Acer Pseudoplatanus L., *Tilia Cordata* Mill. and *Pinus Sylvestris* L. as Valuable Tree Species in the Carpathian Forests

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Abstract Sycamore maple, little-leaf linden, and Scots pine occurring in unique mixed stands, such as beech and sycamore maple in the Bieszczady Mountains, linden forest in the Obrożyska Reserve (the Beskid Sądecki Mountains), and scattered Carpathian pine forests, were the subject of this study. It was found that sycamore maple can be a highly productive admixture and a co-dominant or even dominant species in beech forests as a protective species of the upper timberline at altitudes between 930 and 1,160 m. Little-leaf linden in stands where site conditions meet its requirements, especially in the lower part of the lower mountain zone at altitudes up to 600–700 m, is a suitable admixture or even co-dominant species that increases productivity. In the Polish Carpathian forests three pine population groups were distinguished on the basis of morphological (cone) traits—lowland, foothill, and mountain group—which also varied according to timber quality, stem, and crown traits, as well as copper (Cu), iron (Fe), and potassium (K) content in needles. Pine is a very good nursing tree species that enables other tree species, especially fir, to occur among pine trees or underneath their canopies.

1 Introduction

Polish Carpathian forests are dominated mainly by silver fir (*Abies alba* Mill.), European beech (*Fagus sylvativa* L.), and Norway spruce (*Picea abies* L.) that together account for about 71 % of the state forests in this region (Rozwałka 2003). Each of these main tree species occupies suitable habitats in terms of

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altitude, fertility, and climatic conditions. In addition to these, there are many other tree species that can serve as valuable admixtures or even co-dominant species in the Carpathian region.

The main admixture species in fir, beech, or spruce stands growing on mountain-rich sites is sycamore maple (*Acer pseudoplatanus* L.). It finds suitable conditions for growth in the Bieszczady Mountains (Głaz 1985), where together with beech forms many stands and constitutes rare forest associations like *Lunario-Aceretum* and *Phyllitido-Aceretum*, and two subassociations, *Dentario glandulosae-Fagetum lunarietosum* and *Dentario glandulosae-Fagetum allietosum ursini*, as well as two unique associations, *Sorbo-Aceretum carpaticum* and *Aceri-Fagetum* (Michalik 1993; Michalik and Szary 1993, 1997; Wilczek 1995; Matuszkiewicz 2001). The latter creates forests mostly near the upper timberline, and due to their inaccessibility (steep slopes) and the low merchantable value of beech and sycamore timber, they have not been harvested up to now and can be considered as primeval forests (Schuck et al. 1994).

On lower elevations (up to 600 m) little-leaf linden (*Tilia cordata* Mill.) can be found where together with beech, oak (*Quercus robur* L. and *Q. petrea* Liebl.), hornbeam (*Carpinus betulus* L.), spruce, fir, pine, and maple (*Acer pseudoplatanus* L., *A. platanoides* L. and *A. campestre* L.) constitutes the *Tilio-Carpinetum* forest association. These forests are in the "Las lipowy Obrożyska" Forest Reserve, now called the Obrożyska Reserve, which is situated near the Poprad River (Beskid Sądecki Mountains) in the vicinity of Muszyna town. The Reserve was created in 1919 and at present covers 101.74 ha (98.25 ha of forests), including 26.68 ha of primeval forests under strict protection (Plan Urządzania 1999). Little-leaf linden forest is considered a relict of linden stands, abundantly occurring in this part of the Carpathians in the postglacial climatic optimum (the Atlantic period 8000–5000 BC), and is unique in Poland and the Carpathians.

Scots pine (*Pinus sylvestris* L.) dominated stands, the majority of which are of nonnative origin, constitute about 17.5 % of the Carpathian forests, mostly in the uplands (up to 600–700 m). At higher elevations and on rich forest sites (such as mountain broad-leaved forest sites), pine stands occur as patches of admixture, often of native origin, in silver fir or beech stands. Among the pine stands some variation is observed, which can have some influence on the introduction of pine to forests. This diversity is the result of the mixing of Scots pine from northern and southern refugium, which took place at the beginning of the Holocene period in the Carpathian area (Tobolski and Hanover 1971; Ralska-Jasiewiczowa 2004).

The aim of this study was to determine the species composition and productivity of forest stands relevant to these three species, and to outline the possibilities of implementation of some conclusions drawn from the observation of these forests in deliberate forest management.

2 Materials and Methods

2.1 Field Measurements

In the primeval forests consisting of sycamore, maple, and beech (*Aceri-Fagetum* and *Dentario glandulosae-Fagetum* forest associations), occurring in the Moczarne Reserve of the Bieszczady Mountains, four permanent sample plots were established in 1993 (Table 1). On every plot diameter at breast height (DBH) and height measurements of trees $\geq$ 8 cm of DBH were measured using a standard calliper and Vertex III hypsometer. In 2003 measurements were carried out to determine changes in species composition, stand volume, and basal area.

