g.*, *Molinia caerulea*, *Pteridium aquilinum*, *Moehringia trinervia* (L.) Clairv. or *Brachytecium rutabulum* (Hedw.) Schimp., located in the northern and western parts of the interdunal depression (Table 1).

All five groups of relevés were separated in the PCoA ordination (Fig. 2). Communities sampled inside the interdunal depression were located on the right of the graph, while those recorded on slopes and dune ridges were on the left side.

The two states of vegetation (identified in surveys conducted in 1922-24 and 2022) are presented in Fig. 3 and 4. Standing water occupied an area of ca. 0.04 ha in 1922-24 but was not present in 2022. Non-forest vegetation types (*Molinio-Arrhenatheretea*, *Nardo-Callunetea*, *Oxycocco-Sphagnetea*, *Phragmitetea*, *Scheuchzerio-Caricetea*) occurred on ca. 0.50 ha in 1922-24 and were also not present in 2022. Scrub and forest communities (community with *Pinus sylvestris*) occurred on ca. 0.02 ha in 1922-24 and over the entire area in 2022 (ca. 0.56 ha, *Rhamno-Prunetea – Frangulo-Rubetum plicati*, and *Vaccinio-Piceetea – Querco-Pinetum*). Mire (*Scheuchzerio-Caricetea*), bog (*Oxycocco-Sphagnetea*), and sedge (*Phragmitetea – Magnocaricion*) vegetation types were registered on ca.

Table 1.

Vegetation characteristics of *Querco-Pinetum molinietosum* and *Frangulo-Rubetum plicati* patches surveyed in the Zdrojowa Góra interdunal depression, KNP

Successive number of relevé Field number of relevé	1 6	2 16	3 2	4 4	5 5	6 1	7 3	8 13	9 14	10 18
Area of relevé [m^2]	50	50	50	50	50	50	50	50	50	50
Cover of upper tree layer A1 [%]	60	60	70	30	40	65	45	80	0	40
Cover of lower tree layer A2 [%]	0	40	25	25	0	35	0	10	15	5
Cover of tree layer in total A [%]	60	80	85	55	40	85	45	85	15	45
Cover of shrub layer B [%]	65	45	15	40	35	45	35	60	60	75
Cover of herb layer C [%]	85	80	45	70	65	30	70	40	60	75
Cover of moss layer D [%]	55	75	15	30	20	2	40	1	5	10
Association name	*Querco-Pinetum molinietosum*							*Frangulo-Rubetum plicati*		
Upper tree layer A1										
Betula pendula Roth A1			1				3b			2b
Betula pubescens Ehrh. A1	4a	4a	4b	2a	3a					
Pinus sylvestris L. A1	1			2b	1					2b
Populus tremula L. A1						4b				
Lower tree layer A2										
Betula pendula Roth A2						1		5a		
Betula pubescens Ehrh. A2			2b	2b		3a				1
Pinus sylvestris L. A2		1								
Quercus robur L. A2		3a							2a	1
Tree layer A										
Viscum album L. A					+		2b	2a		
Shrub layer B										
Betula pubescens Ehrh. B	1	2a	1	2a		2a		2a	1	
Frangula alnus Mill. B	4a	3b	2a	2b	3b	3a	3a	4a	4a	4b
Juniperus communis L. B	+	r								+
Padus avium Mill. B		+							+	
Populus tremula L. B	+			1	1		r			1
Quercus robur L. B	+	+		+	+		r		+	
Sorbus aucuparia L. emend. Hedl. B									r	1
Woody species in herb layer C										
Betula pubescens Ehrh.						r				
Corylus avellana L.		+	r						+	+
Frangula alnus Mill.	+	+	+	+	1	1	1	+	+	+
Juniperus communis L.		+					+			
Malus sylvestris (L.) Mill.								r	r	
Padus avium Mill.		r	r					+	+	
Pinus sylvestris L.			+	r		+	+			
Populus tremula L.	+			+	+	r	+			r
Prunus domestica L.		+							r	
Prunus cerasifera Ehrh.							r	r	r	
Pyrus communis L.								r		
Quercus robur L.	+	+	+	r	+	+	+	r	r	+
Sambusus nigra L.								+		
Sorbus aucuparia L. emend. Hedl.				r				+	r	+
Sorbus intermedia (Ehrh.) Pers				r						
Viburnum opulus L.								r		

Table 1. continued

Successive number of relevé Field number of relevé	1 6	2 16	3 2	4 4	5 5	6 1	7 3	8 13	9 14	10 18
Herb layer C										
Agrostis stolonifera L.			1						r	
Antoxanthum odoratum L.							1			
Carex acutiformis Ehrh. s.l.*						2a			+	
Carex nigra Reichard			+	r			2a	+		
Carex pilulifera L.	+	r	+	r	+	r	+			
Convallaria majalis L.									+	+
Deschampsia caespitosa (L.) P. Beauv.								r		
Deschampsia flexuosa L.	2a	2a	2b	3a	1	r	3a		+	+
Dryopteris carthusiana (Vill.) H. P. Fuchs			+			1	r		+	
Fragaria vesca L.									r	
Galeopsis sp.								r	+	
Galium aparine L.									r	
Holcus lanatus L.						r				
Juncus effusus L.			+			+		2a	r	
Lycopodium clavatum L.				r			+			
Lysimachia vulgaris L.				r	r	r		+	+	r
Maianthemum bifolium (L.) F. W. Schmidt								+	1	3b
Melampyrum pratense L.	+									
Melica nutans L.		+						+	+	1
Milium effusum L.								+	+	
Molinia caerulea (L.) Moench	2b		+	2a	3a	1	2b		1	
Moehringia trinervia (L.) Clairv.		1	1	r	+	+	+	2b	2b	+
Mycelis muralis (L.) Dumort.			+					+	1	
Poa palustris L.									r	
Polygonatum multiflorum (L.) All.			+					+	1	
Potentilla erecta (L.) Raeusch.		r			r		r			
Pteridium aquilinum (L.) Kuhn	1	3a	2a	2b	2b			2a	3a	2b
Rubus subgenus Rubus			1	+	1	r		+	+	+
Trientalis europaea L.	+	1	1	2a	2a		+	1	1	+
Urtica dioica L.								r		
Vaccinium myrtillus L.	4b	3b	1	2b	1	+	1			r
Vaccinium vitis-ideaea L.	1			2a	+					+
Viola palustris L.								r		
Moss layer D										
Brachythecium rutabulum (Hedw.) Schimp.	1			2a	2a	+	2b	+	1	2a
Dicranum polysetum Sw. ex anon.				+	+		1			
Dicranum scoparium Hedw.			+			r	1			
Hylocomium splendens (Hedw.) Schimp.		2a								
Hypnum cupressiforme Hedw.		r								
Leucobryum glaucum (Hedw.) Angstr.						r				
Plagiomnium affine (Blandow ex Funck) T. Kop.	1	r								
Pleurozium schreberi (Willd. ex Brid.) Mitt.	3b	3a		2b	2a		1			+
Polytrichastrum formosum (Hedw.) G.L.Sm.	r									

