DENDROBIOLOGY
2010, vol. 63, 33–41

Karolina Sobierajska, Krystyna Boratyńska, Katarzyna Marcysiak

Variation of cone characters in *Pinus mugo* (Pinaceae) populations in the Giant Mountains (Karkonosze, Sudetes)

Received: 11 August 2009; Accepted 03 February 2010

Abstract: The subalpine communities of *Pinus mugo* were destructed and replaced by pasture lands on plateau parts and moderately inclined slopes of the mountains during between the 15th and the 18th centuries. The species were able to survive that pressure probably on the abrupt slopes of the glacial cirques. The pasturing stopped in the 19th century, and the mountain pine started to reforest its previous habitats since that time. It was also planted in several places and some of contemporary populations can origin from the seeds of the Giant Mountains. In the latter case the populations on the plateau shall reveal differences in the cone characters from autochtonous ones from the glacial cirques. This study was structured on this hypothesis. The characteristics of seven *Pinus mugo* populations in the Giant Mts. were compared on the basis of 15 morphological characters of cones. Each population was represented by at least 30 individuals, and for every individual 10 cones were examined. Four of the sampled populations, treated as local, occurred on the steep slopes of the glacial cirques and the other three on the mountain plateaus, used as pastures in the 17th to 18th centuries, potentially originated from another region. Results show rather small differences among the compared populations, independently of origin. The separation of the plateau from the steep slope ones is rather inconspicuous, if any. This suggests the local origin of plateau populations, even when planted.

Additional key words: dwarf mountain pine, population, cone, morphology, biometry, discriminant, cluster, analysis of variance.

Addresses: K. Sobierajska, K. Boratyńska, Polish Academy of Sciences, Institute of Dendrology, Parkowa 5, 62-035 Kórnik, Poland, e-mail: sobieraj83@hotmail.com,
K. Marcysiak, Kazimierz Wielki University, Department of Botany, Ossolińskich 12, 85-072 Bydgoszcz, Poland

Introduction

Dwarf mountain pine (*Pinus mugo* Turra) occurs in the subalpine zone of the eastern and central European mountains. This type of geographic range developed at the beginning of the Holocene and probably caused differences between isolated populations of the species (Tufto and Hindar, 2003; Reisch et al. 2003; Van Rossun and Triest 2003).

In Poland, dwarf mountain pine forms its own communities in the subalpine zone of the Tatras and Sudetes, especially in the highest area – the Giant Mountains and the northernmost part of the species' range. The pine rarely occurs at lower altitudes, mainly on peat bogs (Jalas and Suominen 1973; Gostyńska-Jukaszewska and Zieliński 1976).

Information about *P. mugo* in the Giant Mts. comes from the end of the 18th century as *P. pumilio* Haenke

(Jirásek et al. 1791). In the Sudetes the pine forms extended thickets of an association described as *Pinetum mugo sudeticum* (Matuszkiewicz and Matuszkiewicz 1975; Matuszkiewicz 2001). In this mountain range the species is found typically at the altitude of 1250–1450 m. It is sporadically found down in the valleys; the lowest stand was reported at 850 m in peat bog near Jakuszyce, while the highest known are found on the north-eastern slopes of Śnieżka Mountain in Poland, at 1550 m (Boratyński 1994) and on the southern slopes in the Czech Republic, at 1560 m (Skalický 1983).

The Giant Mountains were strongly deforested in 15^{th}–18^{th} centuries. The subalpine communities of *Pinus mugo* were also destructed and replaced by pasture lands at the plateau parts and moderately inclined slopes of the mountains. The traditional use of the upper parts of the Giant Mts. as pastures caused the extinction of *Pinus mugo* thickets over large areas, except in the glacial cirques. Grazing activity stopped at the end of the 19^{th} century and *P. mugo* naturally recovered at least in part of the area, but in some places it was probably planted (Staffa 2005). It is possible that the seeds used for reforestation could have originated from other mountain ranges. In the Czech Republic seeds from the Austrian Alps were used and 30% of contemporary dwarf pine cover in the Czech part of the Sudetes is thought to be of that origin (Lokvenc et al. 1994; Lokvenc 2001). There are no such data for the Polish part of the mountain range. In the Giant Mts. we can find parts of a borderline of pine determined by human activity, as well as a natural border (Jodłowski 2007) and the species range in these mountains is stable. The structure of the scattered zone of *P. mugo* shows that Polish populations are probably natural, while in the Czech parts of the mountains we can find the opposite situation (Milková 2001; Svoboda 2001; Jodłowski 2007).