In the strictly protected linden forests of the Obrożyska Reserve, three permanent sample plots were established in 1990 (Table 1). In 2000, stands growing on the plots were remeasured. Additionally, 26 circular sample plots (0.04 ha each) in a grid of 100 $\times$ 100 m were established in the strictly protected part in 1995. The control measurements on the small plots were carried out in 2005. Detailed descriptions of site conditions were presented in a paper by Jaworski et al. (2005). The scope of the measurements on large and small sample plots in linden forests was the same as in the case of sycamore stands. All established sample plots are permanently marked in the studied forests in order to perform the measurements every 10 years.

In 39 stands of *Pinus sylvestris* L., mostly autochthonous, the investigations of the occurrence and differentiation of the main tree species were conducted. In each pine stand the DBH and height measurement of a selected 20 mean sample trees (80–170 years of mean age), without visible injuries from the upper stand stratum, were carried out. Additionally, vitality, crown size, traits of branches, bark type and thickness, stem quality (including knots and knobs) of pine trees as well as number and DBH of species co-occurring with pine in stands were determined. A sample of 300 cones was collected from the bottom of each forest. Wood samples from the base of thicker branches and small branches with needles (1–3 years old) and those with 1-year-old cones were gathered from felled mean pine trees. Wood samples were taken from a height of 1.3 m up the trunk in order to determine radius increment.

2.2 Analyses

The measurements of stands carried out on the classical permanent sample plots in forests with linden (3 plots) and sycamore (4 plots) allowed the calculation of the number of trees, stand volume, and basal area using the “ZASOBY” computer program based on the Ukrainian and Moldavian volume tables for standing linden trees (Anonymous 1987) and Czuraj’s tables (1991) for the remaining tree species.

Table 1 Location of sample plots and their site and stand characteristics (linden and sycamore forests)

	Tilia cordata Reserve			*Acer pseudoplatanus* in Bieszczady National Park			
Sample plot	Obrożyska 1	Obrożyska 2	Obrożyska 3	Moczarne 1	Moczarne 2	Rabia Skała 1	Rabia Skała 2
Mountain range	Beskid Sądecki			Bieszczady			
Area [ha]	0.25	0.50	0.50	0.25	0.33	0.25	0.20
Latitude	49°20′54″N	49°20′56″N	49°20′07″N	49°06′43″N	49°06′40″N	49°06′33″N	49°06′29″N
Longitude	20°52′20″E	20°52′24″E	20°52′22″E	22°28′70″E	22°28′87″E	22°27′23″E	22°27′35″E
Aspect	W	W	SW	NNE	E	NWW	NW
Slope [°]	16	11–30	14–19	18	25	18	12–18
Altitude [m a.s.l.]	510	520	515	1,010	930	1,120	1,160
Plant				association	*Tilio-*	*Carpinetum*	
	Dentario			*glandulosae-Fagetum*		*Dentario glandulosae-Fagetum allietosum ursini*	*Aceri-Fagetum*

The measurements of pine tree crown enabled the calculation of live crown ratio: ratio of crown width to tree height (Assmann 1968). The content of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe) and copper (Cu) was determined in 1-year-old needles by the Kjeldahl method (N), vanadium method (P) and AAS method (K, Ca, Mg, Fe, Cu) (Ostrowska et al. 1991). Dry weight of needles was determined after drying in temperature 105 °C with accuracy 0.0001 g. From 300 cones gathered in every stand, 50 were randomly chosen and the following cone trait measurements were done: length, distance between top and largest diameter, largest diameter, width at middistance between top and largest diameter, width of top, scale length, width, and thickness. For each cone the number of scales and cone form, on the basis of scale morphology (*plana*, *gibba*, *hamata*, *reflexa*), were determined (Staszkiewicz 1993). On the basis of those measurements many cone shape indexes were computed and analyzed. Measurements were made of the setting angle of 1-year-old cones on branches from felled mean trees on each plot.

The usability of cone traits as morphological markers of pine trees was verified using an analysis of the principal components and discriminant analysis. The description of the provenance groups distinguished on the basis of those markers put special emphasis on the pine traits that are important for commercial and silvicultural/management purposes. The groups were compared with respect to the size, quality and growth of pine trees, the characteristics of the stem and crown, and content of nutrients. The analysis of variance ANOVA with covariates like age, stand, and site features (adjusted means are shown in tables) and Scheffe's post hoc test were used (StatSoft 1997).

3 Results and Discussion

3.1 Sycamore-Beech Stands in the Bieszczady Mountains

The volume of stands with sycamore maple growing on the sample plots in the Bieszczady Mountains depended on the altitude and site conditions. The highest volume (486.56 m^3 ha^{-1}) was recorded on the lowest established plot: Moczarne 2 (Table 2). The stand on the highest altitude analyzed (Rabia Skała 2 plot) was characterized by a much lower volume (128.62 m^3 ha^{-1}). *Acer pseudoplatanus* was a dominant tree species by basal area and volume on the Moczarne 1 plot and Rabia Skała 1 plot. Its share amounted to 61.8 and 57.0 % by basal area and 65.0 and 61.8 % by volume (Table 2) for each plot, respectively. On Moczarne 2 plot *Fagus sylvatica* predominated in species composition (68.0 % by basal area and 60.9 % by volume). The stand on the Rabia Skała 2 plot was composed of a similar percentage of sycamore maple and beech (Table 2). The highest sycamore maple trees reached 34 m in the stand growing on the Moczarne 2 plot, which was established at the lowest altitude (Table 1). The height of sycamore maple trees growing in the stand at an altitude of 1,160 m (Rabia Skała 2 plot) was 10 m at the most.