Table 1. continued

Successive number of relevé Field number of relevé	1 6	2 16	3 2	4 4	5 5	6 1	7 3	8 13	9 14	10 18
Polytrichum commune Hedw.			2a	+		r				
Pseudoscleropodium purum (Hedw.) M.Fleisch.		2a								
Sciuro-hypnum oedipodium (Mitt.) Ignatov & Huttunen		+	1							

Cover values of alphanumeric symbols used: 5b=87.5-100%, 5a=75-87.5%, 4b=62.5-75%, 4a=50-62.5%, 3b=37.5-50%, 3a=25-37.5%, 2b=12.5-25%, 2a=5-12.5%, 1=1-5%, '+'= 0.5-1%, r=0.01-0.5%, rr=0.01%
* including intermediates with other *Carex* species

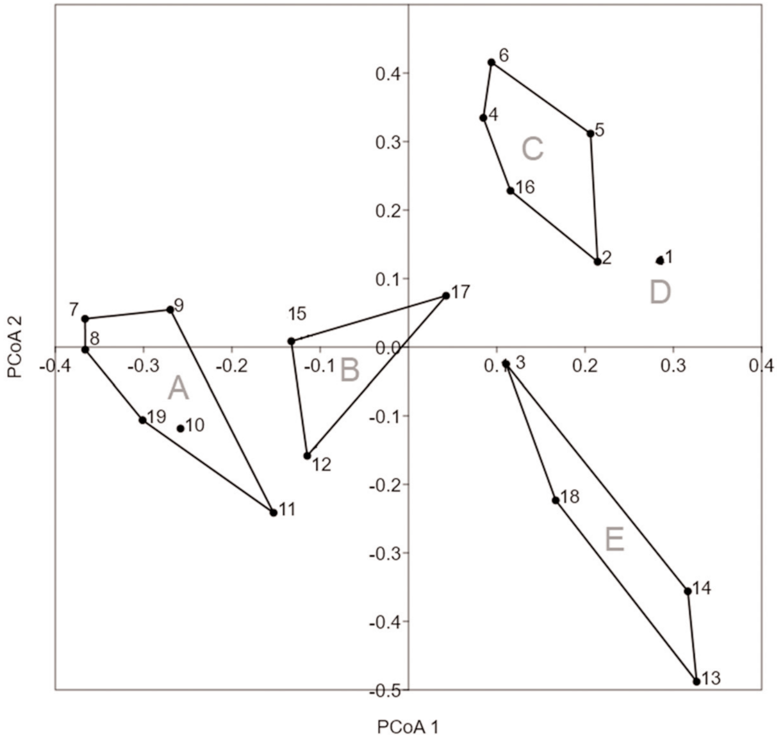

Fig. 2.

PCoA ordination of phytosociological data obtained in 2022, including Ward's classification

A – *Leucobryo-Pinetum*, B – *Querco-Pinetum typicum*, C – *Querco-Pinetum molinietosum*, D – *Querco-Pinetum molinietosum* with *Carex acutiformis*, E – *Frangulo-Rubetum plicati*

0.26 ha in 1922-24 but were not recorded in 2022. Wet and semixeric communities (*Molinio--Arrhenatheretea*, and *Nardo-Callunetea*) occurred on ca. 0.24 ha in 1922-24 and on ca. 0.56 ha (*Rhamno-Prunetea – Frangulo-Rubetum plicati*, and *Vaccinio-Piceetea – Querco-Pinetum*) in 2022. About 0.02 ha of vegetation (a community with *Pinus sylvestris*) could not be classified based on moisture in 1922-24.

Significant differences in all EIVs (*i.e.*, light, moisture, and fertility) were found between 1922-24 and 2022 (Fig. 5). After ca. 100 years, the undergrowth vegetation of the interdunal depression indicates lower light and moisture conditions and a higher level of fertility.

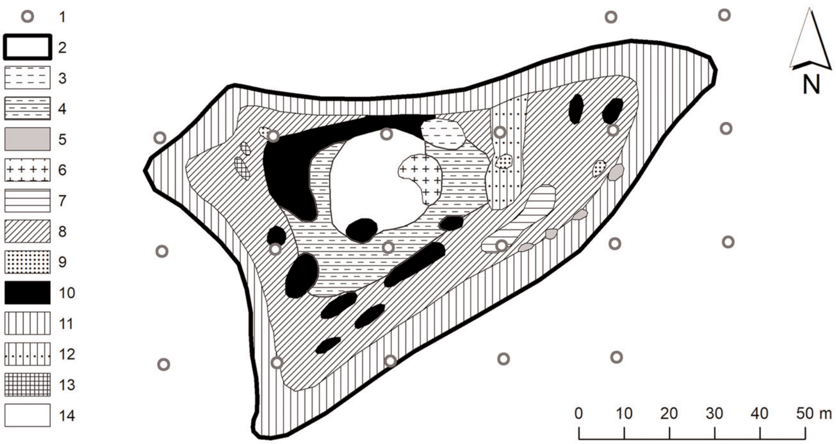

Fig. 3.

Vegetation diversity in the Zdrojowa Góra interdunal depression in 1922-24 [modified Kobendza (1930) by calibration and georeferencing]

1 – contemporary vegetation sampling points, 2 – boundary of Kobendza's research area, 3-14 – vegetation types: 3 – *Agrostis canina*, 4 – *Agrostis canina* L. and *Carex lasiocarpa*, 5 – *Calluna vulgaris* (L.) Hull, 6 – *Carex acutiformis*, 7 – *Carex lasiocarpa*, 8 – *Carex nigra* Reichard, 9 – *Eriophorum vaginatum* L., 10 – *Juncus conglomeratus* L., 11 – *Nardus stricta*, 12 – *Pinus sylvestris*, 13 – *Polytrichum commune* Hedw., 14 – open water