Dwarf mountain pine has been the subject of numerous studies, focusing mainly on interspecific variability of *Pinus mugo* s.l. and taxonomic relations with *Pinus sylvestris* (Szweykowski 1969; Szweykowski and Bobowicz 1977; Korshikov and Pirko 2002; Boratyńska et al. 2004). Several studies have emphasized the differences between *Pinus mugo* in the Giant Mts., especially the frequently examined populations from Równia pod Śnieżką and Łabski Szczyt-Szrenica, with the other parts of the species range. Studies based on the morphology and anatomy of the needles and the morphology of the cones proved the latter to be more appropriate to distinguish between populations and closely related taxa (Szweykowski and Bobowicz 1977; Boratyńska and Bobowicz 2001; Boratyńska et al. 2005; Marcysiak and Boratyński 2007).

Variation within *Pinus mugo* in the Giant Mts. on the basis of needle traits was recently verified by Sobierajska and Boratyńska (2008); while cone characters were not examined. The analyses of the needle characters did not indicate the allochtonous origin of the populations from the plateau, when comparing to those from steep slopes. The samples from Równia pod Śnieżką and from the slopes between Łabski Szczyt and Szrenica are only slightly different. The *cp*SSR analysis also did not reveal differences among populations from the Giant Mountains (own unpublished data). All of them differed at much higher level from samples from the Tatra Mountains and the Alps (Sobierajska et al. 2008).

Thus the aim of the present study was to check the possible separation between populations from the plains in the upper parts of the mountains that may have been reforested with the use of alien seeds. The variation in *Pinus mugo* populations from the Giant Mts. was also characterised on the basis of the morphological traits of the cones.

Materials and methods

Cones of *Pinus mugo* were collected from seven populations in the Giant Mts. Four of them grew on the steep slopes of the glacial cirques and the other three on the mountain plateaus (Table 1). Równia pod Śnieżką (GM 1), slopes between Łabski Szczyt and Szrenica (GM 2) and Śląskie Kamienie (GM 7) populations were probably artificially reforested after the cessation of grazing.

Each population was represented by 30 individuals, growing at least 30 m from the next. Ten normally developed and mature cones were randomly collected from each separate specimen. The study material was

Table 1. Studied populations of *Pinus mugo*

No.	Acronym	Location name	Longitude E	Latitude N	Altitude (m)	Number of tested specimens
1	GM 1	Równia pod Śnieżka	15°47’	50°44’	1400–1420	30
2	GM 2	Łabski Szczyt – Szrenica	15°33’	50°47’	1350–1450	32
3	GM 3	Śnieżka above Kocioł Łomniczki	15°47’	50°44’	1300–1500	31
4	GM 4	Kocioł Małego Stawu	15°47’	50°44’	1350–1400	31
5	GM 5	Czarny Kocioł Jagniątkowski	15°35’	50°47’	1300–1400	33
6	GM 6	Wielki Kocioł Śnieżny	15°34’	50°46’	1400–1450	32
7	GM 7	Śląskie Kamienie	15°36’	50°46’	1410–1420	32

collected in autumn 2005 year. The total of 218 individuals (2170 cones) were analysed using the following cones traits: length of cone (character 1), maximal diameter of cone (character 2), cone scale number (character 3), length of apophyse (character 4), width of apophyse (character 5), thickness of apophyse (character 6), distance between umbo and scale top (character 7), diameter of cone in the middle distance between top and maximal diameter (character 8), measurement of convex side of cone from stalk to the top (character 9), measurement of concave side of cone from stalk to the top (character 10), ratio of cone length/maximal diameter (character 11), ratio of cone length/number of scales (character 12), ratio of apophyse length/width (character 13), ratio of apophyse length/thickness (character 14) and ratio of convex/concave cone measurements (character 15). Mentioned above characters are generally accepted as being diagnostic and able to distinguish *P. mugo* from *P. sylvestris* (Bobowicz and Krzakowa 1986, 1988; Marcysiak and Boratyński 2007). The detailed method of measurement has been described previously for the closely related *P. uncinata* (Marcysiak 2004).

Data obtained were analysed statistically. Minimal and maximal values of characters were found, arithmetical means and standard deviation were calculated and analysed for every population. One way ANOVA was used to find the characters, which significantly differentiated individuals, populations and group of populations from two different geomorphologic situations, namely cliffs versus plain and slightly inclined slopes. Populations were compared using HSD Tukey's test (*post hoc* procedure). A discriminant analysis was performed along the first two discriminant variable and the aglomeration on the shortest Eucklidean distances to find the inter-populational differences. (Łomnicki 2001; Watała 2002; Stanisz 2007a, b). The data were analysed statistically using Statistica PL 7.0 for Windows software (StatSoft) and JMP Software (SAS Institute Inc.).

Results

The cone of *P. mugo* from different populations of the species in the Giant Mts are characterized with measurements typical for the taxon (Table 2). The average length of cone (character 1) oscillate between 28.7 and 32.7 mm and width (character 2) between 18.8 and 20.4 mm. The longest cones have been found in the population from Równia pod Śnieżką (GM 1), the shortest from Wielki Kocioł Śnieżny (GM 6) and the narrowest from the Kocioł Małego Stawu (GM 4). The number of scales in the cone (character 3) was lowest in the populations with smallest cones (e.g. GM 6), while the highest was in the populations with big, but not biggest ones. The number appears only slightly connected with the dimensional characters of the cone.

