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ORIGINAL PAPER

Solidagini virgaureae-Juniperetum communis – an overlooked association of oligotrophic subcontinental juniper scrub

Piotr T. Zaniewski[(1)]✉, Ewa Zaniewska[(2)]

[(1)] Department of Forest Botany, Institute of Forest Sciences, Warsaw University of Life Sciences – SGGW, 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 Warsaw, Poland

ABSTRACT

Common juniper *Juniperus communis* L. formations occurring on oligotrophic sandy substrates in central European lowlands are of high ecological value, but although once widespread, they have disappeared over most of Europe. In suboceanic areas of Central Europe, the *Vaccinio-Juniperetum communis* Passarge & G. Hofmann 1968 association is recognized. In addition, the *Helichryso-Juniperetum* association was published by Barkman as its subcontinental vicariant, occurring in central and north-eastern parts of Poland. However, according to the International Code of Phytosociological Nomenclature – ICPN, the vicariant was not valid due to insufficient phytosociological documentation. In Poland, common juniper shrub patches are usually recognized as a plant community with *Juniperus communis*. The phytosociological classification of plant communities in Europe identifies the *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968 alliance, containing European lowland juniper scrub communities. Lowland juniper patches are protected as Natura 2000 habitat type 5130. However, the subcontinental vicariant does not have a valid phytosociological indicator. This article's aims are to document new patches of subcontinental juniper scrub, validate the *Helichryso-Juniperetum* association identified by Barkman, describe the internal variation of the syntaxon, and provide an overview of the distribution of juniper scrub and its dynamics in central and north-eastern Poland. To accomplish these objectives, study sites were established in the Nowa Warszawa Forest (NWF), located on the edge of Warsaw, and in the Niepust range in Kampinos National Park (KNP). Fieldwork was conducted in 2021. Juniper scrub was documented with 17 relevés. The old association name was not considered applicable due to the low frequency of *Helichrysum arenarium* and its absence in the designated type. Thus, *Solidagini virgaureae-Juniperetum communis* was instead typified. The diagnostic value of species differential at the association level was reviewed by comparing species frequencies with the synoptic table of *Vaccinio-Juniperetum* from Mecklenburg-Vonpommerns. Two new subassociations and a third provisional subassociation were distinguished and typified. The *S-J cladonietosum mitis* is characterised by a large share of grassland species, higher than in the *S-J typicum*. The provisional *S-J molinietosum caeruleae* is characterised by the presence of *Molinia caerulea*. The large number of species differential at the association level within the subassociations indicates that they all belong to *Solidagini virgaureae-Juniperetum communis*. In our opinion,

✉e-mail: piotr_zaniewski@sggw.edu.pl

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they should be included in the 5130 Natura 2000 habitat type. Juniper scrub formations are rapidly declining in central and north-eastern Poland. Their active conservation has already started in the Ciosny nature reserve and KNP.

KEY WORDS

Helichryso-Juniperetum, *Juniperus communis*, lichens, Natura 2000, 5130 habitat, Warsaw, Kampinos Forest

Introduction

Common juniper *Juniperus communis* L. formations belong to the most species-rich scrub communities forming on oligotrophic sandy substrates in the lowlands of Central Europe (Faliński *et al*., 1993; Faliński, 1998; Rahmonov, 2007). They are a significant habitat for vascular plants, bryophytes and lichens (*e.g*., Barkman, 1985a, b; Barkman and Vries, 1993; Faliński *et al*., 1993; Clifton *et al*., 1997; Zaniewski *et al*., 2020). They used to play an important role in ecological succession on former farmland, military training grounds, and deforested wasteland, including grazed habitat patches (*e.g*., Chętnik, 1928; Bobiński, 1959; Faliński, 1998; Thomas *et al*., 2007; Rahmonov and Oleś, 2010; Perzanowska, 2012; Łaska, 2015), but as its importance was underestimated it was often treated as a weed (Chętnik, 1928; Bobiński, 1959, 1969; Thomas *et al*., 2007). On the other hand, its positive role in the afforestation of wastelands, including active dunes, has long been recognised (Bobiński, 1969). Presently, juniper formations are rapidly disappearing over most of Europe (*e.g*., Clifton *et al*., 1997; Verheyen *et al*., 2009; Broome *et al*., 2017).

Juniper formations in the central European lowlands are somewhat poorly understood and their syntaxonomy remains unclear. German authors usually place lowland oligotrophic juniper scrub communities within the *Vaccinio-Juniperetum communis* Passarge & G. Hofmann 1968 association in the *Dicrano polyseti-Pinion sylvestris* (Libbert 1933) W. Matuszkiewicz 1962 alliance (Berg *et al*., 2001, 2004). In Polish phytosociological classifications, similar formations with juniper are usually not treated as separate associations. However, the possibility of there being different juniper associations was noted by Wysocki and Sikorski (2009). Higher rank syntaxonomic units connected with Juniper scrub are also not recognized (*e.g*., Brzeg and Wojterska, 2001; Matuszkiewicz, 2008; Wysocki and Sikorski, 2009; Ratyńska *et al*., 2010; Perzanowska, 2012; Kącki *et al*., 2013). Such scrubs are usually placed within their respective plant communities based on the characteristic species combination of their undergrowth. They were distinguished as a community with *Juniperus communis* within the *Dicrano-Pinion sylvestris* (Libbert 1933) W. Matuszkiewicz 1962 (Łaska, 2015) or *Koelerion glaucae* Volk 1931 (Wysocki and Sikorski, 2009) alliances.

In a phytosociological classification of plant communities in Europe, Mucina *et al*. (2016) distinguish European lowland juniper scrub as a unique alliance, *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968, belonging to the order *Vaccinio-Juniperetalia communis* Passarge 1972, within the heathland class *Calluno vulgaris-Ulicetea minoris* Br.-Bl. et Tx. ex Klika et Hadač 1944. This alliance includes lowland juniper scrub on oligotrophic soils in a subatlantic temperate climate. It was incorporated in Germany (Bergmeier, 2020). This approach is also used more widely. Some mountain juniper formations from Romania represented by the *Vaccinio-Juniperetum communis* Kovács 1979 association were also included in this syntaxon (Sanda *et al*., 2008; Togor and Petru, 2013). Juniper scrub occurring on heathlands of the *Calluno vulgaris-Ulicetea minoris* class is protected as 5130 Natura 2000 habitat (European Commission DG Environment, 2013). However, the lack of clear and validated phytosociological identifiers presents difficulties classifying juniper scrub habitats with undergrowth dominated by psammophilous grassland species and heather in lowland Poland (Perzanowska, 2012).

Helichryso-Juniperetum was distinguished by Barkman (1985a, b) as a new association occurring on oligotrophic sandy substrates of central and north-eastern Poland. He treated this association as a subcontinental vicariant of *Dicrano-Juniperetum* Barkman 1985. However, according to the International Code of Phytosociological Nomenclature – ICPN (Theurillat *et al*., 2021), neither name is valid. The two associations were published by Barkman, first in the journal Vegetatio (Barkman, 1985a) and then reproduced separately in a book (Barkman, 1985b), in both cases without providing phytosociological documentation. Since 1979, phytosociological documentation has been necessary to validly publish a new association name (Article 7 of ICPN). As a result, the holotype of *Helichryso-Juniperetum* nov. ass. is not available. In addition, *Dicrano-Juniperetum* is a name used later for the validly published association *Vaccinio-Juniperetum communis* Passarge et G. Hofmann 1968 (Berg *et al*., 2001, 2004; Bergmeier, 2020). Consequently, some difficulties exist in properly naming this syntaxon (*e.g*., Heinken, 2008).

Despite valuable work, Barkman (1985a, b) failed to validly publish the new name for this association. Therefore, to validate the *Helichryso-Juniperetum* association, it is necessary to carry out typification by selection of a type among validly published phytosociological relevés (Theurillat *et al*., 2021). If the original phytosociological data is not available, but the first diagnosis is to be acknowledged, it is recommended that a relevé be taken in the same geographical area as the original (Theurillat *et al*., 2021). One of the main study areas used by Barkman (1985a, b) was Warsaw and its surroundings – especially Kampinos National Park (Bobiński, 1974). Well-developed and diverse patches of subcontinental juniper scrub are still present in the Nowa Warszawa Forest (NWF) complex. In addition, some patches of this vegetation type are present within Niepust range, Kampinos National Park (KNP). These areas, located on the edge of Warsaw and within KNP, are suitable sites for the selection of a phytosociological relevé as a type and for validation of Barkman's *Helichryso-Juniperetum* association.

This study's aims are to document patches of juniper scrub within the NWF complex located on the edge of Warsaw, and within the Niepust range in KNP, to carry out a typification and validation of the subcontinental juniper scrub association according to the ICPN, with recognition of Barkman's (1985a, b) work, to describe internal variation of the association, and to provide an overview of its distribution and dynamics in central and north-eastern Poland.