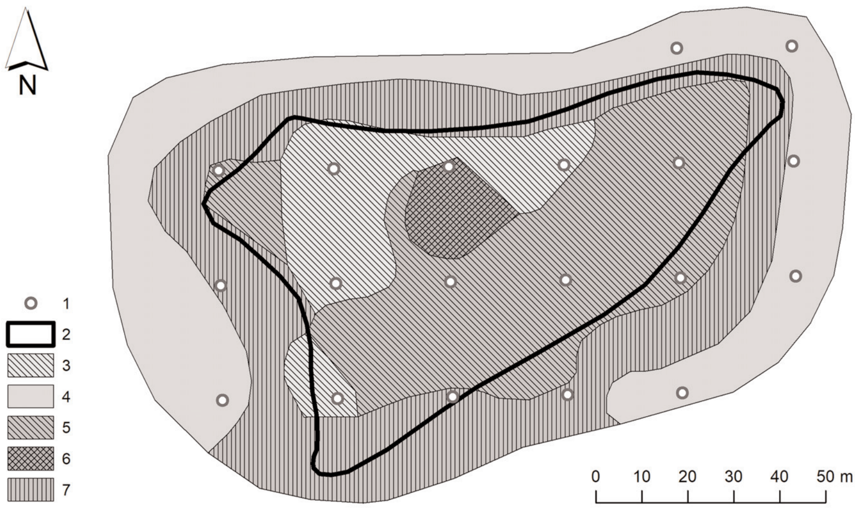

Fig. 4.

Vegetation diversity of in the Zdrojowa Góra interdunal depression in 2022

1 – contemporary vegetation sampling points, 2 – boundary of Kobendza's research area, 3-7 – vegetation types: 3 – *Frangulo-Rubetum plicati*, 4 – *Leucobryo-Pinetum*, 5 – *Querco-Pinetum molinietosum*, 6 – *Querco-Pinetum molinietosum* with *Carex acutiformis*, 7 – *Querco-Pinetum typicum*

Discussion

Despite the increasing number of long-term vegetation studies, few are dedicated to lowland vegetation in central Poland. In KNP, such studies were based mainly on the inventory by Kobendza (1930). Changes in pine forest vegetation were assessed by Solon (2007) and changes in meadow vegetation were described by Michalska-Hejduk (2001). Our study documents vegetation change in the Zdrojowa Góra interdunal depression over ca. 100 years.

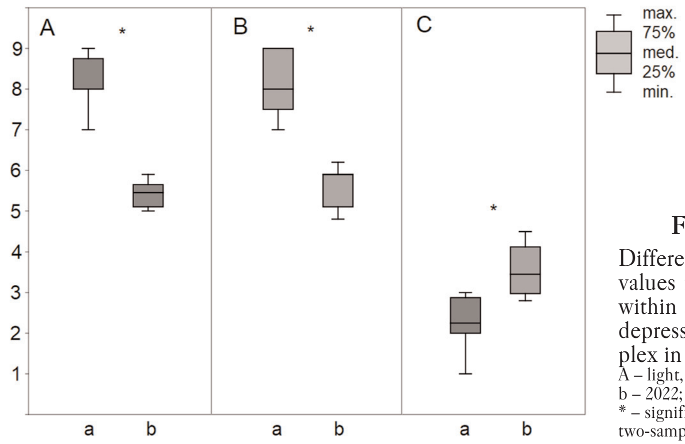

Fig. 5.

Differentiation of ecological indicator values for herb and bryophyte layers within sample plots in the interdunal depression, Zdrojowa Góra dune complex in Kampinos National Park
A – light, B – moisture, C – fertility; a – 1922-24, b – 2022;
* – significant differences according to Wilcoxon two-sample paired signed rank test at α=0.05

Georeferencing historical spatial vegetation data requires additional procedures (Kowalska, 2012). Site topography is often used as a source of control points (Pancer-Koteja *et al.*, 2009, Kowalska, 2012). DEMs are an additional source of good quality and accurate data on microtopographic relief (Affek, 2014). A particular feature of our work was the use of microtopography of the study site during geoprocessing of the sketch of the area, made possible by six elevation isolines drawn by Kobendza. These matched the elevation distribution derived from DEM (GUGiK, 2022) much better than the most accurate 1:25000 topographical map of the time (WIG, 1933).

Vegetation states in 1922-24 and 2022 differ. Scale is an important issue in vegetation monitoring (Wildi *et al.*, 2004). The concepts of vegetation units and habitat types depend on the scale used during mapping (Chytrý and Otýpková, 2003). The interdunal depression described by Kobendza (1930) contained 11 community types, including many small patches of non-forest vegetation from five phytosociological classes (Kobendza, 1930): *Molinio-Arrhenatheretea*, *Nardo-Callunetea*, *Oxycocco-Sphagnetea*, *Phragmitetea*, *Scheuchzerio-Caricetea*, the *Pinus sylvestris* community (probably from the *Vaccinio-Piceetea* class), and open water. In comparison, the vegetation documented in this study on the same site was much more homogeneous (only two classes of plant communities) and was dominated by scrub (*Rhamno-Prunetea*) and early successional forest (*Vaccinio-Piceetea*) communities. In this study, 50 m^2 relevés were made, which is recommended for inventorying scrub vegetation despite the probability of losing some of the finest-scale information (Chytrý and Otýpková, 2003).

Five vegetation types belonging to three associations were distinguished in 2022. The wet buckthorn scrub community *Frangulo-Rubetum plicati* was the least successionally advanced community recorded within the study site. Parts of the area were covered by varying densities of *Betula pendula* in the tree layer. This scrub association often occurs in afforested areas. It is known for its ability to persist under a tree layer (Matuszkiewicz *et al.*, 2012). This association was not mentioned in two prior phytosociological assessments conducted in KNP (Solon, 2003; Andrzejewska *et al.*, 2010). The wet buckthorn scrub community could be included in juvenile forms of *Querco-Pinetum molinietosum* or other forest communities.

The *Querco-Pinetum molinietosum* was present in the interdunal depression. Its vegetation could be described as an early stage of wet oak-pine mixed forest, with its vertical structure reflecting earlier successional stages, represented by buckthorn scrub communities. The predominance of birch in the tree layer is an additional sign of early-successional patches of this association (Matuszkiewicz *et al*., 2012). Dune edges were occupied mainly by *Querco-Pinetum typicum* – the dominant plant community in the KNP dune belts. This vegetation type is of spontaneous successional origin within the interdunal depression, but on the middle and upper slopes of the nearby dunes it comes mostly from planted pine. *Leucobryo-Pinetum* was noted only on the surrounding dune ridges and did not appear within the area of direct comparison. It also is reflective of past tree planting.