Cones with the longest apophyses (character 4) have been detected in the population from the slopes of Łabski Szczyt – Szrenica (GM 2), where the number of the scales was highest. The shortest apophyses were characteristic for population from the Śnieżka slopes (GM 3). The width of apophyse (character 5) was also connected with the dimensions of the cone and the highest values have in the populations characterizing with the big cones, as for example in Równia pod Śnieżką (GM 1), while the narrowest in the populations with medium sized cones (e.g. Kocioł Małego Stawu, GM 4). The length of apophyse has higher values than width in every examined population. The thickest apophyses were observed in the cones from the Śnieżka slopes (GM 3), while the thinnest from the Kocioł Małego Stawu (GM 4). The cones were slightly asymmetric (character 15).

Variability in the cone traits was verified with the variation coefficient, which never exceeded 20% and for the majority of characters had lower values. Cone asymmetry (character 15), cone shape (character 11), width of apophyse (character 5) and maximal diameter of cone (character 2) were the most constant, and the variation coefficients of those features rarely exceeded 10%.

Tukey's test (HSD) showed that the populations varied considerably between each other in terms of the characters examined (Table 3). The most statistically significant differences between populations were found for the diameter of cone in the middle distance between the top and maximal diameter (character 8), the thickness of the apophyse (character 6) and the ratio of apophyse length/thickness (character 14). The ratio of cone length/number of scales (character 12), cone scale number (character 3) and measurements of cone (characters 9 and 10) were differentiated at a lower level. The population from Wielki Kocioł Śnieżny (GM 6) was distinctive from all the others in cone scale number (character 3). This population had the lowest number of scales (average value about 78) and very short cones. Populations from Równia pod Śnieżka (GM 1) and Kocioł Małego Stawu (GM 4) are differentiated by 13, the highest number of characters, while populations Równia pod Śnieżka (GM 1) and Śląskie Kamienie (GM 7) are differentiated by 7, the lovest number of characters (Table 2).

Populations from the plain and slightly inclined slopes (GM 1, GM 2, and GM 7) differ from cliff ones (GM 3–GM 6) in the four characters (Table 4). The measurement of convex side of cone from stalk to the top (character 9) and maximal diameter of cone (character 2) differentiate at $p<0.01$, and length of cones (character 1) and measurement of concave side of cone from stalk to the top (character 10) at $p<0.05$ between these groups of populations. The ten characters differentiate at statistically significant level among particular populations, while all characters

Table 2. Statistical characteristic of traits of *Pinus mugo* cones (character numbers as in Materials and methods and in Table 6 population, acronyms in Table 1)