Materials and methods

Study sites. The NWF (known also as Las Młociński Forest) is in the north-western part of Warsaw, bordering KNP. It belongs to the eastern foreland of the Puszcza Kampinoska Forest and is traditionally treated as part of it (*e.g*., Kobendza, 1930; Zielińska, 1967). The origin of NWF dates to 1907, when the Warsaw magistrate purchased 115 hectares of land for a suburban park, today's Młociński Park, adjacent to the NWF complex from the east. The area of today's NWF was intended to be used to build a 'garden city,' but the initiative failed. In the first years after World War II the area was afforested (Zieliński, 2017). Numerous plantings, mainly pine (*Pinus sylvestris* L. and locally also *Pinus banksiana* Lamb.), were carried out on the sandy wastelands and heath (Chojnacki and Kozłowska, 2010). Currently, the NWF is the only ecological corridor linking the eastern part of the Kampinos National Park with the Middle Vistula Valley. It is covered primarily by forest communities, with a dominant part being pine forests from the *Dicrano-Pinion* (Libbert 1933) W. Matuszkiewicz 1962 alliance (Chojnacki, 1991; Chojnacki and Kozłowska, 2010). Relatively floristically rich psammophilous grasslands can be found in the western part of the area, adjacent to KNP (near Wólka Węglowa village). In addition, patches of valuable dense psammophilous grasslands survive in the vicinity of Północny cemetery (Chojnacki

and Kozłowska, 2010). The forest complex and its surroundings are also the location of one of the last sites in Warsaw of the eastern pasqueflower, *Pulsatilla patens* (L.) Mill., the small pasqueflower *Pulsatilla pratensis* (L.) Mill. (Torzewski and Kozienko, 2018), and many other rare vascular plants species (Torzewski and Sosak-Świderska, 2018), lichens, and bryophytes. Eight patches (ca. 2.5 ha in total) of well-developed juniper scrub communities are found in the northern and western parts of the forest (Fig. 1A).

The Niepust range is in the south-eastern part of KNP, close to Pociecha and Truskaw villages (Fig. 1B). At the beginning of the 20th century, it was pasture and had the largest area of *Nardus* grasslands in Kampinos Forest (Kobendza, 1930). The range was also part of the largest open juniper scrub formations area in KNP (Bobiński, 1969). Pastures in the Niepust range were purchased by KNP in 1977 and placed under strict protection in 1980 (Zespół, 1977; Ferchmin, 2010; Otręba *et al*., 2010). Protection resulted in spontaneous secondary succession and encroachment of scrub and early successional forest communities on parts of the site (Ferchmin, 2010; Zaniewski *et al*., 2022). Wildfire affected about 70 ha in 1988. After 1997, the status of the area was changed to active protection (Otręba *et al*., 2010). Since then, many conservation activities have been implemented to protect its valuable meadows, heathlands, xeric grasslands, and inland dunes (Ferchmin, 2010; Pepłowska-Marczak, 2016; Anna Kębłowska, pers. comm. July 2022). Three patches (*ca*. 0.4 ha in total) of well-preserved juniper scrub, not or only slightly overtopped by trees, are located in the open part of the Niepust range.

Methods.

Fieldwork. The field study was carried out during the 2021 growing season. Seventeen phytosociological relevés (50 m2 each) were taken within juniper patches located in the NWF (Fig. 1A) and Niepust range (Fig. 1B) using the scale of Barkman *et al.* (1964). Cover was used as a measure of species abundance (Barkman *et al*., 1964; Dengler *et al*., 2008; Theurillat *et al*., 2021). Division of higher alphanumerical values as proposed by Barkman *et al*. (1964) was used to decrease data uncertainty, as noted by Podani (2006). Such a procedure is intuitive and easy to implement because the delineation of cover classes corresponding to the alphanumeric symbols from '2a' to '5b' requires only three successive divisions into halves. The value 'rr' was additionally taken as the lowest species cover in a relevé, corresponding to about 0.01%, while a cover of 0.5% was taken as the limit between the symbols 'r' and '+'. Both epigeic cryptogams and vascular plants were included in the phytosociological inventory.

Numerical analyses and typification of syntaxa. Phytosociological data was arithmetically transformed according to Tüxen and Ellenberg (1937) and then square root transformed to decrease the dominance effect. Its classification was performed using Ward's (1963) grouping method, and ordering was performed using the PCoA method with the Bray-Curtis measure. Numerical analyses were performed using PAST 4 software (Hammer *et al*., 2001). Interpretation of the identified groups of relevés was based on Barkman (1985a, b) and Matuszkiewicz (2008). Typification and validation of association and subassociation names were done according to the 4th International Code of Phytosociological Nomenclature – ICPN (Theurillat *et al*., 2021). The European syntaxonomic system (Mucina *et al*., 2016) was used to define the syntaxonomic position of syntaxa. According to Article 16 of ICPN (Theurillat *et al*., 2021), the type relevé of the new association name must contain the name-giving taxon. Due to the low frequency of *Helichrysum arenarium* (L.) Moench. in the phytosociological material and the lack of its registration in the type relevés, the species could not be preserved in the association name. Thus, *Solidago virgaurea* L. was chosen as a new name-giving species. It has a high frequency in the study sites and was

absent in the synoptic table from Mecklenburg-Vonpommerns. The species differential (D.Ass.) to *Solidagini virgaureae-Juniperetum communis* were primarily chosen according to Barkman (1985a, b). Then their diagnostic value at the association level was reviewed by comparing frequencies within the NWF and Niepust range with the synoptic table of *Vaccinio-Juniperetum* from Mecklenburg--Vonpommerns in Germany (Berg *et al*., 2001, 2004). This dataset represents the juniper scrub formation as a suboceanic vicariant of *Solidagini-Juniperetum* and belonging to the *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968 alliance. Differential species of the subassociations (D.Subass.) were chosen based on their frequencies and/or cover values within the obtained groups of relevés. Vascular plant nomenclature was according to Mirek *et al*. (2020), for mosses based on Hill *et al*. (2006), for liverworts following Söderström *et al*. (2016), and for lichens after Fałtynowicz and Kossowska (2016), with the exception of *Cladonia mitis* Sandst., which is given species status (Myllys *et al*., 2003; Indexfungorum, 2022; Mycobank, 2022).

Results

A total of 17 relevés were taken in eleven juniper patches (Fig. 1A, B; Table 1). They represented scrub formations with diverse types of undergrowth.

Fig. 1.

The distribution of Juniper scrub patches and phytosociological relevés within A) the Nowa Warszawa Forest and B) Niepust range, Kampinos National Park

TYPIFICATION OF THE *SOLIDAGINI VIRGAUREAE-JUNIPERETUM COMMUNIS* ASSOCIATION. Relevé no. 9 from Table 1 presented here was chosen as a holotype for *Solidagini virgaureae-Juniperetum communis* Barkman ex Zaniewski P.T. *et* Zaniewska E. ass. nov.

Table 1.

Internal variation and differential (D.) species of *Solidagini virgaureae-Juniperetum communis* Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov. association (*S-J*) and its subassociations in Nowa Warszawa Forest and Niepust range. Vegetation layers are A – tree, B – shrub, C – herb, D – bryophyte and lichen. *D. Subass. *S-J cladonietosum mitis*, **D. Subass. *S-J typicum*, *** D. Subass. prov. *S-J molinietosum caeruleae*

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	mol.	*typicum*									*cladonietosum mitis*						
Cover of vegetation layers [%]: Trees A	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0
Shrubs B	80	65	70	30	30	80	40	50	50	60	60	45	45	50	50	45	25
Herbs C	85	60	65	80	70	30	50	35	65	40	35	55	50	35	30	15	20
Mosses D	95	85	90	80	55	90	70	60	80	75	55	65	65	80	70	80	40
Slope [°] and aspect	2 NE	1 NE	0	0	0	0	0	5 SW	6 SW	5 SW	3 E	3 S	1 E	6 S	0	2 S	3 SE
Mineral soil exposure [%]	0	0.1	0	1	0.5	0.1	2	1	4	3	5	20	5	5	2	3	30
Juniperus communis L. B	3b	4a	4a	3a	3a	4b	3a	3b	3b	4a	4a	3b	3a	4a	3b	3b	2b
Juniperus communis L. C	+	+	1		+	r	1	+		+			1		1	+	r
D.Ass. *Solidagini-Juniperetum* primarily based on Barkman (1985a, b), revised according to Table 2																	
Solidago virgaurea L. s.str.		r	r		r	r	r	r	r	+		+	+	+	1		r
Brachythecium albicans (Hedw.) Schimp.		rr	r			r	r	+	1	+		r	+	1	+		1
Cetraria islandica (L.) Ach.*											r		1	r	+	r	
Rhacomitrium canescens (Hedw.) Brid.*							1					2b	r	+	2b	2b	
Genista tinctoria L.	r	1															
Carex ericetorum Pollich				+	r			1	r	1		+	+				
Thymus serpyllum L.						r				1		1					2a
Peucedanum oreoselinum (L.) Moench								+	1	1	1			+			1
Viscaria vulgaris Röhl.										1							
Cladonia furcata (Huds.) Schrad.											+			+		r	
Carex hirta L.												+					
Koeleria glauca (Spreng.) DC.												1					+
Helichrysum arenarium (L.) Moench																	r
ChCl. *Nardetea strictae* Rivas Goday et Borja Carbonell in Rivas Goday et Mayor López 1966 et *Calluno-Ulicetea* Br.-Bl. et Tx. ex Klika et Hada 1944 (= *Nardo-Callunetea* Prsg 1949) (Matuszkiewicz, 2008)																	
Luzula campestris (L.) DC.**		r					r		rr	r							
Calluna vulgaris (L.) Hull	2b	3b	4a	5a	4a	2b	4a	3a	3b	r	2b	3a	3a	2a			
Agrostis capillaris L.	r	r	+			r		r	+	+		r	+	r		r	
Pohlia nutans (Hedw.) Lindb.		r		+	2a		r	r	r		+			+	r	r	
Pilosella officinarum Vail.		+				+	1	+	+	1	+	1	1	r	1		1
Cladonia chlorophaea agg		rr		+	+		+		r					r		rr	
Dicranum scoparium Hedw.				r	+	r	+	+	r	r			r	r	r		
Cladonia deformis (L.) Hoffm.				r													
Placynthiella oligotropha (Vain.) Coppins & P. James				r	1												
Carex pilulifera L.									+								
Viola canina L. s.str.														r			
Veronica officinalis L.															+		