In his sketch, Kobendza (1930) reported high diversity of non-forest communities belonging to five phytosociological classes (*Molinio-Arrhenatheretea*, *Nardo-Callunetea*, *Oxycocco-Sphagnetea*, *Phragmitetea*, and *Scheuchzerio-Caricetea*), as well as one scrub or forest community containing *Pinus sylvestris*. Meadows and *Nardus* grasslands in central Poland are anthropogenic communities formed in deforested areas and owe their existence to regular mowing or grazing. Due to the long-lasting and homogeneous use of meadows and pastures, these communities achieve a stable species composition and significant floristic diversity. Even minor changes in management, especially drainage, agricultural mechanization, or the cessation of use, can cause irreversible changes in such communities (Michalska-Hejduk, 2004). These vegetation types were documented by Kobendza (1930) together with open mire, bog, and sedge communities, despite the small area he assessed. This variety of vegetation can coexist under agricultural land use due to differences in nutrient stress and anoxia (Kozub *et al*., 2019). In the case of the Zdrojowa Góra interdunal depression, the diversity of these factors could be related to local variations in moisture. The present study indicates the presence of communities belonging to only two classes of scrub and forest vegetation (*Rhamno-Prunetea* and *Vaccinio-Piceetea*). This indicates the homogenisation of vegetation in the study site. The two vegetation conditions, one observed in ca. 1922-24 and the other in 2022, differ significantly. The condition observed by Kobendza (1930) shows dominance of open mire, bog, sedge, and meadow vegetation, while in 2022 scrub and early successional forest communities predominate. The main ecological process occurring on the site was secondary succession. It is highly probable that this process started after 1977 when grazing ceased.

Abandonment of grazing has resulted in the initiation of ecological succession. The decline in interest in meadow management caused by poor soil quality in KNP or in difficult to access meadows located far from paved roads has led to the overgrowth of large parts of KNP with trees and shrubs. As a result, patches in which secondary succession is advanced are observed throughout the area (Michalska-Hejduk, 2001). There are many successional pathways that abandoned wet meadow communities may take depending on the initial non-forest vegetation, but also on the groundwater level in overgrown patches (Czortek *et al*., 2021; Michalska-Hejduk, 2001, 2006). Abandonment of mowing and grazing within the Łąki Strzeleckie meadow area, located in KNP, resulted in the recruitment of birch seedlings with admixture of alder on wet sites. The encroachment of trees on mesic meadows was slower and started later, mainly with *Salix cinerea* L. After 30 years, the meadow was covered by birch, alder, and willow scrub, with only small unforested patches surviving within most wet habitats (Diehl, 2003). The vegetation change within the Zdrojowa Góra interdunal depression shares some similarities with the Łąki Strzeleckie meadows. The wetter parts, located in the centre of the site, are already covered by early successional forest vegetation. Large parts of its border are still occupied by scrub communities. The process of ecological succession in KNP can be modified or even inhibited by changes in rainfall. Such fluctuations were observed in Długie Bagno transitional bog vegetation, located about 1 km north of the study site (Tyburski, 2017). Changes in precipitation and cessation of grazing were also important factors influencing compositional shifts in vegetation in the Tatra Mountains (Czortek *et al.*, 2018). Ecological succession connected with reduced agriculture or abandonment is common and has recently been observed in many other sites, *i.e.*, in Pieniny National Park (Pancer-Koteja *et al.*, 2009), the Vistula river valley (Kowalska, 2012), and the Narew river valley (Zaniewski *et al.*, 2021).

Decreased habitat moisture can be a result of several factors. In the early 1920s, the centre of the interdunal depression of Zdrojowa Góra was filled with water for periods of a few months up to the entire year (Kobendza, 1930). In comparison, in the early and late spring of 2022, surface water was not present on the site. Moreover, groundwater was not observed at the bottom of a pit about 50 cm deep where a tree had uprooted on the edge of the deepest part of the depression. Decreased moisture was indicated by a significantly lower score of the moisture EIV in 2022 compared to 1922-24. According to Kobendza (1930), the high water table at the site resulted from its past deforestation and agricultural use. After 1977, agricultural use in the interdunal depression was abandoned and secondary succession began. Birch is known for its high rate of evapotranspiration in wetlands, reducing the groundwater table (Grygoruk *et al.*, 2011). Therefore, the secondary succession of birch bushes can induce higher water loss from the system compared to formerly open meadows (Grygoruk *et al.*, 2014).

A second reason for a general decrease in the groundwater table within KNP could be drainage. The groundwater table dropped from 0.2 to 0.5 m between 1960 and 1990 (Kazimierski *et al.*, 2003). Degeneration processes connected with the decrease in groundwater table levels were observed within meadow communities in the western part of KNP (Michalska-Hejduk, 2001). On the other hand, the main drainage channel of the Niepust area, located about 50 m from the interdunal depression, has not been cleaned for years. This probably contributed to the increase in the groundwater level and the wetness of meadows and neighbouring areas (Anna Kębłowska, personal observations). Changes in wet meadow phytocoenoses connected with high rainfall and thus increasing groundwater table levels were also observed in the other parts of KNP (Michalska-Hejduk, 2006). Nevertheless, it is probable that drainage and establishment of birch after the end of agricultural use of the area both contributed to the decreased water table within the interdunal depression. The denivelation between the bottom of the interdunal depression and the abandoned pastures is about 1.8 m. Thus, the local increase in the groundwater table level could be too weak to reflect its position in the early 1920s.

The increase in habitat fertility can be connected with general habitat regeneration. Grazing of wet meadows prevents tree and shrub encroachment (Sienkiewicz-Paderewska *et al.*, 2020). Mowing and grazing can also decrease soil fertility (Oelmann *et al.*, 2009; Enriquez *et al.*, 2014; Kotas *et al.*, 2017). The entire Niepust area was being grazed at the beginning of the 20th century (Kobendza, 1930). At the time, the characteristic vegetation feature was the presence of the largest area of oligotrophic *Nardus* mat-grass sward in the entire Kampinos Forest. Such communities originate after decades of grazing and heavy impoverishment of soils (Schelfhout *et al.*, 2017). This may indirectly indicate the high intensity of grazing and decreased soil fertility in Niepust pastures that occurred in the past.

The Niepust range also was grazed after World War II. However, the area was purchased by KNP in 1977 and placed under strict protection in 1980 (Ferchmin, 2010; Otręba *et al.*, 2010). Since then, the interdunal depression has not been managed and was subject to secondary succession. Cessation of agriculture in oligotrophic wet meadows can result in additional decreases in soil fertility during the early stages of succession (Swacha *et al.*, 2018). However, the results we obtained indicated slightly increased fertility based on EIV species present 100 years following the previous survey. There are several possible reasons for this. Historically, past severe nutrient impoverishment of soils occurred due to grazing, which has been reversed by ecological succession, occurring over about 46 years, with organic matter accumulation and decomposition resulting in nutrient accumulation and its increased availability. The recent increase of deadwood in KNP ecosystems (Torzewski and Otręba, 2018) supports this hypothesis. The third possibility is that this is part of a general increase in fertility of habitats seen across Poland (Brzeziecki, 1999). A decrease of most oligotrophic species within wet meadow communities has occurred in the western part of KNP (Michalska-Hejduk, 2001). The gradual proliferation of species connected with the deciduous forest has recently been observed in the strictly protected Kaliszki and Sieraków areas of KNP (Brzeziecki *et al.*, 2020b). Similar eutrophication processes have been observed elsewhere in Europe (*e.g.*, Pancer-Koteja *et al.*, 2009; Evangelista *et al.*, 2016).