Statistical characteristics	Acronym	Characters														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mean	GM 1	32.66	20.41	86.28	6.06	7.83	2.32	3.12	16.84	45.62	41.11	1.61	0.38	0.78	2.67	1.11
	GM 2	32.29	19.28	90.06	6.30	7.44	2.17	3.05	18.30	44.93	40.15	1.68	0.36	0.85	2.97	1.12
	GM 3	29.44	18.75	85.75	5.42	7.26	2.50	2.98	14.02	42.79	36.59	1.57	0.35	0.75	2.22	1.18
	GM 4	31.12	18.06	87.63	5.92	6.61	1.74	2.92	12.12	44.08	37.90	1.73	0.36	0.91	3.60	1.17
	GM 5	31.38	18.62	86.44	5.58	6.87	2.27	3.12	12.72	43.03	38.40	1.68	0.37	0.82	2.52	1.12
	GM 6	28.74	18.33	78.63	6.23	7.25	2.06	3.26	12.65	42.38	37.75	1.57	0.37	0.87	3.11	1.13
	GM 7	32.35	19.91	87.94	5.87	7.30	2.15	2.85	13.55	45.42	39.08	1.63	0.37	0.81	2.79	1.17
Minimum	GM 1	19	15	50	4.2	5.6	1.5	1.6	10	27	28	1.08	0.24	0.01	0.03	0.87
	GM 2	17	14	58	4.1	4.9	1.2	1.8	13	19	24	1.05	0.21	0.58	1.86	0.45
	GM 3	18	14	48	2.8	5.0	1.6	1.5	9	29	20	1.00	0.20	0.43	1.26	0.86
	GM 4	23	13	62	3.4	4.6	0.8	1.3	8	33	22	1.20	0.24	0.47	1.42	1.02
	GM 5	15	13	58	3.1	2.5	1.4	1.5	7	24	22	1.11	0.23	0.55	1.29	0.98
	GM 6	17	11	47	4.3	3.4	1.2	1.8	8	28	24	1.06	0.22	0.58	1.77	0.91
	GM 7	21	14	57	3.5	4.8	1.4	1.4	9	32	20	1.20	0.24	0.49	1.38	0.92
Maximum	GM 1	50	29	128	8.1	10.2	3.8	4.9	23	67	60	2.05	0.58	1.09	4.73	1.55
	GM 2	58	24	116	9.3	9.5	4.0	5.9	23	66	58	3.11	0.72	1.41	5.38	1.50
	GM 3	43	27	113	7.9	9.9	4.8	5.7	20	63	53	2.00	0.52	1.17	3.70	1.95
	GM 4	47	24	122	8.5	9.4	3.6	5.0	22	67	56	2.61	0.63	1.32	8.13	1.82
	GM 5	46	25	126	8.0	9.2	3.5	4.7	25	60	55	2.30	0.56	1.80	4.36	1.67
	GM 6	44	26	112	8.6	10.3	3.1	5.1	19	60	55	2.54	0.56	2.18	5.79	1.67
	GM 7	51	32	117	8.3	10.0	3.1	4.1	19	68	55	2.05	0.52	1.27	4.71	2.00
Standard deviation	GM 1	4.62	2.44	11.80	0.73	0.79	0.38	0.49	2.15	5.83	5.33	0.18	0.06	0.13	0.56	0.10
	GM 2	5.56	1.83	11.34	0.84	0.86	0.39	0.55	1.74	6.31	5.58	0.24	0.07	0.12	0.53	0.08
	GM 3	4.81	2.61	12.14	0.95	0.99	0.46	0.60	2.00	6.18	5.85	0.19	0.06	0.12	0.46	0.14
	GM 4	4.62	2.13	10.98	0.86	0.95	0.44	0.51	1.75	5.59	5.45	0.19	0.05	0.13	0.93	0.11
	GM 5	5.49	2.39	11.92	0.88	0.93	0.42	0.50	2.17	6.40	5.74	0.19	0.06	0.14	0.56	0.09
	GM 6	5.28	2.37	11.92	0.89	0.93	0.36	0.57	2.15	6.02	6.06	0.22	0.06	0.16	0.69	0.11
	GM 7	4.87	2.35	10.43	0.84	0.84	0.32	0.44	2.07	6.05	5.76	0.16	0.05	0.12	0.55	0.13

Table 3. Characters differening statistical significant level (p<0.05) populations of *P. mugo* revealed by Tukey's test (character numbers as in Materials and methods and in Table 6, population acronyms as in Table 1)

GM 2	2, 3, 4, 5, 6, 8, 11, 12, 13, 14					
GM 3	1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 14, 15	1, 3, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15				
GM 4	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	2, 4, 5, 6, 7, 8, 10, 11, 13, 14, 15	1, 2, 4, 5, 6, 8, 11, 13, 14			
GM 5	1, 2, 4 5, 8, 9, 10, 11, 12, 13, 14	2, 3, 4, 5, 6, 8, 9, 10, 13, 14	1, 5, 6, 7, 8, 10, 11, 13, 14	4, 5, 6, 7, 8, 13, 14, 15		
GM 6	1, 2, 3, 5, 6, 7, 8, 9, 10, 13, 14	1, 2, 3, 6, 7, 8, 9, 10, 11	3, 4, 6, 7, 8, 12, 13, 14, 15	1, 3, 4, 5, 6, 7, 8, 9, 11, 13, 14, 15	1, 3, 4, 5, 6, 7, 11, 13, 14	
GM 7	5, 6, 7, 8, 10, 13, 15	2, 4, 7, 8, 11, 13, 14, 15	1, 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 5, 6, 8, 11, 13, 14	2, 4, 5, 6, 7, 8, 9, 11, 14, 15	1, 2, 3, 4, 7, 8, 9, 11, 13, 14, 15
	GM 1	GM 2	GM 3	GM 4	GM 5	GM 6

among individuals (Table 4). The highest values of variation components determining differences between the two groups of populations were detected in diameter of cone in the middle distance between the top and maximal diameter (character 8) and in ratio of apophyse length/thickness (character 14) (Table 5). Generally, the highest values of variation component are found among individuals.

The discriminant analysis showed, that diameter of the cone in the middle distance between the top and maximal diameter (character 8) and, in lower degree, the thickness of apophyse (character 6), the distance between umbo and scale top (character 7), the maximal diameter of cone (character 2) and the ratio of apophyse lenght/thickness (character 14) are discriminating among populations at the highest level (Fig. 1). The two first discriminant variables comprised 87% of the total variation. On the space between two first discriminant variables the individuals of the populations examined formed one scattered group. The populations from Równia pod Śnieżką and Łabski Szczyt – Szrenica (GM 1 and 2, respectively), are the most different from the others. The 95% confidence intervals of all compared population except of GM 1 and GM 2 are overlapping in great degree (Fig. 1).