Table 1. continued (2)

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	mol.	*typicum*									*cladonietosum mitis*						
ChCl. *Koelerio-Corynephoretea* Klika in Klika et Novák 1941 (Matuszkiewicz, 2008)																	
Ceratodon purpureus (Hedw.) Brid.		+	r		+	+	1	1	2a	+	2a		1	1	1	1	1
Festuca ovina L. s.str.	+	+	+	r	1	+	+	1	2a	2a	1		1	+	2a	+	+
Agrostis vinealis Schreb.					r	r		r	r			+		+	r		+
Rumex acetosella L.		r		+	1	+	1	1	1	1	+	+		r	+		
Spergula morisonii Boreau							+	+	+	r	+		+	+	+	1	+
Hypochoeris radicata L.						r	+	r				r	r		r		r
Corynephorus canescens (L.) P. Beauv.*										r	+	2a	1	2a	r	1	2a
Cetraria aculeata (Schreb.) Ach.*													r	+		+	+
Cladonia phyllophora Hoffm. *				r							r	r	r	+	+	rr	
Polytrichum piliferum Hedw.*				r							1	r	+	1		2b	2b
Veronica dillenii Crantz *														rr	rr	rr	
Cladonia mitis Sandst. *				r	r	r	+	+	r	r	1	2b	3a	3a	2b	2b	2a
Cladonia uncialis (L.) F.H. Wigg.*							rr	+			+		1	+	1	+	+
Cladonia macilenta agg				+	1		rr		r					rr			
Jasione montana L.							r			r			r	r	+	r	
Cladonia subulata (L.) Weber							r				r						
Senecio vernalis Waldst. & Kit.								rr			r						
Cephaloziella divaricata (Sm.) Schiffn.									+						rr	r	+
Sedum acre L.										1							
Dianthus carthusianorum L.												1					
Cladonia foliacea (Huds.) Willd.																r	
Festuca polesica Zapał.																	+
ChCl. *Molinio-Arrhenatheretea* Tx. 1937 (Matuszkiewicz, 2008)																	
Molinia caerulea (L.) Moench s.str. ***	2a																
Festuca rubra L.			+									+					
Achillea millefolium L. s.str.										r				r			
Knautia arvensis (L.) J. M. Coult.										+							
ChCl. *Trifolio-Geranietea* T. Müller 1962 (Matuszkiewicz, 2008)																	
Polygonatum odoratum (Mill.) Druce	r		+				+	+	1		+		+	1	+	1	
Anthericum ramosum L.							+										
Silene nutans L.										1							
ChCl. *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl. et al. 1939 (Matuszkiewicz, 2008)																	
Pinus sylvestris L. A												2b					
Pinus sylvestris L. B				+		1	+				1		1		1	+	1
Pinus sylvestris L. C			r	+	1					r			1	r	r		+
Vaccinium myrtillus L.	4a			+						1							
Vaccinium vitis-ideaea L.	2a										2a						
Melampyrum pratense L.	+	+	1			2a	1	+		+			+		1		
Cladonia gracilis (L.) Willd.							r								r		
Dicranum polysetum Sw. ex anon.		1	1	1	+	+		1	2a	2a	1		r	+	r	r	
Hylocomium splendens (Hedw.) Schimp.	r					+							r				
Pleurozium schreberi (Willd. ex Brid.) Mitt.	5a	4b	5a	4b	3b	5a	4a	3b	3b	4a	3a	2b	2b	2b	2a	1	+
Ptilium crista-castrensis (Hedw.) De Not.	+																

Table 1. continued (3)

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	mol.	*typicum*									*cladonietosum mitis*						
		Other															
Hypericum perforatum L.**		r	r			+	+			+		r			r		
Placynthiella uliginosa (Schrad.) Coppins & P. James*											+		r	+		r	r
Trapeliopsis granulosa (Hoffm.) Lumbsch*				+	1						r			r		r	r
Anthoxanthum odoratum L. s.str.										r							
Cardaminopsis arenosa (L.) Hayek						r											
Chamaecytisus ratisbonensis (Schaeff.) Rothm.	r	1															
Betula pendula Roth B	2a	+	+			+	+			+			1		+		
Betula pendula Roth C		rr			+		r								r		
Calamagrostis epigejos (L.) Roth		r					+							r			
Cladonia coniocraea auct.		rr					rr										
Cladonia cornuta (L.) Hoffm.				r							rr						
Cladonia fimbriata (L.) Fr.				rr	+					rr		r	r		rr		r
Cladonia glauca Flörke				r		rr	r		r		rr			rr	rr	rr	
Cladonia rangiformis Hoffm.						r	r	+	+	1			+	+	+	+	r
Cladonia rei Schaer.							r								rr		r
Cladonia squamosa (Scop.) Hoffm.															r		
Convallaria majalis L.								+			+						
Deschampsia flexuosa (L.) Trin.				r	r												
Euonymus europaeus L. B												+					
Euphorbia cyparissias L.										+							
Frangula alnus Mill. B	+		1			+	+	1	1	1		1		1			
Frangula alnus Mill. C	+	r	+			+	r	+	r	+	r	r	r	+			
Hedera helix L.						r											
Holcus mollis L.			r														
Hypnum cupressiforme Hedw.		+				+	r	r								r	
Linaria vulgaris Mill.			+					r							r		
Padus serotina (Ehrh.) Borkh. B								+		r							
Padus serotina (Ehrh.) Borkh. C						rr							r				
Placynthiella dasaea (Stirt.) Tonsberg					r												
Plagiomnium affine (Blandow ex Funck) T.J.Kop.	rr								+								
Plagiothecium curvifolium Schlieph. ex Limpr.			r								rr			r			
Polytrichastrum formosum (Hedw.) G.L.Sm.														+			
Polytrichum juniperinum Hedw.		+		1	1			r				+		+			
Populus tremula L. B	3a	1					+	1			1						
Populus tremula L. C	+	+					r	+									
Potentilla arenaria Borkh.												+					
Pseudoscleropodium purum (Hedw.) M.Fleisch.	2a	1	+					+									
Pyrus communis L. C																	+
Pyrus pyraster (L.) Burgsd. B							r										

Table 1. continued (4)

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	mol.	*typicum*									*cladonietosum mitis*						
Quercus petraea (Matt.) Liebl. B									+	+			+				
Quercus robur L. B	2b	+	+			+	+	1	1	+	+		1	1	1	+	
Quercus robur L. C	+	+	r	+		+	+	r	+	+					r		
Quercus rubra L. C							rr										
Rhamnus cathartica L. B												+					
Ribes alpinum L. C											r						
Sciuro-hypnum oedipodium (Mitt.) Ignatov & Huttunen	1	r			1		r	+			r	r	r	1			
Sorbus aucuparia L. em. Hedl. C							r										
Taraxacum sect *Ruderalia*		rr															

Cover values [%] of alphanumeric symbols: 5b=87.5-100%, 5a=5-87.5%, 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%

Dates and coordinates of the relevés (No. day-month-year, WGS84° N, WGS84° E): 1. 21-05-2021, 52.31507, 20.88736; 2. 16-05-2021, 52.32268, 20.90442; 3. 30-05-2021, 52.31570, 20.88964; 4. 09-09-2021, 52.32150, 20.75785; 5. 09-09-2021, 52.32046, 20.75879; 6. 16-05-2021, 52.32207, 20.90308, 7. 16-05-2021, 52.32122, 20.90132, 8. 16-05-2021, 52.31457, 20.88735; 9. 30-05-2021, 52.31741, 20.89294; 10. 02-06-2021, 52.31779, 20.89399; 11. 21-05-2021, 52.31493, 20.88711; 12. 09-09-2021, 52.31680, 20.75352, 13. 30-05-2021, 52.31054, 20.88952; 14. 30-05-2021, 52.31707, 20.89146; 15. 02-06-2021, 52.32166, 20.90204; 16. 30-05-2021, 52.31729, 20.89166; 17. 30-05-2021, 52.31565, 20.88551

Syntaxonomic scheme:

Class: *Calluno-Ulicetea* Br.-Bl. et Tx. ex Klika et Hadač 1944

Order: *Vaccinio-Juniperetalia communis* Passarge 1972

Alliance: *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968

Association: *Solidagini virgaureae-Juniperetum communis* Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov., *holotypus hoc loco*: relevé no. 9, Table 1.