Open habitat conservation vs secondary succession in Kampinos National Park. Meadows are important habitat patches because they increase biodiversity in protected forest areas (Dąbrowska-Prot and Wasiłowska, 2010). This is why many meadow restoration and management projects were implemented in KNP (Bomanowska *et al.*, 2009). The use of secondary succession in habitat restoration in KNP is also increasing (Otręba *et al.*, 2010). Despite agricultural abandonment in the late 20th century, the areas of Niepust and neighbouring Paśniki are still among the most seminatural vegetation-diverse sites in KNP (Ferchmin, 1974, 2010). The active conservation of seminatural vegetation in Niepust started at the end of the 20th century (Otręba *et al.*, 2010) and continues to the present, preventing natural succession that would lead to the establishment of forest in place of present-day grasslands, heaths, and meadows (Ferchmin, 2010; Pepłowska-Marczak, 2016; Andrzejewska *et al.*, 2021). However, secondary succession in the Zdrojowa Góra interdunal depression is already advanced. This area can serve as a reference site where the spontaneous development of forest can be observed.

Summary and conclusions

- the vegetation of the Zdrojowa Góra interdunal depression completely changed between the years 1922-24 and 2022,
- the cessation of agricultural use in 1977 allowed secondary succession to proceed, replacing the dominant non-forest plant communities with scrub and early successional forest vegetation,
- the reestablishment of forest communities can explain a gradual change in undergrowth vegetation, exhibited by decreased light and increased fertility, as shown by changes in ecological indicator values,
- the replacement of mire, bog, and sedge species with less water-demanding vegetation may relate to decreased groundwater table; this process is also occurring elsewhere in Kampinos National Park,
- microtopography can be successfully used when geoprocessing historical surface vegetation data.

Authors' contributions

P.T.Z. – project conception, fieldwork, statistics, GIS, literature review, writing; E.Z. – project conception, fieldwork, literature review, writing; A.K. – project conception, fieldwork, literature review, writing; Ł.K. – project conception, fieldwork, GIS, literature review, writing.

Conflict of interest

No conflicts of interest are declared.

Funding source

This research received no external funding.

Acknowledgements

The study was conducted according to permission No. DE 0604/22/21 by Kampinos National Park.

References

Affek, A., 2014. Lotnicze skanowanie laserowe (ALS) w modelowaniu rzeźby terenu – nowe możliwości i pułapki. *Problemy Ekologii Krajobrazu*, 38: 217-236.

Andrzejewska, A., Ferchmin, M., Kębłowska, A., Otręba, A., 2010. Charakterystyka geobotaniczna Puszczy Kampinoskiej. In: A. Obidziński, ed. *Z Mazowsza na Polesie i Wileńszczyznę. Zróżnicowanie i ochrona szaty roślinnej pogranicza Europy Środkowej i Północno-Wschodniej*. Warszawa: Polskie Towarzystwo Botaniczne – Zarząd Główny, pp. 41-56.

Andrzejewska, A., Kębłowska, A., Otręba, A., Tyburski, Ł., 2021. Kampinoskie wydmy. Izabelin: Kampinoski Park Narodowy, 33 pp.

Barkman, J.J., Doing, H., Segal, S., 1964. Kritische Bemerkungen und Vorschläge zur Quantitativen Vegetationsanalyse. *Acta Botanica Neerlandica*, 13: 394-419.

Bomanowska, A., Michalska-Hejduk, D., Kirpluk, I., Szczepko, K., Olech, B., Olszewski, A., Marczak, D., 2009. Czynna ochrona terenów porolnych – propozycje, podejmowane działania, perspektywy. In: D. Michalska-Hejduk, A. Bomanowska, eds. *Rola Kampinoskiego Parku Narodowego w zachowaniu różnorodności biologicznej i krajobrazowej dawnych obszarów wiejskich*. Łódź-Izabelin: Kampinoski Park Narodowy, pp. 153-166.

Braun-Blanquet, J., 1928. Pflanzensoziologie. Grundzüge der Vegetationskunde, Biologische Studienbücher. Berlin: Springer, 330 pp.

Brzeziecki, B., 1999. Wzrost żyzności siedlisk leśnych: zjawisko pozorne czy rzeczywiste? *Sylwan*, 143 (11): 99-107.

Brzeziecki, B., Woods, K., Bolibok, L., Zajączkowski, J., Drozdowski, S., Bielak, K., Żybura, H. 2020a. Over 80 years without major disturbance, late-successional Białowieża woodlands exhibit complex dynamism, with coherent compositional shifts towards true old-growth conditions. *Journal of Ecology*, 108 (3): 1138-1154. DOI: https://doi.org/10.1111/1365-2745.13367.

Brzeziecki, B., Zajączkowski, J., Olszewski, A., Bolibok, L., Andrzejczyk, T., Bielak, K., Buraczyk, W., Drozdowski, S., Gawron, L., Jastrzębowski, S., Szeligowski, H., Żybura, H., 2020b. Struktura i dynamika wielogeneracyjnych starodrzewów sosnowych występujących w obszarach ochrony ścisłej Kaliszki i Sieraków w Kampinoskim Parku Narodowym. Część 1. Zróżnicowanie gatunkowe, zagęszczenie i pierśnicowe pole przekroju. *Sylwan*, 164 (5): 392-403. DOI: https://doi.org/10.26202/sylwan.2020057.

Cannone, N., Sgorbati, S., Gugliemin, M., 2007. Unexpected impacts of climate change on alpine vegetation. *Frontiers in Ecology and the Environment*, 5 (7): 360-364. DOI: https://doi.org/10.1890/1540-9295(2007)5[360:UIOCCO]2.0.CO;2.

Chytrý, M., Otýpková, Z., 2003. Plot sizes used for phytosociological sampling of European vegetation. *Journal of Vegetation Science*, 14: 563-570. DOI: https://doi.org/10.1111/j.1654-1103.2003.tb02183.x.

Chytrý, M., Tichý, L., Dřevojan, P., Sádlo, J., Zelený, D., 2018. Ellenberg-type indicator values for the Czech flora. *Preslia*, 90: 83-103. DOI: https://doi.org/10.23855/preslia.2018.083.