Individuals were more differentiated with regard to the first variable (about 77%), depending mainly on the diameter of the cone in the middle distance between the top and maximal diameter (character 8). Individuals from the populations: GM 4, GM 5, GM 6, GM 7 and GM 2 (also GM 1) were the most distant, with higher values of diameter of cone in the middle distance between the top and maximal diameter (Table 3). The second variable, depending mainly on the ratio of apophyse length/thickness (character 14) was less important (10% variation). The intervals of the variation of every tested population are very similar in respect to this discriminant variable (Fig. 1).

The range of variation in populations growing on plateaus showed that the differentiation of population from Śląskie Kamienie (GM 7) did not exceed the variation of the species, while the range of the Łabski Szczyt – Szrenica (GM 2) population underlined its little separation. Population from Równia pod Śnieżka (GM 1) had the greatest range of variation, including the majority of the variation found in the other populations (Table 6).

Cluster analysis showed that all the populations formed one loosely-linked group (Fig. 2). The most closely related were the populations from slopes at Łabski Szczyt and Szrenica (GM 2) and from Równia pod Śnieżką (GM 1) All the other populations are joining step by step to this group. The most distant are populations from Równia pod Śnieżka and Kocioł Małego Stawy (GM 1 and 4, respectively).

Discussion

The *Pinus mugo* cone characters show much variability, as demonstrated by Staszkiewicz and Tyszkiewicz (1976). They found that the length of the cones ranged from 16 to 49 mm, which was confirmed by Christensen (1987). Staszkiewicz and Tyszkiewicz (1976) regarded cones shorter than 21 mm as small, while those longer than 40 mm were considered big. Accordingly the cones examined in this study were medium-sized, with an average length of 29.4 to 32.7 mm (Table 2). Bobowicz and Krzakowa (1986) obtained similar values for cone length in populations from the Tatra Mts.

The width of cones described by the authors cited above was similar and ranged between 16 and 20 mm. Staszkiewicz and Tyszkiewicz (1976) only found cones less than 15 mm wide.

The ratio of cone length/width, which describes the cone shape, varies. In the present study we found that cone length was noticeably greater than width (with a ratio from 1.57 to 1.73), as in Bobowicz and Krzakowa (1986), while Staszkiewicz and Tyszkiewicz (1976) and Christensen (1987) observed almost spherical cones, as well as cones that were twice as long as their width.

The cone scale traits were also highly variable. The most differentiated cone scale length was described

Table 4. Analysis of variance (test wrt random effects): the p-value for 15 trait of cones seven populations of P. mugo and three sources of variability (significant value in italic)

Source of variation	No of traits														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Situation	0.0306	0.0079	0.2294	0.2732	0.0699	0.7309	0.6142	0.0478	0.0041	0.0148	0.9440	0.1742	0.6339	0.8955	0.5361
Population (situation) & random	0.1201	0.1646	0.0014	0.0000	0.0000	0.0000	0.0017	0.0000	0.8191	0.3156	0.0000	0.2680	0.0000	0.0000	0.0000
Specimen (situation, population) & random	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 5. Variance component estimates for 15 trait of cones from seven population of *P. mugo* express in % (rounded to an integer)

Component of variation	No of traits														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Population (situation)&random	2	2	6	10	8	28	5	40	0	0	8	1	15	36	6
Specimen (situation, population)&random	62	63	55	46	49	41	52	30	62	57	51	59	32	29	10
Residual	36	35	39	44	43	31	43	30	38	43	41	40	53	35	84

Table 6. The determination coefficients between discriminant variables U_1 and U_2 and analised characters of cones seven populations of *P. mugo*

No	Characters	U_1 (77.17%)	U_2 (10.01%)
1	Length of cone (mm)	0.19	0.03
2	Maximal diameter of cone (mm)	0.36	0.21
3	Cone scale number (item)	0.23	0.12
4	Length of apophyse (mm)	0.32	1.19
5	Width of apophyse (mm)	1.04	0.07
6	Thickness of apophyse (mm)	0.63	2.45
7	Distance between umbo and scale top (mm)	0.02	0.12
8	Diameter of cone in the middle distance between top and maximal diameter (mm)	17.15	0.00
9	Measurement of convex side of cone from stalk to the top (mm)	0.11	0.01
10	Measurement of concave side of cone from stalk to the top (mm)	0.35	0.01
11	Ratio of cone length/maximal diameter (characters 1/2)	0.00	0.07
12	Ratio of cone length/number of scales (characters 1/3)	0.01	0.02
13	Ratio of apophyse length/width (characters 4/5)	0.17	2.06
14	Ratio of apophyse length/thickness (characters 4/6)	0.33	5.29
15	Cone asymmetry (ratio of convex/concave cone measurements (characters 9/10)	0.66	0.25

by Staszkiewicz and Tyszkiewicz (1976), with values from 2 to 10 mm, but all the other authors cited observed that scale length was always more than 5 mm, as confirmed by our study.