D.Ass. (differential species): *Brachythecium albicans* (Hedw.) Schimp., *Carex ericetorum* Pollich, *Carex hirta* L., *Cetraria islandica* (L.) Ach., *Cladonia furcata* (Huds.) Schrad., *Genista tinctoria* L., *Helichrysum arenarium* (L.) Moench, *Koeleria glauca* (Spreng.) DC., *Peucedanum oreoselinum* (L.) Moench, *Rhacomitrium canescens* (Hedw.) Brid., *Solidago virgaurea* L. s.str., *Thymus serpyllum* L., *Viscaria vulgaris* Röhl.

Description: The oligotrophic subcontinental common juniper scrub formation with domination of *Juniperus communis* in a shrub layer, and domination of psammophilous grassland and/or heathland species (*e.g.*, *Calluna vulgaris* (L.) Hull, *Ceratodon purpureus* (Hedw.) Brid., *Cladonia mitis*, *Corynephorus canescens* (L.) P. Beauv., *Festuca ovina* L. s.str., *Polytrichum piliferum* Hedw., *Rhacomitrium canescens*, *Thymus serpyllum*) in the herb and bryophyte layers. The tree layer is poorly or not developed. Co-dominance of species from coniferous forests, *e.g.*, *Pleurozium schreberi* (Willd. ex Brid.) Mitt., may also occur.

According to the 4th ICPN (Article 5b), the typified relevé becomes the type of a '*typicum*' subassociation of *Solidagini virgaureae-Juniperetum communis*.

The frequency of many species recorded in *Solidagini virgaureae-Juniperetum communis* from NWF and Niepust differed from *Vaccinio-Juniperetum* from Mecklenburg-Vonpommerns (Table 2). The species previously known as differential to *Helichryso arenarii-Juniperetum communis* were registered only in the NWF and Niepust range. Some species previously differential to *Vaccinio-Juniperetum* were registered only in Mecklenburg-Vonpommerns, but others were found only in NWF and Niepust. In the case of *Dicranum scoparium* Hedw., a similar frequency was

Table 2.

Comparison of species frequencies between *Solidagini-Juniperetum* (*S-J*) from Nowa Warszawa Forest and Niepust range, central Poland (this study) and *Vaccinio-Juniperetum* (*V-J*) from Mecklenburg-Vonpommerns in Germany (Berg *et al*., 2001, 2004). Species groups: *reported as differential to *S-J* by Barkman (1985a) and confirmed as differential to *S-J* in this study; ** reported as differential to *V-J* by Barkman (1985a) and confirmed as differential to *V-J* in this study; *** reported as differential to *V-J* by (Barkman, 1985a) and not confirmed as differential to *V-J* in this study

Species name	*S-J* [%]	*V-J* [%]
Juniperus communis L.	100	100
Brachythecium albicans (Hedw.) Schimp.*	71	0
Carex ericetorum Pollich*	41	0
Carex hirta L.*	6	
Cetraria islandica (L.) Ach.*	29	0
Cladonia furcata (Huds.) Schrad.*	18	0
Genista tinctoria L.*	12	0
Helichrysum arenarium (L.) Moench*	6	0
Koeleria glauca (Spreng.) DC.*	12	0
Peucedanum oreoselinum (L.) Moench*	35	0
Rhacomitrium canescens (Hedw.) Brid.*	35	0
Solidago virgaurea L. s. str.*	76	0
Thymus serpyllum L.*	24	0
Viscaria vulgaris Röhl.*	6	0
Campanula rotundifolia L.**	0	8
Chamaenerion angustifolium (L.) Scop.**	0	15
Hieracium umbellatum L.**	0	8
Polypodium vulgare L.**	0	8
Potentilla erecta (L.) Raeusch.**	0	8
Stellaria media (L.) Vill.**	0	39
Deschampsia flexuosa (L.) Trin.***	12	100
Dicranum scoparium Hedw.***	59	54
Carex pilulifera L.***	6	0
Luzula campestris (L.) DC.***	24	0
Plagiothecium curvifolium Schlieph. ex Limpr.***	18	0
Pseudoscleropodium purum (Hedw.) M.Fleisch.***	24	0
Trapeliopsis granulosa (Hoffm.) Lumbsch***	35	0
Cladonia gracilis (L.) Willd.***	12	0
Agrostis vinealis Schreb.***	47	0

Frequency of other species in *S-J*/*V-J* [%/%]:
Achillea millefolium L. s.str. 12/0, *Agrostis capillaris* L. 65/8, *Aira praecox* L. 0/15, *Anthericum ramosum* L. 6/0, *Anthoxanthum odoratum* L. s.str. 6/15, *Armeria maritima* (Mill.) Willd. ssp. *elongata* (Hoffm.) Bonnier 0/8, *Betula pendula* Roth 53/15, *Betula pubescens* Ehrh. 0/8, *Bromus hordeaceus* L. 0/8, *Calamagrostis epigejos* (L.) Roth 18/0, *Calluna vulgaris* (L.) Hull 82/69, *Campylopus introflexus* (Hedw.) Brid. 0/27, *Cardaminopsis arenosa* (L.) Hayek 6/0, *Carex arenaria* L. 0/62, *Cephaloziella divaricata* (Sm.) Schiffn. 24/0, *Cerastium holosteoides* Fr. em. Hyl. 0/8, *Ceratodon purpureus* (Hedw.) Brid. 82/27, *Cetraria aculeata* (Schreb.) Ach. 24/0, *Chamaecytisus ratisbonensis* (Schaeff.) Rothm. 12/0, *Cladonia chlorophaea* agg. 41/46, *Cladonia coniocraea* auct. 12/0, *Cladonia cornuta* (L.) Hoffm. 12/0, *Cladonia deformis* (L.) Hoffm. 6/0, *Cladonia fimbriata* (L.) Fr. 41/0, *Cladonia foliacea* (Huds.) Willd. 6/0, *Cladonia glauca* Flörke 47/0, *Cladonia macilenta* agg. 29/0, *Cladonia mitis* Sandst. 82/0, *Cladonia phyllophora* Hoffm. 41/0, *Cladonia rangiformis* Hoffm. 59/0, *Cladonia rei* Schaer. 18/0, *Cladonia* sp. 0/31, *Cladonia squamosa* (Scop.) Hoffm. 6/0, *Cladonia subulata* (L.) Weber 12/0, *Cladonia uncialis* (L.) F.H. Wigg. 47/0, *Convallaria majalis* L. 12/8, *Corynephorus canescens* (L.) P. Beauv. 47/0, *Dianthus carthusianorum* L. 6/0, *Dicranum polysetum* Sw. ex anon. 76/0, *Dryopteris carthusiana* (Vill.) H. P. Fuchs 0/15, *Empetrum nigrum* L. 0/15, *Epilobium montanum* L. 0/8,

Euonymus europaeus L. 6/0, *Euphorbia cyparissias* L. 6/0, *Fagus sylvatica* L. 0/23, *Festuca ovina* agg (incl. *F. ovina* L. s.str. and *F. polesica* Zapał.) 94/15, *Festuca rubra* L. s.str. 12/0, *Frangula alnus* Mill. 71/0, *Galium mollugo* L. s.str. 0/8, *Hedera helix* L. 6/0, *Holcus lanatus* L. 0/8, *Holcus mollis* L. 6/0, *Hylocomium splendens* (Hedw.) Schimp. 18/9, *Hypericum perforatum* L. 41/0, *Hypnum cupressiforme* Hedw. 29/54, *Hypocheris radicata* L. 41/15, *Hypogymnia physodes* (L.) Nyl. 0/36, *Jasione montana* L. 35/8, *Knautia arvensis* (L.) J. M. Coult. 6/0, *Lepraria incana* (L.) Ach. 0/15, *Leucobryum glaucum* (Hedw.) Angstr. 0/9, *Linaria vulgaris* Mill. 18/0, *Lonicera periclymenum* L. 0/15, *Luzula multiflora* (Retz.) Lej. 0/15, *Melampyrum pratense* L. 53/15, *Molinia caerulea* (L.) Moench s.str. 6/8, *Mycelis muralis* (L.) Dumort. 0/8, *Padus serotina* (Ehrh.) Borkh. 24/0, *Pilosella officinarum* Vail. 71/15, *Pinus sylvestris* L. 76/31, *Placynthiella dasaea* (Stirt.) Tonsberg 6/0, *Placynthiella oligotropha* (Vain.) Coppins & P. James 12/0, *Placynthiella uliginosa* (Schrad.) Coppins & P. James 29/0, *Plagiomnium affine* (Blandow ex Funck) T.J. Kop. 12/0, *Pleurozium schreberi* (Willd. ex Brid.) Mitt. 100/0, *Pohlia nutans* (Hedw.) Lindb. 59/0, *Polygonatum odoratum* (Mill.) Druce 59/0, *Polytrichastrum formosum* (Hedw.) G.L.Sm. 6/0, *Polytrichum juniperinum* Hedw. 35/9, *Polytrichum piliferum* Hedw. 41/0, *Populus tremula* L. 29/0, *Potentilla arenaria* Borkh. 6/0, *Pteridium aquilinum* (L.) Kuhn 0/8, *Ptilium crista-castrensis* (Hedw.) De Not. 6/0, *Pyrus communis* L. 6/0, *Pyrus pyraster* (L.) Burgsd. 6/0, *Quercus petraea* (Matt.) Liebl. 18/0, *Quercus robur* L. 82/15, *Quercus rubra* L. 6/0, *Rhamnus cathartica* L. 6/0, *Ribes alpinum* L. 6/0, *Rosa canina* L. 0/19, *Rubus* sp. 0/8, *Rumex acetosella* L. 71/46, *Sciuro-hypnum oedipodium* (Mitt.) Ignatov & Huttunen 53/0, *Sedum acre* L. 6/0, *Senecio vernalis* Waldst. & Kit. 12/0, *Silene nutans* L. 6/0, *Sorbus aucuparia* L. emend. Hedl. 6/31, *Spergula morisonii* Boreau 59/0, *Stellaria graminea* L. 0/8, *Taraxacum sect ruderalia* 6/0, *Vaccinium myrtillus* L. 18/23, *Vaccinium vitis-ideaea* L. 12/8, *Veronica dillenii* Crantz 18/0, *Veronica officinalis* L. 6/8, *Viola canina* L. s.str. 6/8.