Chytrý, M., Tichý, L., Hennekens, S.M., Schaminée, J.H.J., 2014. Assessing vegetation change using vegetation-plot databases: a risky business. *Applied Vegetation Science*, 17: 32-41. DOI: https://doi.org/10.1111/avsc.12050.

Czortek, P., Borkowska, L., Lembicz, M., 2021. Long-term shifts in the functional diversity of abandoned wet meadows: Impacts of historical disturbance and successional pathways. *Ecology and Evolution*, 11: 15030-15046. DOI: https://doi.org/10.1002/ece3.8186.

Czortek, P., Kapfer, J., Delimat, A., Eycott, A.E., Grytnes, J.A., Orczewska, A., Ratyńska, H., Zięba, A., Jaroszewicz, B., 2018. Plant species composition shifts in the Tatra Mts as a response to environmental change: a resurvey study after 90 years. *Folia Geobotanica*, 53: 333-348. DOI: https://doi.org/10.1007/s12224-018-9312-9.

Dąbrowska-Prot, E., Wasiłowska, A., 2010. Ecological importance of meadow patches in protected forest area: floristic diversity and the dynamics of insect communities. *Polish Journal of Ecology*, 58: 741-758.

Dengler, J., Chytrý, M., Ewald, J., 2008. Phytosociology. In: *Encyclopedia of Ecology*: 2767-2779. DOI: https://doi.org/10.1016/B978-008045405-4.00533-4.

Dengler, J., Jansen, F., Glöckler, F., Peet, R.K., De Cáceres, M., Chytrý, M., Ewald, J., Oldeland, J., Lopez--Gonzalez, G., Finckh, M., Mucina, L., Rodwell, J.S., Schaminée, J.H.J., Spencer, N., 2011. The Global Index of Vegetation-Plot Databases (GIVD): a new resource for vegetation science. *Journal of Vegetation Science*, 22: 582-597. DOI: https://doi.org/10.1111/j.1654-1103.2011.01265.x.

Diehl, B., 2003. Sukcesja roślinna na Łąkach Strzeleckich a zmiany w zespołach ptaków. In: R. Andrzejewski, ed. *Kampinoski Park Narodowy, Przyroda Kampinoskiego Parku Narodowego*. Tom I. Izabelin: Kampinoski Park Narodowy, pp. 717-728.

Ellenberg, H., Leuschner, C., 2010. Vegetation Mitteleuropas mit den Alpen – Bücher & Zeitschriften für Garten, Gartenbau & Landwirtschaft, Stuttgart: Ulmer Verlag, 6th ed. 1334 pp.

Enriquez, A.S., Chimner, R.A., Cremona, M.V., 2014. Long-term grazing negatively affects nitrogen dynamics in Northern Patagonian wet meadows. *Journal of Arid Environments*, 109: 1-5. DOI: https://doi.org/10.1016/j.jaridenv.2014.04.012.

Evangelista, A., Frate, L., Carranza M.L., Attorre, F., Pelino, G., Stanisci, A., 2016. Changes in composition, ecology and structure of high-mountain vegetation: a re-visitation study over 42 years. *AoB Plants*, 8: plw004. DOI: https://doi.org/10.1093/aobpla/plw004.

Faliński, J.B., 1990. Kartografia Geobotaniczna, 2 kartografia fitosocjologiczna. Warszawa-Wrocław: Państwowe Przedsiębiorstwo Wydawnictw Kartograficznych, 283 pp.

Ferchmin, M., 1974. Trzecia Ścieżka Przyrodnicza (przewodnik dydaktyczny). Laski-Izabelin: Kampinoski Park Narodowy, 12 pp.

Ferchmin, M., 2010. Szata roślinna wydm i bagien Puszczy Kampinoskiej. In: A. Obidziński, ed. *Z Mazowsza na Polesie i Wileńszczyznę. Zróżnicowanie i ochrona szaty roślinnej pogranicza Europy Środkowej i Północno-Wschodniej*. Warszawa: Polskie Towarzystwo Botaniczne – Zarząd Główny, pp. 57-66.

GUGiK, 2022. Główny Urząd Geodezji i Kartografii, Geoportal [WWW Document]. Available from: https://www.geoportal.gov.pl/ [accessed 7.14.22].

Grygoruk, M., Batelaan, O., Mirosław-Świątek, D., Szatyłowicz, J., Okruszko, T., 2014. Evapotranspiration of bush encroachments on a temperate mire meadow – A nonlinear function of landscape composition and groundwater flow. *Ecological Engineering*, 73: 598-609. DOI: https://doi.org/10.1016/j.ecoleng.2014.09.041.

Grygoruk, M., Mirosław-Świątek, D., Okruszko, T., Batelaan, O., Szatylowicz, J., 2011. Estimation of actual evapotranspiration of birch thickets on a fen based on diurnal fluctuations of shallow groundwater level. *Woda--Środowisko-Obszary Wiejskie*, 11: 121-136.

Hammer, O., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Paleontologia Electronica*, 4 (1): 9.

Herz, L., 2022. Puszcza Kampinoska. Przewodnik, 5th ed. Pruszków: Rewasz Oficyna Wydawnicza, 360 pp.

Kapfer, J., Hédl, R., Jurasinski, G., Kopecký, M., Schei, F.H., Grytnes, J.A., 2017. Resurveying historical vegetation data – opportunities and challenges. *Applied Vegetation Science*, 20: 164-171. DOI: https://doi.org/10.1111/avsc.12269.

Kapusta, J., Petrovič, F., Hreško, J., 2018. Monitoring open water area changes in a small tarn using historical orthophotomaps and a historical bathymetric map: a case study of the Litworowy Staw lake, the High Tatras. *Journal of Mountain Science*, 15: 2089-2102. DOI: https://doi.org/10.1007/s11629-018-4915-4.

Kazimierski, B., Sikorska-Maykowska, M., Pilichowska-Kazimierska, E., 2003. Wody. In: R. Andrzejewski, ed. *Kampinoski Park Narodowy, Przyroda Kampinoskiego Parku Narodowego*. Tom I. Izabelin: Kampinoski Park Narodowy, pp. 135-212.

Kleinod, K., Wissen, M., Bock, M., 2005. Detecting vegetation changes in a wetland area in Northern Germany using earth observation and geodata. *Journal for Nature Conservation*, 13: 115-125. DOI: https://doi.org/10.1016/j.jnc.2005.01.004.

Kobendza, R., 1930. Stosunki fitosocjologiczne Puszczy Kampinoskiej. *Planta Polonica*, 2: 1-200.