Cone scale width was usually 1–2 mm greater than scale length, Staszkiewicz and Tyszkiewicz (1976) only observed that character more differentiated.

Results of the studies on the morphology and anatomy of needles, isoenzyme analysis and genetic markers analysis of several *Pinus mugo* populations in the Giant Mts, Tatra Mts. and the Alps indicated the high level of genetic differences, both in DNA and allozymes, between the populations. Those populations from Równia pod Śnieżką (GM 1) and Łabski Szczyt – Szrenica (GM 2) differed slightly from the other populations in the Giant Mts. but were very distant from populations in the Tatra Mts. and the Alps. On the basis of that research it was hard to determine the origin of the seeds used for the reforestation of these two populations (Sobierajska et al. 2008).

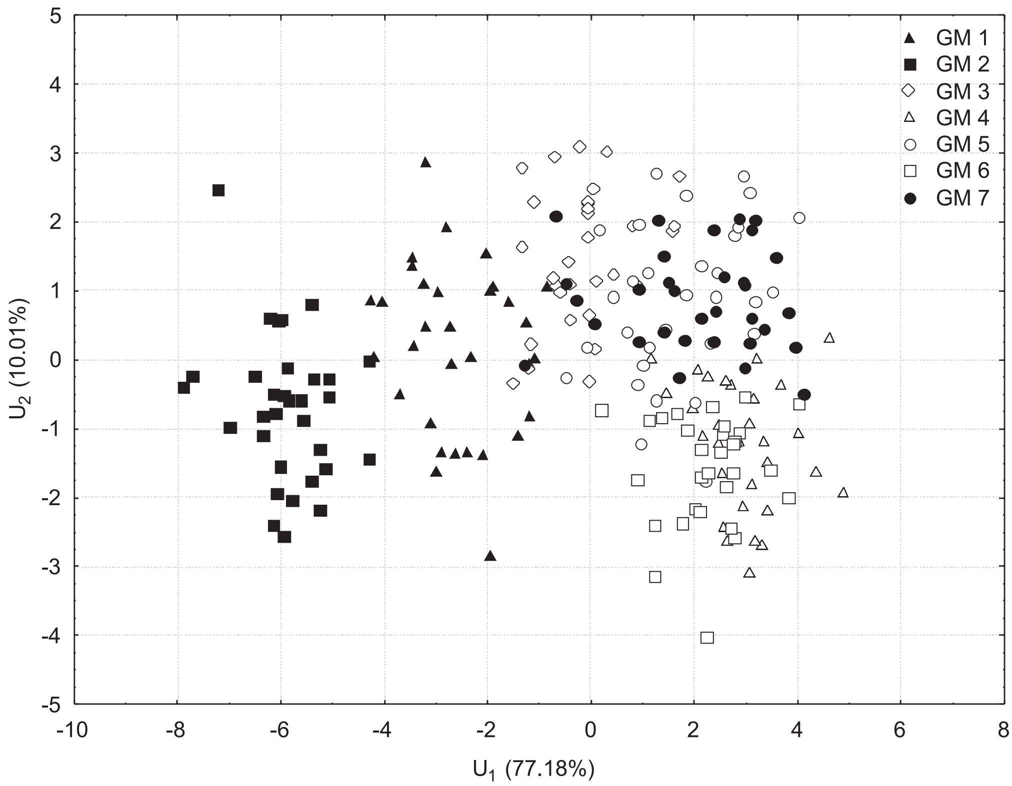

Fig. 1. Results of the discriminant analysis for seven populations of *P. mugo* based on the 15 cone characters plotted along the two first discriminating variables U_1 and U_2 (acronyms of populations as in Table 1)

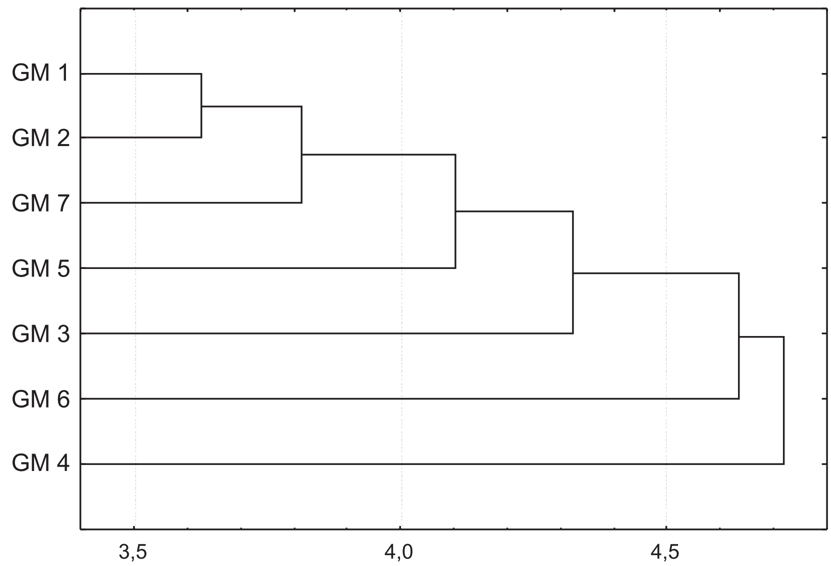

Fig. 2. Dendrogram of seven samples of *P. mugo* constructed on the shortest Euclidean distances based on the 15 characters of cones for *P. mugo* (acronyms populations as in Table 1)