a feature of both sites. *Deschampsia flexuosa* (L.) Trin. occurred in both regions, but more commonly in Mecklenburg-Vonpommerns.

Typification of internal variation of the *Solidagini-Juniperetum* association. Three groups of relevés were distinguished using Ward's grouping analysis (Fig. 2a). They occupied distinct positions within reduced PCoA multidimensional space (Fig. 2b). They were classified into two new subassociations and one provisional subassociation, respectively:

Solidagini virgaureae-Juniperetum communis Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov. *cladonietosum mitis* subass. nov., *holotypus hoc loco*: relevé no. 12, Table 1,

D. Subass. (differential species): *Cetraria islandica*, *Cladonia mitis* Sandst., *Cladonia phyllophora* Hoffm., *Cladonia uncialis* (L.) F.H. Wigg., *Cetraria aculeata* (Schreb.) Ach., *Corynephorus canescens* (L.) Hull, *Polytrichum piliferum* Hedw., *Veronica dillenii* Crantz, *Placynthiella uliginosa* (Schrad.) Coppins & P. James, *Rhacomitrium canescens* (Hedw.) Brid., *Trapeliopsis granulosa* (Hoffm.) Lumbsch.

Description: The oligotrophic subcontinental common juniper scrub formation with strong domination of species from psammophilous grasslands (*e.g.*, *Ceratodon purpureus*, *Cladonia mitis*, *Corynephorus canescens*, *Festuca ovina*, *Polytrichum piliferum*, *Rhacomitrium canescens*, *Thymus serpyllum*) in the undergrowth. Co-dominance of heathland species may also occur.

Solidagini virgaureae-Juniperetum communis Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov. *typicum* subass. nov., *holotypus hoc loco*: relevé no. 9, Table 1.

D. Subass. (differential species): *Hypericum perforatum* L., *Luzula campestris* (L.) DC.

Description: The oligotrophic subcontinental common juniper scrub formation with the co-domination of psammophilous grassland and heathland species (*e.g.*, *Calluna vulgaris*, *Ceratodon purpureus*, *Festuca ovina*, *Pohlia nutans*). Co-domination of coniferous forest species (*e.g.*, *Dicranum polysetum*, *Pleurozium schreberi*) in the undergrowth is possible.

Solidagini virgaureae-Juniperetum communis Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov. *molinietosum caeruleae* subass. nov. nom. prov., *holotypus hoc loco*: relevé no. 1, Table 1.

D. Subass. nom. prov. (differential species): *Molinia caerulea* (L.) Moench.

Description: The oligotrophic subcontinental common juniper scrub formation with co-domination of *Molinia caerulea*.

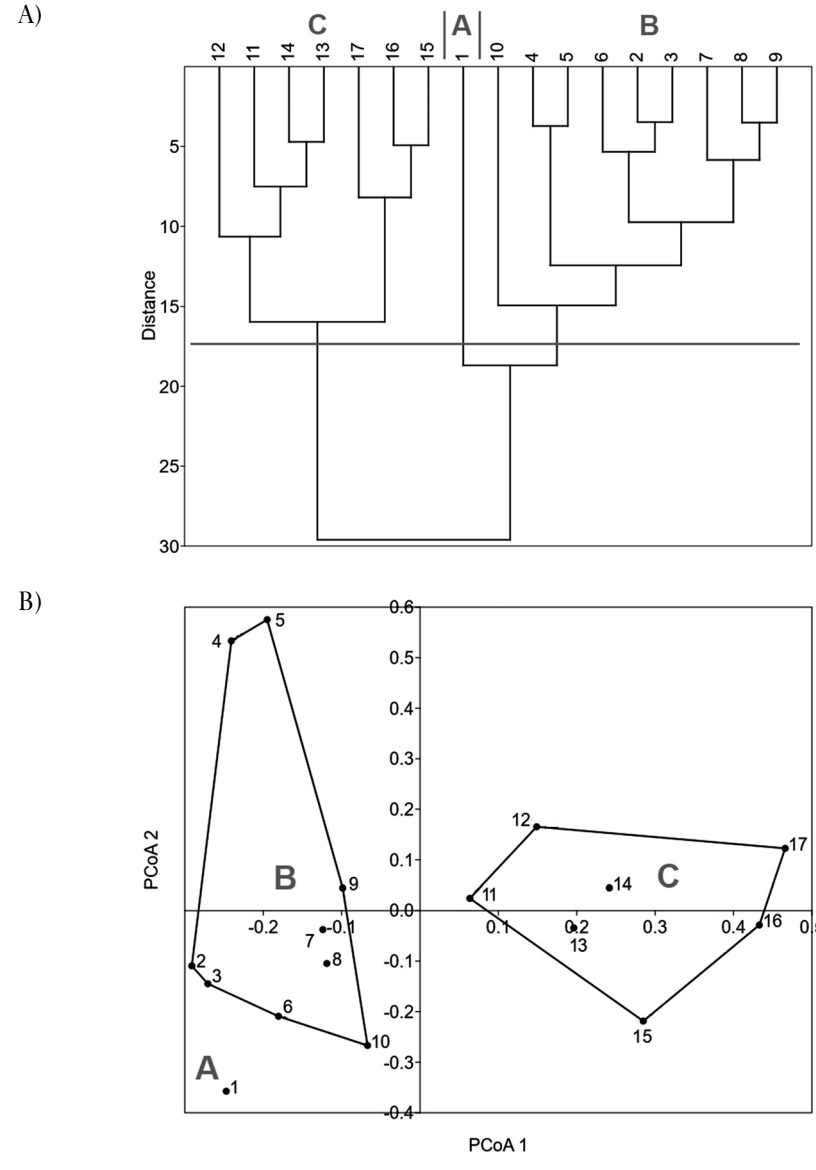

Fig. 2.

A) Ward's classification and B) PCoA ordination of *Solidagini virgaureae-Juniperetum communis* scrub (*S-J*) within Nowa Warszawa Forest and Niepust range (A – *S-J molinietosum caereleae*, B – *S-J typicum*, C – *S-J cladonietosum mitis*)

Discussion

Syntaxonomy of juniper scrub in central and north-eastern Poland. Little is known about the syntaxonomy of juniper scrub vegetation in central and north-eastern Poland. The diversity of juniper formations in Kampinos National Park was noted by Bobiński (1987), who provisionally divided them into boreal – with domination by lichens in the undergrowth, and atlantic – dominated by heather. In the present study, this division was reflected by distin-

guishing two subassociations: *S-J typicum* – often covered by heather, and *S-J cladonietosum mitis* – characterized by extensive lichen cover. A different approach to juniper scrub classification was presented by Barkman (1985a, b), who compared the formations studied in central and north-eastern Poland with analogous vicariances in western Europe. He classified all the juniper scrub he studied in central and north-eastern Poland (*e.g.*, near Warsaw) in the *Helichryso arenarii-Juniperetum communis* (the present *Solidagini virgaureae-Juniperetum communis*) association, in contrast to the *Dicrano-Juniperetum* (the valid name being *Vaccinio-Juniperetum*) occurring west of Poland (Barkman, 1985a, b). However, due to the absence of phytosociological documentation by Barkman, knowledge of species composition in juniper scrub formations was fragmentary and mainly concerned the frequency of selected species diagnostic to *Helichryso-Juniperetum*. Species frequently observed in this community included *Brachytheciastrum velutinum* (Hedw.) Ignatov & Huttunen, *Carex ericetorum*, *Carex hirta* L., *Ceratodon purpureus* (Hedw.) Brid., *Cladonia arbuscula* [most probably represented by *Cladonia arbuscula* (Wallr.) Flot. em. Ruoss ssp. *mitis* (Sandst.) Ruoss, the synonym of *Cladonia mitis* Sandst.], *Helichrysum arenarium*, *Pilosella oficinarum* Vail., *Rhacomitrium canescens* and *Thymus serpyllum*. Less frequently recorded species were *Fragaria vesca* L., *Hylocomium splendens* (Hedw.) Schimp. and *Knautia arvensis* (L.) Coult. (Barkman 1985a, b). Further taxons could be found in the list of species diagnostic to the *Helichryso-Juniperetum* association. Most of these species were also recorded in relevés in the present study. The other attempt at juniper scrub description was carried out in eastern Poland by Faliński (1998), who used the *Sedo maximi-Juniperetum* (*nomen nudum*) name for juniper formations on former farmland within and around the Jelonka reserve. This area was also one of Barkman's study sites (Barkman and Vries, 1993). It is assumed that the application of the *Sedo maximi-Juniperetum* name was probably an attempt to describe the same community type. However, according to ICPN (Theurillat *et al.,* 2021), the name is invalid (*nom. inval.*), as it lacks the original diagnosis.