Kopecký, M., Macek, M., 2015. Vegetation resurvey is robust to plot location uncertainty. *Diversity and Distributions*, 21: 322-330. DOI: https://doi.org/10.1111/ddi.12299.

Kotas, P., Choma, M., Šantrůčková, H., Lepš, J., Tříska, J., Kaštovská, E., 2017. Linking Above- and Belowground Responses to 16 Years of Fertilization, Mowing, and Removal of the Dominant Species in a Temperate Grassland. *Ecosystems*, 20: 354-367. DOI: https://doi.org/10.1007/s10021-016-0031-x.

Kowalska, A., 2011. Przekształcenia roślinności równiny zalewowej doliny środkowej Wisły, gmina Łomianki – strefa podmiejska Warszawy. *Acta Botanica Silesiaca*, 7: 5-16.

Kowalska, A., 2012. Mapy roślinności w badaniach przekształceń środowiska geograficznego. *Prace Komisji Krajobrazu Kulturowego*, 16: 157-169.

Kozub, Ł., Goldstein, K., Dembicz, I., Wilk, M., Wyszomirski, T., Kotowski, W., 2019. To mow or not to mow? Plant functional traits help to understand management impact on rich fen vegetation. *Applied Vegetation Science*, 22: 27-38. DOI: https://doi.org/10.1111/avsc.12411.

Krause, B., Culmsee, H., Wesche, K., Bergmeier, E., Leuschner, C., 2011. Habitat loss of floodplain meadows in north Germany since the 1950s. *Biodiversity and Conservation*, 20: 2347-2364. DOI: https://doi.org/10.1007/s10531--011-9988-0.

Matuszkiewicz, W., 2008. Przewodnik do oznaczania zbiorowisk roślinnych Polski. Warszawa: PWN, 537 pp.

Matuszkiewicz, W., Sikorski, P., Szwed, W., Wierzba, M., 2012. Zbiorowiska roślinne Polski. Lasy i zarośla. Warszawa: Wydawnictwo Naukowe PWN, 394 pp.

Michalska-Hejduk, D., 2001. Stan obecny i kierunki zmian roślinności nieleśnej Kampinoskiego Parku Narodowego. *Monographiae Botanicae*, 89: 1-136. DOI: https://doi.org/10.5586/mb.2001.001.

Michalska-Hejduk, D., 2004. Najcenniejsze przyrodniczo obszary łąk i turzycowisk zachodniej części Kampinoskiego Parku Narodowego oraz propozycje ich ochrony. *Parki Narodowe i Rezerwaty Przyrody*, 23: 203-218.

Michalska-Hejduk, D., 2006. Zmiany w składzie gatunkowym łąk trzęślicowych *Molinietum caeruleae* Kampinoskiego Parku Narodowego w latach 1994-2004. *Studia Naturae*, 54: 159-172.

Oelmann, Y., Broll, G., Hölzel, N., Kleinebecker, T., Vogel, A., Schwartze, P., 2009. Nutrient impoverishment and limitation of productivity after 20 years of conservation management in wet grasslands of north-western Germany. *Biological Conservation*, 142: 2941-2948. DOI: https://doi.org/10.1016/j.biocon.2009.07.021.

Otręba, A., Ferchmin, M., Kębłowska, A., Kloss, M., Michalska-Hejduk, D., 2010. Ochrona flory i roślinności w Kampinoskim Parku Narodowym. In: A. Obidziński, ed. *Z Mazowsza na Polesie i Wileńszczyznę. Zróżnicowanie i ochrona szaty roślinnej pogranicza Europy Środkowej i Północno-Wschodniej*. Warszawa: Polskie Towarzystwo Botaniczne – Zarząd Główny, pp. 67-91.

Pancer-Koteja, E., Szwagrzyk, J., Guzik, M., 2009. Quantitative estimation of vegetation changes by comparing two vegetation maps. *Plant Ecology*, 205: 139-154. DOI: https://doi.org/10.1007/s11258-009-9604-5.

Pepłowska-Marczak, D., 2016. Wpływ zabiegów ochrony czynnej na liczebność i rozmieszczenie lelka *Caprimulgus europaeus* na wrzosowisku w Kampinoskim Parku Narodowym. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej*, 18, 49A (4):79-90.

Podani, J., 2006. Braun-Blanquet's legacy and data analysis in vegetation science. *Journal of Vegetation Science*, 17: 113-117. DOI: https://doi.org/10.1111/j.1654-1103.2006.tb02429.x.

QGIS Development Team, 2022. QGIS Geographic Information System. Open Source Geospatial Foundation Project. Available from: http://qgis.osgeo.org.

Schelfhout, S., Mertens, J., Perring, M.P., Raman, M., Baeten, L., Demey, A., Reubens, B., Oosterlynck, S., Gibson-Roy, P., Verheyen, K., De Schrijver, A., 2017. P-removal for restoration of *Nardus* grasslands on former agricultural land: cutting traditions. *Restoration Ecology*, 25: S178-S187. DOI: https://doi.org/10.1111/rec.12531.

Sienkiewicz-Paderewska, D., Paderewski, J., Suwara, I., Kwasowski, W., 2020. Fen grassland vegetation under different land uses (Biebrza National Park, Poland). *Global Ecology and Conservation*, 23: e01188. DOI: https://doi.org/10.1016/j.gecco.2020.e01188.

Solon, J., 2003. Wykaz lądowych zbiorowisk roślinnych stwierdzonych w ciągu ostatnich 30 lat na terenie Kampinoskiego Parku Narodowego i otuliny. In: R. Andrzejewski, ed. *Kampinoski Park Narodowy Tom I Przyroda Kampinoskiego Parku Narodowego*. Izabelin: Kampinoski Park Narodowy, pp. 473-478.

Solon, J., 2007. Przemiany zbiorowisk leśnych Kampinoskiego Parku Narodowego w ciągu 80 lat. In: J.M. Matuszkiewicz, ed. *Geobotaniczne rozpoznanie tendencji rozwojowych zbiorowisk leśnych w wybranych regionach Polski*. Warszawa: Monografie IGiPZ 8, pp. 290-343.

Swacha, G., Botta-Dukát, Z., Kącki, Z., Pruchniewicz, D., Żołnierz, L., 2018. The effect of abandonment on vegetation composition and soil properties in *Molinion* meadows (SW Poland). *PLOS ONE*, 13: e0197363. DOI: https://doi.org/10.1371/journal.pone.0197363.

Szymura, T.H., Murak, S., Szymura, M., Raduła, M.W., 2018. Changes in forest cover in Sudety Mountains during the last 250 years: patterns, drivers, and landscape-scale implications for nature conservation. *Acta Societatis Botanicorum Poloniae*, 87 (1): 3576. DOI: https://doi.org/10.5586/asbp.3576.