The current biometrical analyses showed that three populations growing on the plateaus: Równia pod Śnieżką (GM 1), slopes between Łabski Szczyt and Szrenica (GM 2), and Śląskie Kamienie (GM 7) did not differ distinctly from the other populations treated as originating from natural ones. According to the results of the discriminant analysis, individuals from the populations GM 7 and partly GM 1 were in the middle of the group created by all specimens, and only population GM 2 was a little distant. However, the cluster analysis did not confirm this. Here the populations GM 2, GM 1 and GM 7 were close to others. The most distant populations, according to both analyses, was GM 4 (and partly GM 3) from the glacial cirque, however, the differences were not big and probably resulted from the natural variability of the dwarf pine cones. The population from Mały Staw (GM 4) was also different in respect of needle longevity (Boratyński et al. 2009).

Results of the present study and of recent work on the morphology, anatomy and genetics of *Pinus mugo* in the Giant Mts. (Sobierajska and Boratyńska 2008; Sobierajska et al. 2008) may indicate the local source of the seeds used for the reforestation of the upper parts of this mountain range. In spite of that, the populations on the glacial cirques cliffs can be recommended for seed production, as the local ancient provenances are conserved on such a sites (Larson et al. 2006). All other populations of *P. mugo* in the Giant Mts. can be treated as gene conservation areas.

Acknowledgments

The study was supported by the Ministry of Science and Higher Education, grant no. 2 P06L 046 28 and by the Institute of Dendrology of the Polish Academy of Science.

References

Bobowicz M.A., Krzakowa M. 1986. Morphological differences between *Pinus mugo* Turra populations from the Tatra Mts. revealed by cone traits. Acta Societatis Botanicorum Poloniae 55: 263–273.

Bobowicz M.A., Krzakowa M. 1988. Variability of *Pinus mugo* Turra individuals from Hala Gąsienicowa in Tatra Mts. expressed in needle traits with reference to cone characters. Bulletin de la Société des Amis des Sciences et des Lettres de Poznań, Série D, Sciences Biologiques 26: 87–98.

Boratyńska K., Bobowicz M.A. 2001. *Pinus uncinata* Ramond taxonomy based on needle. Plant Systematics and Evolution 227: 183–194.

Boratyńska K., Marcysiak K., Boratyński A. 2005. *Pinus mugo* (Pinaceae) in the Abruzzi Mountains: high morphological variation in isolated populations. Botanical Journal of the Linnean Society 147: 309–316.

Boratyńska K., Muchewicz E., Drojma M. 2004. *Pinus mugo* Turra geographic differentiation based on needle characters. Dendrobiology 51: 9–17.

Boratyński A. 1994. Chronione i godne ochrony drzewa i krzewy polskiej części Sudetów, Pogórza i Przedgórza Sudeckiego. 7. *Pinus mugo* Turra i *Pinus uliginosa* Neumann. Arboretum Kórnickie 39: 63–85.

Boratyński A., Jasińska A., Boratyńska K., Iszkuło G., Piórkowska M. 2009. Life span of needles of *Pinus mugo* turra: effect of altitude and species origin. Polish Journal of Ecology 57: 567–572.

Christensen K.I. 1987. A morphometric study of the *Pinus mugo* Turra complex and its natural hybridization with *Pinus sylvestris* L. (Pinaceae). Feddes Repertorium 98: 623–635.

Gostyńska-Jakuszewska M., Zieliński J. 1976. Atlas rozmieszczenia drzew i krzewów w Polsce, 18. PWN, Poznań–Warszawa.

Jalas J., Suominen J. 1973. Atlas Florae Europaeae, 2. Helsinki.

Jirásek J., Haenke T., Gruber A., Gerstner F. 1791. Beobachtungen auf Reisen nach dem Risengebirge. Walther, Dresden.

Jodłowski M. 2007. Górna granica kosodrzewiny w Tatrach, na Babiej Górze i w Karkonoszach. Instytut Geografii i Gospodarki Przestrzennej Uniwersytetu Jagielońskiego, 188 pp.

Korshikov I.I., Pirko Y.V. 2002. Genetic variation and differentiation of peat-bog and dry-meadow populations of the dwarf mountain pine *Pinus mugo* Turra in the highlands of the Ukrainian Carpathians. Russian Journal of Genetics 38: 1044–1050.