According to Barkman (1985a, b), the *Helichryso arenarii-Juniperetum communis* (the new *Solidagini virgaureae-Juniperetum communis*) association occurred from Warsaw at least to the Russian border, *i.e.*, in central and north-eastern Poland. The author did not give the exact locations where he described *Helichryso-Juniperetum*. However, it is known that his research areas were at least in KNP (Bobiński, 1974) and in the vicinity of the Białowieża Forest – present-day Jelonka reserve and its surrounding (Barkman and Vries, 1993). A relevé taken in the same geographical area as the original is recommended when the original data is unavailable and the aim is to validate the earlier assessment (Theurillat *et al.*, 2021). Thus, we consider our establishment of sites for this study within the NWF complex and Niepust range in KNP to be appropriate.

Barkman's (1985a, b) concept of *Helichryso-Juniperetum* was supported by the list of diagnostic species differential in relation to subatlantic juniper scrub formations in Germany. The species were: *Lembotropis nigricans* (L.) Griseb., *Gypsophila fastigiata* L., *Koeleria glauca*, *Peucedanum oreoselinum*, *Scabiosa ochroleuca* L., *Artemisia campestris* L., *Carex ericetorum*, *C. hirta*, *Genista tinctoria*, *Helichrysum arenarium*, *Potentilla argentea* L., *Solidago virgaurea*, *Thymus serpyllum*, *Veronica spicata* L., *Brachythecium albicans*, *Brachytheciastrum velutinum*, *Cetraria islandica*, *Cladonia furcata* and *Rhacomitrium canescens* (Barkman, 1985a, b). Many of these species were observed within Juniper scrub formations studied in the NWF and Niepust range but were absent in the synoptic table of *Vaccinio-Juniperetum* from Mecklenburg-Vonpommerns, Germany (Berg *et al.*, 2001, 2004). This supports the original proposition by Barkman (1985a, b) that two unique associations of oligotrophic Juniper scrub occur in central European lowlands: one suboceanic and the other subcontinental. Those of the differential species reported by Barkman (1985a, b) that were registered in NWF

and Niepust have been accepted as differential to *Solidagini virgaureae-Juniperetum communis*, and against suboceanic *Vaccinio-Juniperetum communis* Passarge & G. Hofmann 1968 in this work.

Barkman (1985a, b) also listed species differential to the *Vaccinio-Juniperetum* association (his *Dicrano-Juniperetum* is an invalidly published later synonym): *Agrostis vinealis* Schreb., *Campanula rotundifolia* L., *Carex pilulifera* L., *Chamaenerion angustifolium* (L.) Scop., *Deschampsia flexuosa* (L.) Trin., *Hieracium umbellatum* L., *Luzula campestris*, *Polypodium vulgare* L., *Potentilla erecta* (L.) Raeusch., *Rubus fruticosus* s.l., *Sambucus nigra* L., *Senecio sylvaticus* L., *Stellaria media* (L.) Vill., *Urtica dioica* L., *Barbilophozia barbata* (Wallr.) Loeske, *Cladonia coccifera* (L.) Willd., *C. gracilis* (L.) Willd., *C. portentosa* (Dufour) Coem., *Dicranum scoparium*, *Hypnum jutlandicum* Holmen & E.Warncke, *Trapeliopsis granulosa*, *Lophocolea bidentata* (L.) Dumort., *Plagiothecium curvifolium* Schlieph. ex Limpr., *Pseudoscleropodium purum* (Hedw.) M.Fleisch. and *Ptilidium ciliare* (L.) Hampe. Some of these species were identified in the NWF and Niepust range. Thus, nine of Barkman's (1985a, b) species differential to *Vaccinio-Juniperetum* were not diagnostic in this study. They are somewhat frequent in oligotrophic heath and scrub communities in Poland (*e.g.*, Cieśliński, 1979; Faliński *et al*., 1993; Zarzycki *et al*., 2002; Matuszkiewicz, 2008; Chojnacka *et al*., 2010). A further nine species diagnostic to Barkman's *Vaccinio-Juniperetum* association were not present in the synoptic table from Mecklenburg-Vonpommerns, Germany, nor in NWF and Niepust. Thus, their diagnostic value was not confirmed in the present study.

Only in a few cases have juniper scrub formations been treated as a separate syntaxa in Poland. In Central Europe, the most common practice has been to place juniper scrub communities in the *Dicrano-Pinion sylvestris* (Libbert, 1933) W. Matuszkiewicz 1962 alliance (*e.g.,* Berg *et al*., 2001, 2004; Łaska, 2015). However, the phytosociological classification of plant communities in Europe by Mucina *et al.* (2016) distinguishes higher syntaxonomic ranks containing lowland oligotrophic juniper scrub. For this reason, we placed both juniper scrub associations in the *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968 alliance. This syntaxon was published by Passarge and Hoffman (1968) and incorporated into the European reference classification by Mucina *et al.* (2016). The syntaxonomic scheme including both vicariant associations of lowland oligotrophic juniper scrub formations in central European lowlands is:

Class: *Calluno-Ulicetea* Br.-Bl. et Tx. ex Klika et Hadač 1944

Order: *Vaccinio-Juniperetalia communis* Passarge 1972

Alliance: *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968

Association: *Solidagini virgaureae-Juniperetum communis* Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov.

Association: *Vaccinio-Juniperetum communis* Passarge et G. Hofmann 1968

Barkman (1985a, b) did not specify the exact border between *Vaccinio-Juniperetum* and *Solidagini-Juniperetum* ranges. The location of the transition is therefore unknown and needs further study, especially in central and western Poland. There is a significant shortage of published phytosociological documentation of lowland oligotrophic juniper scrub in Poland, indicating the need for further study of the distributions of these syntaxa.

Internal variation of *Solidagini virgaureae-Juniperetum communis*. Studying juniper formations on acidic and poor soils of central lowland Europe, Barkman (1985a, b) drew attention to the high geographical and habitat differentiation of the *Vaccinio-Juniperetum* (published as *Dicrano-Juniperetum*) association. He distinguished two geographical vicariance groups (south--western and north-eastern) and eight subassociations (*D-J knautietosum*, *majanthemetosum*, *myrtilletosum*, *senecietosum sylvatici*, *solanetosum nigri*, *caricetosum areanariae*, *lophozietosum ventricosae*,

orthocauletosum kunzeanae). These subassociations included forms dominated by bryophytes, dwarf shrubs, or grasses, including those with *Molinia* (Barkman, 1990). This indicates the high diversity of lowland oligotrophic juniper scrub undergrowth vegetation. However, Barkman did not similarly divide the *Helichryso-Juniperetum* association (Barkman, 1985a, b, 1990). The undergrowth of subcontinental juniper scrub patches studied in NWF and Niepust range was diverse. Thus, we distinguished two new subassociations (*typicum* and *cladonietosum mitis*), which corresponds with the insights of Bobiński (1987), who differentiates lichen and heather-dominated juniper scrub in Kampinos Forest. We treat the third subassociation (*molinietosum*) as provisory due to it being represented by only one relevé in the dataset. A similar small patch of *Molinia caerulea* co-dominated juniper scrub was also registered within the Niepust range. However, due to natural regeneration of dense pine that overtopped the juniper, it no longer represented a scrub community type. We infer that patches of wet juniper scrub may be more common in central Poland. The *Solidagini-Juniperetum* ass. nov. *cladonietosum mitis* subass. nov. is easily distinguished by the presence of many psammophilous species from *Koelerio-Corynephoretea* Klika in Klika et Novák 1941 class. The highest cover values are achieved by *Cladonia mitis*, *Corynephorus canescens*, *Polytrichum piliferum* and *Rhacomitrium canescens*, which are also differential species of this subassociation. Some other grassland species, like *Ceratodon purpureus* and *Festuca ovina* s.str., are also abundant in typical subassociation. The *Solidagini-Juniperetum* ass. nov. *typicum* subass. nov. is poorly distinguished by diagnostic species. Higher abundance of *Calluna vulgaris* is registered, but not in all relevés. This species is known to enter oligotrophic juniper scrub habitat with time (Faliński *et al*., 1993). Two other species: *Hypericum perforatum* and *Luzula campestris*, were much more frequent in this syntaxon and thus specified as differential. They are connected with more mesic habitat than species from *Koelerio-Corynephoretea* class (Zarzycki *et al*., 2002). The *Solidagini-Juniperetum* ass. nov. *molinietosum caeruleae* provisional subassociation (subass. nom. prov.) is characterized by *Molinia caerulea* – a species more associated with wet habitats (Zarzycki *et al*., 2002) and diagnostic to this syntaxon. A higher cover of *Vaccinium myrtillus* was also noted, but due to there being only one relevé in the dataset, its diagnostic role could not be confirmed. Moreover, this species used to be more frequent in moist conditions than in semixeric habitats (Kobendza, 1930) but can establish in semidry environments with time (Matuszkiewicz *et al*., 2013; Zaniewski *et al*., 2016). Species diagnostic to *Solidagini-Juniperetum* ass. nov. were present in all three subassociations.