Torzewski, K., Otręba, A., 2018. Resources of dead wood on surfaces for long-term research in the Kampinos National Park. *Steciana* 22 (4): 211-216. DOI: https://doi.org/10.12657/steciana.022.025.

Tüxen, R., Ellenberg, H., 1937. Der systematische und ökologische Gruppenwert. Ein Beitrag zur Begriffsbildung und Methodik der Pflanzensoziologie. *Mitteilungen der Floristisch Soziologischen Arbeitsgemeinschaft*, 3: 171-184.

Tyburski, Ł., 2017. Zarastanie torfowiska „Długie Bagno" w Kampinoskim Parku Narodowym. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej*, 49, 51 (2): 40-46.

Wildi, O., Feldmeyer-Christe, E., Ghosh, S., Zimmermann, N.E., 2004. Comments on vegetation monitoring approaches. *Community Ecology* 5 (1): 1-5. DOI: https://doi.org/10.1556/ComEc.5.2004.1.1.

WIG, 1933. Mapa topograficzna w skali 1:25000, Zaborów, Pas 39 – Słup 31 – I, Warszawa: Wojskowy Instytut Geograficzny.

Wozniak, M., Leuven, R.S.E.W., Lenders, H.J.R., Chmielewski, T.J., Geerling, G.W., Smits, A.J.M., 2009. Assessing landscape change and biodiversity values of the Middle Vistula river valley, Poland, using BIO-SAFE. *Landscape and Urban Planning*, 92: 210-219. DOI: https://doi.org/10.1016/j.landurbplan.2009.05.007,

Zaniewski, P.T., Dembicz, I., Zaniewska, E., Kanabus, A., Kozub, Ł., 2021. Synantropizacja flory roślin naczyniowych rezerwatu Wieliszewskie Łęgi (środkowa Polska). *Leśne Prace Badawcze*, 82 (2): 47-66. DOI: https://doi.org/10.48538/lpb-2021-0006.

Zespół, 1977. Zespół ds. Gospodarki Gruntami i Wykupu Nieruchomości. Dokumentacja wykupu gruntów Wspólnoty wsi Truskaw. Izabelin: Kampinoski Park Narodowy, Msc.

STRESZCZENIE

Zmiany roślinności zagłębienia międzywydmowego Zdrojowej Góry (Niepust, Kampinoski Park Narodowy, środkowa Polska) na przestrzeni 100 lat

Badania długookresowe pomagają w lepszym zrozumieniu dynamiki roślinności. Jednak ze względu na niedostatek starych zbiorów danych są one nieczęste. W latach 20. ubiegłego wieku prof. Kobendza opracował i opublikował wysokiej jakości szkic roślinności obniżenia międzywydmowego Zdrojowej Góry położonej na skraju uroczyska Niepust w Kampinoskim Parku Narodowym (środkowa Polska). Zidentyfikował on 11 zbiorowisk roślinnych należących do 5 klas roślinności (*Molinio-Arrhenatheretea*, *Nardo-Callunetea*, *Oxycocco-Sphagnetea*, *Phragmitetea* i *Scheuchzerio-Caricetea*) oraz zbiorowisko z *Pinus sylvestris*. Całość została uzupełniona o 6 oryginalnie wyrysowanych izohips. Obszar ten stanowił podmokłe pastwisko. Obecnie teren ten jest nieużytkowany i podlega sukcesji wtórnej spontanicznej. Pokryty jest roślinnością zaroślową oraz inicjalną roślinnością leśną. Celem pracy było opisanie obecnego stanu roślinności oraz interpretacja jej dynamiki na przestrzeni około 100 lat. Prace przeprowadzono w 2022 roku. Badania wstępne obejmowały wizję terenową i lot fotogrametryczny. Kalibrację szkicu Kobendzy wykonano głównie w oparciu o zróżnicowanie lokalnej mikrotopogafii. W tym celu posłużono się wysokorozdzielczym numerycznym modelem terenu. Lokalizacje zdjęć fitosocjologicznych wyznaczono w regularnej siatce co 25 m. Badania terenowe obejmowały sporządzenie 19 zdjęć fitosocjologicznych oraz kartowanie obszaru zagłębienia międzywydmowego i przyległych stoków wydm z wykorzystaniem ortofotomapy o wysokiej rozdzielczości. Wykonaną dokumentację roślinności poddano analizom numerycznym: klasyfikacji metodą Warda (ryc. 1) i porządkowaniu metodą PCoA (ryc. 2), a następnie analizie fitosocjologicznej. Zmiany parametrów siedliska oceniono z użyciem ekologicznych liczb wskaźnikowych. W tym celu wykorzystano 9 punktów znajdujących się w obrębie zagłębienia międzywydmowego, dla których dostępne były zarówno dane historyczne, jak i współczesne. Istotność różnic sprawdzono testem Wilcoxona dla par wiązanych. Po 100 latach zaobserwowano znaczne zmiany w charakterze roślinności. Zbiorowiska nieleśne (ryc. 3) zostały zastąpione zbiorowiskami zaroślowymi i inicjalnymi stadiami lasu (ryc. 4), z dominacją *Frangula alnus* i *Betula pubescens* (tab. 1). W obrębie zagłębienia wydmowego wyróżniono 2 zespoły roślinne: optymalną i terminalną fazę zarośli kruszyny *Frangulo-Rubetum plicati* oraz młodą fazę wilgotnego boru mieszanego dębowo-sosnowego *Querco-Pinetum*. Głównym procesem syndynamicznym terenu badań była sukcesja wtórna spontaniczna. W ciągu około 100 lat nastąpiła znaczna homogenizacja roślinności. W latach 1922-1924 Kobendza odnotował przede wszystkim zbiorowiska nieleśne (należące do 5 klas: roślinności bagiennej, torfowiskowej, szuwarowej, łąkowej i murawowej), a także zbiorowisko z *Pinus sylvestris*. W 2022 roku teren badań zajęty był przez zbiorowiska zaroślowe i leśne. Zarejestrowano także zmiany właściwości runa. Nastąpił istotny spadek wartości wskaźników światła i wilgotności oraz wzrost wskaźnika żyzności (ryc. 5). Odzwierciedla to proces zarastania obiektu, a także spadek poziomu wód gruntowych i prawdopodobnie regenerację niegdyś zubożonych siedlisk. Uzyskane wyniki potwierdziły tendencje zmian środowiskowych zachodzących w ekosystemach KPN. Wykazano, że mikrotopografia terenu może z powodzeniem zostać wykorzystana podczas kalibracji historycznych map roślinności.