Larson D.W., Matthes U., Gerrath J.A., Larosn N.W.K., Gerrath J.M., Nekola J.C., Walker G.L., Porembski S., Charlton A. 2000. Evidence for the widespread occurrence of ancient forests on cliffs. Journal of Biogeography 27: 319–331.

Lokvenc T. 2001. History of the Giant Mts. dwarf pine (*Pinus mugo* Turra ssp. pumilio Franco). Opera Corcontica 38: 21–42.

Lokvenc T., Minx J., Nehyba A., Stejskal O. 1994. Reconstrukce rovostù kleče horské (*Pinus mugo* Turra) v Krkonošich. Opera Corcontica 31: 71–92.

Łomnicki A. 2001. Wprowadzenie do statystyki dla przyrodników. PWN, Warszawa, 260 pp.

Marcysiak K. 2004. Interpopulational variability of *Pinus uncinata* Ramond ex DC. In Lam. & DC. (Pinaceae) cone characters. Dendrobiology 51: 43–51.

Marcysiak K., Boratyński A. 2007. Contribution to the taxonomy of *Pinus uncinata* (Pinaceae) based on cone characters. Plant Systematics and Evolution 264: 57–73.

Matuszkiewicz W., Matuszkiewicz A. 1975. Mapa zbiorowisk roślinnych Karkonoskiego Parku Narodowego. Ochrona Przyrody 40: 45–112.

Matuszkiewicz W. 2001. Przewodnik do oznaczania zbiorowisk roślinnych Polski. PWN, 537 pp.

Milková J. 2001. Distribution of protected and important plant species in the plots of potential dwarf pine planting in the Eastern Giant Mts. Opera Corcontica 38: 147–159.

Reisch C., Porschold P., Wingender R. 2003. Genetic variation of *Saxifraga paniculata* Mill (Saxifragaceae): molecular evidence for glacial relict endemism in central Europe. Biological Journal of the Linnean Society 80: 11–21.

Skalicky V. 1983. *Pinus mugo*. In: Slavik B. Minimum and maximum altitudes in the distribution of vascular plants in the Czech Socialistic Republic. Zpravy Česke Botanicke Společnosti 18: 89–98.

Sobierajska K., Boratyńska K. 2008. Variability of needle characters of *Pinus mugo* Turra populations in the Karkonosze Mountains in Poland. Dendrobiology 59: 41–49.

Sobierajska K., Boratyńska K., Marcysiak K., Lewandowski A., Dzialuk A., Boratyński A. 2008. Variation of *Pinus mugo* in the Giant Mountains (Sudethians). Book of Abstracts. Xth Symposium of the International Organization of Plant Biosystematists in Slovakia.

Staffa M. 2005. Historia poznania Karkonoszy oraz rozwój osadnictwa. In: Mierzejewski M.P. (ed.). Karkonosze – Przyroda nieożywiona i człowiek. Wydawnictwo Uniwersytetu Wrocławskiego. Wrocław, pp. 23–50.

Stanisz A. 2007a. Przystępny kurs statystyki. Modele liniowe i nieliniowe, t. 2. StatSoft, Kraków, 866 pp.

Stanisz A. 2007b. Przystępny kurs statystyki. Analizy wielowymiarowe, t. 3. StatSoft, Kraków, 500 pp.

Staszkiewicz J., Tyszkiewicz M. 1976. Zmienność populacyjna i osobnicza szyszek kosodrzewiny *Pinus mugo* Turra ze szczególnym uwzględnieniem materiałów z Karpat. Fragmenta Floristica et Geobotanica Polonica 22 (1–2): 19–28.

Svoboda M. 2001. The effect of *Pinus mugo* (Turra) plantations on alpine-tundra microclimate, vegetation distribution, and soils in Krkonoše National Park, Czech Republic. Opera Corcontica 38: 187–204.

Szweykowski J. 1969. The variability of *Pinus mugo* Turra in Poland. Bulletin de la Société des Amis des Sciences et des Lettres, de Poznań, Série D, Sciences Biologiques 10: 39–54.

Szweykowski J., Bobowicz A.M. 1977. Variability of *Pinus mugo* Turra in Poland IV. Needles and cones in some Polish populations. Bulletin de Societè Amis des Sciences et des Lettres, Poznań, Sèrie D, Sciences Biologiques 10: 37–54.

Tufto J., Hindar K. 2003. Effective size in management and conservation of subdivided populations. Journal of Theoretical Biology 222: 273–281.

Watała C. 2002. Biostatystyka – wykorzystanie metod statystycznych w pracy badawczej w naukach biomedycznych. α-medica press, 423 pp.

Van Rossun F., Triest L. 2003. Spatial genetic structure and reproductive success in fragmented and continuous populations of *Primula vulgaris*. Folia Geobotanica 38: 239–254.