Juniper scrub formations change with time (Faliński *et al*., 1993; Rahmonov, 2007). Three stages of juniper scrub development during secondary succession were distinguished in eastern Poland (Faliński *et al*., 1993; Faliński, 1998): initial, optimal, and terminal. They are characterized by increasing domination by grassland, pre-forest, and forest species, respectively, together with the development of shrub and then tree layers. Altogether these stages can last up to 80 years during an undisturbed successional sere (Faliński, 1998). It is highly probable that Barkman (1985a, b) studied both earlier and later phases of *Solidagini-Juniperetum* development. His diagnostic species are among the indicators of the initial, optimal, and terminal stages of succession (*cfr.* Faliński *et al*., 1993; Faliński, 1998; Rahmonov, 2007). The vertical structure and species composition of juniper formations observed in the NWF in this study indicate that the formations are especially representative of the latter part of the optimal stage of juniper scrub development, as defined by Faliński (1998). This is indicated by the increased presence of *Pinus sylvestris* and *Populus tremula* L. in the shrub layer. Pine encroachment into such scrub communities is common on oligotrophic sites (*e.g.*, Faliński, 1998; Rahmonov, 2007; Zaniewski *et al*., 2020). The presence of aspen is considered a permanent feature of juniper scrub in central Poland

(Bobiński, 1969, 1974) and also indicates progressive secondary succession (Faliński, 1998). Codominance and predominance of *Populus tremula* were adopted as features of the *Sedo maximi-Populetum* (*nomen nudum*.) community replacing juniper scrub later in secondary succession (Faliński, 1998). The other indicators of successional stage recorded in the study site are a large share of psammophilous grassland *Koelerio-Corynephoretea* species and the presence of many pre-forest and forest-edge species (*e.g.*, *Calluna vulgaris*, *Peucedanum oreoselinum*). An additional characteristic of Juniper scrub sites in this investigation is the presence of typical forest species (especially from *Vaccinio-Piceetea* class). According to Faliński (1998), these species tend to indicate the terminal stage of succession of juniper formation. This may indirectly indicate that juniper patches studied in NWF are fairly long-lived.

The Niepust range was affected by wildfire in 1988 (Otręba *et al.*, 2010) and juniper scrub on a previously burned site has been identified there. The effects of fire can still be recognised by the higher abundance of *Polytrichum juniperinum* Hedw. in relevés no. 4 and 5. This early successional moss species establishes after fire (Marozas *et al.*, 2007). Fire is an important factor influencing *Juniperus communis* scrub formations. Common juniper easily ignites, which directly results in its death (Deák *et al*., 2014); their susceptibility to fire is largely due to their shallow root system, which usually burns (Kobendza, 1930). Moreover, the species does not resprout after burning (Quevedo *et al.*, 2007). Fire kills juniper shrubs both in open habitats (Deák *et al.*, 2014) and forests (Kobendza, 1930). Large fires are decreasing or even eliminating local juniper populations (Kobendza, 1930; Diotte and Bergeron, 1989) and can reduce their abundance even at the regional level (Quevedo *et al.*, 2007). However, individual junipers can survive fire (Faliński, 1998) and be a source of seeds (García *et al.*, 1999; Thomas *et al.*, 2007). Thus, low-intensity and spatially diverse fires are thought to sustain a mosaic of habitat structures and to protect *Juniperus communis* populations (Thomas *et al.*, 2007; Deák *et al.*, 2014). At least two surveyed juniper scrub patches within the Niepust range likely originated after fire.

Decline of juniper formations in central and north-eastern Poland. Common juniper can live up to about 100-years, although longer life spans are possible (Bobiński, 1964, 1974; Ward, 1982; Cedro *et al*., 2007). Patches of juniper scrub can persist for several hundred years in favourable, unshaded conditions (Ward, 1982). At the beginning of the 20th century, common juniper was widely used as a source of firewood and for making small farm and household equipment in Poland. As a result, more harvesting usually took place near villages and towns, causing local decline. In some cases, juniper was removed from pine forests due to its high flammability (Chętnik, 1928). However, in Poland, as late as the mid-20th century, vast, unforested juniper patches were still a common component of the landscape. The area of juniper formations occurring in the open (excluding juniper in the forest understorey) in Poland in 1972 was very large, amounting to 8140 thousand ha, including 4410 thousand ha within State Forests and 3730 thousand ha in private forests (Bobiński, 1974). Juniper communities were also observed in the Kampinos Forest. The largest non-forested *Juniperus communis* areas were in the Niepust, in the triangular area between the villages of Truskaw, Laski, and Pociecha. They occurred over an area of more than 300 ha, with cover amounting 30% or more (Bobiński, 1969). Other larger juniper scrub patches were present near Kamion, the Białe Góry dunes near Wiejca village, and many other non-forested parts of the Kampinos Forest (Kobendza and Kobendza, 1958). Moreover, forest undergrowth in KNP had 10-60% juniper cover over an area of more than 1560 ha. In addition, many monumental junipers were known in KNP, the oldest exceeding 100 years of age (Bobiński, 1969). Junipers at times were the only large plants protecting dunes from wind erosion (Kobendza and Kobendza, 1958).

Moderate grazing is thought to be a suitable long-term management method for juniper scrub conservation (Markowski and Fałtynowicz, 1984). However, nowadays agricultural land abandonment is widespread in Europe (Plieninger *et al.*, 2016), including central Poland (Majchrowska, 2013). Cessation of non-intensive grazing is probably one of the main reasons for juniper scrub decline, as it promotes scrub patch overgrowth by trees (Thomas *et al.*, 2007). As a result, extensive patches of juniper scrub are increasingly rare as they are vanishing in Poland (Kucharski and Kurzac, 2002; Cedro *et al.*, 2007) and over most of Europe (Clifton *et al.*, 1997; Verheyen *et al.*, 2009; Broome *et al.*, 2017). In central and north-eastern Poland, the last examples of juniper scrub are found especially in the area of Czerwony Bór in Podlasie (Łaska, 2015), near Czartoria village in the vicinity of Nowogród, and close to the Nereśl River near Tykocin (Wołkowycki and Banaszuk, 2010). Stable populations of the species, characterised by a dynamic equilibrium between the death and establishment of individuals, are rare, although they can still be found within pine forests east of Poland, for example, in eastern Polesie (Lukash *et al.*, 2017). The patches studied by Barkman in Niepust have declined to a large extent (Ferchmin, 2010) due to changes in management (*e.g.*, the cessation of grazing followed by spontaneous secondary succession and planting of pine) and to natural events (*i.e.*, wildfire). Large areas of juniper scrub are still present within Grochalskie Piachy (Zaniewski *et al.*, 2020), and small patches of scrub communities are dispersed in several sites. The area of juniper scrub in Kampinos National Park and Puszcza Kampinoska Forest has dramatically decreased. A similar decline occurred in the Jelonka nature reserve in eastern Poland, the second area Barkman's research was known to have been carried out. This decline in juniper is mainly due to spontaneous secondary succession occurring because of strict site protection (Adamowski *et al.*, 2010). Common juniper has also declined in forest edge scrub communities in nearby Białowieża Forest (Łuczaj, 2014).

Active conservation of Juniper scrub patches in Europe has already started (Thomas *et al.*, 2007), including in Poland. For example, in the Ciosny nature reserve, many forest overstory trees, including non-native species, were cut to allow more light to reach remnant understory junipers. In addition, litter raking was done to assist germination of new juniper seedlings (GDOŚ, 2015). Raking is a promising practice as it exposes bare ground that is highly important for juniper seed germination (De Frenne *et al.*, 2020). Active conservation of remnant juniper scrub patches has also recently been implemented in KNP (Anna Kębłowska, pers. comm. July 2022).

Should *Solidagini-Juniperetum* be protected under the Natura 2000 Habitat Directive as a 5130 habitat type? Research on juniper scrub in Poland focuses mainly on understanding the diversity and dynamics of scrub patches as they pass through successional stages during the transition to closed forest communities (*e.g.*, Faliński, 1998; Rahmonov, 2007). Less attention has been paid to its phytosociological differentiation (*e.g.*, Barkman, 1985a; Bobiński, 1987; Faliński, 1998). For this reason, the assignment of individual juniper scrub stands to European Natura 2000 habitat 5130 (European Commission DG Environment, 2013) can be problematic, especially for scrub patches with characteristics similar to grasslands of the class *Koelerio-Corynephoretea* (Perzanowska, 2012).

According to the Interpretation Manual of European Union Habitats (European Commission DG Environment, 2013), the full name of 5130 Natura 2000 is '*Juniperus communis* formations on heaths or calcareous grasslands.' Two distinct vegetation types are distinguished under this code. The first is juniper formations in mesophilous or xerophilous calcareous and nutrient-poor grasslands. But the second directly refers to juniper scrub on heathlands of the *Calluno vulgaris-Ulicetea minoris* class. *Vaccinio-Juniperetum* suboceanic juniper scrub, with undergrowth domi-

nated by psammophilous grassland and heathland species, already belongs to the 5130 habitat type (Berg *et al*., 2004). Together with *Solidagini-Juniperetum*, the associations occur in acidophilous habitats of lowlands of central Europe and are characterised by a similar undergrowth type. They are placed in the *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968 alliance, *Vaccinio-Juniperetalia communis* Passarge 1972 order, within the heathland class *Calluno-Ulicetea* Br.-Bl. et Tx. ex Klika et Hadač 1944. Additionally, the *Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968 alliance is considered a phytosociological indicator of 'F3.1a Lowland to montane temperate and submediterranean Juniperus scrub' habitat type of the European Red List of habitats, related to the 5130 Natura 2000 habitat type (European Commission, 2016). Therefore, we propose that the subcontinental *Solidagini-Juniperetum* association be included as a phytosociological category corresponding to 5130 Natura 2000 habitat.

Regardless of their syntaxonomic position, some patches of juniper scrub formation occurring on oligotrophic habitats of lowland Poland were already treated as a 5130 Natura 2000 habitat type by Wołkowycki (2010) and Łaska (2015). The lack of valid phytosociological identifiers made it difficult to classify Juniper scrub habitats when the undergrowth is dominated by psammophilous grassland species and heather (Perzanowska, 2012). In this study, we validated the *Solidagini-Juniperetum* name invalidly published by Barkman as *Helichryso-Juniperetum* (1985a, b) and divided the association into two new subassociations and a third provisional one. The resulting internal division of *S-J* is similar to 'heather' and 'lichen' types of Juniper scrub distinguished in KNP in the 20th century by Bobiński (1987). The adopted lower syntaxonomic ranks are also comparable to those of the suboceanic vicariant – *Vaccinio-Juniperetum*, presented by Barkman (1985a). Both new subassociations recorded in NWF and Niepust range were rich in species differential to *Solidagini-Juniperetum*. Thus, we propose treating them as belonging to the same Natura 2000 habitat type. Systematising the syntaxonomy of oligotrophic lowland juniper formations, together with providing original phytosociological data, should improve understanding and simplify interpretation of the 5130 habitat type in central and north-eastern Poland.

Summary of results and conclusions

- a phytosociological inventory of subcontinental juniper scrub patches located in the Nowa Warszawa forest complex (the edge of Warsaw and Puszcza Kampinoska Forest) and Niepust range (Kampinos National Park) was carried out,
- the *Solidagini virgaureae-Juniperetum communis* association name was typified and the diagnosis of *Helichryso-Juniperetum* by Barkman acknowledged (*Solidagini virgaureae-Juniperetum communis* Barkman ex Zaniewski P.T. et Zaniewska E. ass. nov.),
- two new subassociations of *S-J* were documented (*S-J typicum* subass. nov. and *S-J cladonietosum mitis* subass. nov.) and a third (*S-J molinietosum caeruleae*) was provisionally proposed,
- in our opinion, the *Solidagini-Juniperetum* association and its newly described subassociations represent 5130 Natura 2000 habitat type,
- juniper scrub formations that were widespread in central and north-eastern Poland in the 20th century are now scarce.

Authors' contributions

P.T.Z. – concept, fieldworks, numerical analysis, literature review, writing; E.Z. – concept, fieldworks, literature review, writing.

Conflict of interest

No conflict of interest declared.

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STRESZCZENIE

Solidagini virgaureae-Juniperetum communis – przeoczany zespół oligotroficznego jałowczyska subkontynentalnego

Zarośla z jałowcem *Juniperus communis* L. kształtujące się na oligotroficznych podłożach piaszczystych nizin środkowej Europy należą do najbardziej bogatych gatunkowo zbiorowisk roślinnych. W ich skład wchodzi wiele gatunków roślin naczyniowych, mszaków i porostów. Zbiorowiska te były niegdyś rozpowszechnione w Polsce, występując w miejscach wylesionych, na nieużytkach porolnych, pastwiskach czy poligonach wojskowych. Rola jałowca w sukcesji ekologicznej była niedoceniana i często był on wręcz traktowany jako chwast. Obecnie zarośla z jałowcem w szybkim tempie znikają z krajobrazu. W obszarze suboceanicznym środkowej Europy zarośla jałowca ujęte są w obrębie zespołu *Vaccinio-Juniperetum communis* Passarge et G. Hofmann 1968. W części subkontynentalnej, na obszarze środkowej i północno-wschodniej części Polski, Barkman (1985a, b) wyróżnił zespół *Helichryso-Juniperetum*, będący wikariantem geograficznym jałowczysk suboceanicznych. Ze względu na brak dokumentacji fitosocjologicznej, zgodnie z Międzynarodowym Kodeksem Nomenklatury Fitosocjologicznej, opublikowana nazwa jest nieważna. Płaty jałowczysk są w Polsce zwykle opisywane jako zbiorowisko z *Juniperus communis* lub przypisywane do innych syntaksonów na podstawie zarejestrowanych kombinacji florystycznych. Jednak najnowsza klasyfikacja fitosocjologiczna zbiorowisk roślinnych Europy wyróżnia jałowczyska w obrębie osobnego rzędu i związku (*Vaccinio-Juniperion communis* Passarge in Passarge et G. Hofmann 1968). Jałowczyska są ponadto chronione jako siedlisko Natura 2000 o kodzie 5130. Brak jednoznacznej definicji fitosocjologicznej jałowczysk subkontynentalnych stwarza problemy z klasyfikacją ich płatów. Z tego powodu istnieje potrzeba usystematyzowania syntaksonomii tych zbiorowisk. Celem badań była inwentaryzacja fitosocjologiczna płatów jałowczysk, typifikacja zespołu oligotroficznego jałowczyska subkontynentalnego z maksymalnym uwzględnieniem diagnozy Barkmana (pomimo faktu, że nie została ona opublikowana w sposób ważny), opisanie wewnętrznego zróżnicowania zespołu oraz podsumowanie wiedzy o rozmieszczeniu i dynamice jałowczysk w środkowej i północno-wschodniej Polsce. Prace terenowe przeprowadzono w 2021 roku w położonym na granicy Warszawy Lesie Nowa Warszawa (LNW) oraz na obszarze Niepustu w Kampinoskim Parku Narodowym (KNP) (ryc. 1a, b). Obiekty te odpowiadają jednemu z rejonów geograficznych dawnych badań Barkmana. Występujące tu płaty jałowczysk udokumentowano 17 zdjęciami fitosocjologicznymi (tab. 1). W związku z niską frekwencją *Helichrysum arenarium* dokonano opisania zespołu jako *Solidagini virgaureae-Juniperetum communis* (*S-J*). Oceny zaproponowanych przez Barkmana gatunków diagnostycznych (wyróżniających dla zespołu) dokonano przez porównanie częstości gatunków odnotowanych w wykonanych zdjęciach fitosocjologicznych z częstościami z tabeli synoptycznej jałowczysk suboceanicznych *Vaccinio-Juniperetum communis* z Mecklenburg-Vonpommerns w Niemczech (tab. 2). Za wyróżniające dla *Solidagini virgaureae-Juniperetum communis* przyjęto większość z zaproponowanych przez Barkmana gatunków. Na podstawie wyników klasyfikacji Warda (ryc. 2a) i porządkowania PCoA (ryc. 2b) dokonano podziału wewnętrznego zespołu. Wyróżniono dwa nowe podzespoły oraz trzeci podzespół prowizoryczny. Podano także ich gatunki wyróżniające. Podzespół *S-J cladonietosum mitis* charakteryzuje się wysokim udziałem gatunków murawowych z klasy *Koelerio-Corynephoretea*. Z kolei *S-J typicum* ma znacznie mniejszy ich udział. Za gatunek wyróżniający prowizoryczny podzespół trzęślicowy przyjęto *Molinia caerulea*. Wszystkie trzy podzespoły charakteryzowały się znacznym udziałem

gatunków wyróżniających *Solidagini virgaureae-Juniperetum communis*. Autorzy uważają, że powinny być one włączone jako wskaźniki fitosocjologiczne siedliska 5130. Zespół oligotroficznego jałowczyska subkontynentalnego szybko zanika w środkowej i północno-wschodniej Polsce. Przykładem współczesnej ochrony czynnej płatów oligotroficznych jałowczysk są zabiegi wykonane niedawno w rezerwacie „Ciosny" koło Łodzi, a także w KNP.