The values of volume and basal increment during the 10-year control period were higher for beech (volume from 16.17 on the Rabia Skała 2 plot to 49.14 $m^3\ ha^{-1}$ on the Moczarne 1 plot and basal area from 3.4 on the Moczarne 2 plot to 4.7 $m^2\ ha^{-1}$ on the Moczarne 1 plot) than for sycamore maple (volume from 2.45 on the Rabia Skała 2 plot to 15.90 $m^3\ ha^{-1}$ on the Moczarne 2 plot and basal area from 1.0 on the Moczarne 2 plot to 1.7 $m^2\ ha^{-1}$ on the Rabia Skała 1 plot) on all sample plots (Table 3). In each stand analyzed the total volume and basal area increased during the 10 years regardless of the stand development, site conditions, and altitude (Table 3). Bartkowicz et al. (2008) presented a detailed description of changes in the proportions of sycamore maple and common beech on the studied plots.

Sycamore maple can be a highly productive admixture, co-dominant, or even dominant species (standing volume from 65 at the highest elevation to 261 m^3 ha^{-1} at lower altitude) in mixed sycamore-beech stands growing at altitudes between 930 and 1,160 m (Table 2). The stands (*Aceri-Fagetum*) situated at the highest elevation (Rabia Skała 2) near upper timberline perform mainly protective functions (soil and water protection, biodiversity) due to the tree dwarf form (elfin wood), low timber quality, and mostly vegetative reproduction. These stands of natural or even virgin-type climax association characteristics are unique in the Polish Carpathians and should be under strict protection (Michalik and Szary 1997; Kucharzyk 2003).

Table 2 Species composition by volume and basal area (DBH ≥ 8 cm) of stands with sycamore in four plots in the Bieszczady National Park in 2003

Plot	Species	Number of trees ha^{-1} N	Volume [m^3 ha^{-1}] V	Basal area [m^2 ha^{-1}] G	Species composition [%] V	G
Moczarne 1	*F. sylvatica*	456	140.58	15.65	35.0	38.2
	A. pseudoplatanus	116	261.64	25.28	65.0	61.8
	Total	572	402.22	40.93	100.0	100.0
Moczarne 2	*F. sylvatica*	336	296.21	27.84	60.9	68.0
	A. pseudoplatanus	48	189.71	12.95	39.0	31.6
	A. platanoides	3	0.64	0.13	0.1	0.4
	Total	387	486.56	40.92	100.0	100.0
Rabia Skała 1	*F. sylvatica*	600	96.03	17.88	38.2	43.0
	A. pseudoplatanus	152	155.18	23.66	61.8	57.0
	Total	752	251.21	41.54	100.0	100.0
Rabia Skała 2	*F. sylvatica*	710	63.10	15.88	49.1	52.5
	A. pseudoplatanus	370	65.52	14.36	50.9	47.5
	Total	1,080	128.62	30.24	100.0	100.0

Table 3 Increment of volume and basal area of main tree species and total on studied plots in the Bieszczady Mountains in the 10-year control period

Plot	Species	Increment 1993–2003	
		Volume [$m^3 \cdot ha^{-1}$]	Basal area [$m^2 \cdot ha^{-1}$]
Moczarne 1	*F. sylvatica*	49.14	4.7
	A. pseudoplatanus	12.15	1.2
	Total	61.29	5.8
Moczarne 2	*F. sylvatica*	32.06	3.4
	A. pseudoplatanus	15.90	1.0
	Total	47.97	4.5
Rabia Skała 1	*F. sylvatica*	25.54	4.4
	A. pseudoplatanus	11.69	1.7
	Total	37.23	6.1
Rabia Skała 2	*F. sylvatica*	16.17	4.0
	A. pseudoplatanus	2.45	1.5
	Total	18.62	5.5

Similar natural stands consisting of beech and sycamore maple can be found in the Stužica Reserve in Slovakia (near the Polish and Ukrainian border), which have been studied since the 1930s (Korsuň 1938).

3.2 Linden Stands in Obrożyska Reserve

The volume and basal area of studied stands with linden (on three permanent plots) growing in the Obrożyska Reserve ranged between 761.21 and 54.77 (Obrożyska 3) to 860.54 m^3 ha^{-1} and 62.24 m^2 ha^{-1} (Obrożyska 2) (Table 4). *Tilia cordata* was definitely a dominant tree species in two stands (Obrożyska 1 and 2) when regarding its partition by volume and basal area (Table 3). On the Obrożyska 3 plot linden share was lower (73.3 % by basal area, 76.8 % by volume) because of the occurrence of a significant number of *Abies alba* trees (276 individuals per ha), mainly in the stand layer under the main linden canopy stratum (Table 4).

Considering data obtained from the 26 sample plots established in a 100 × 100 m grid (1 plot of 0.04 ha), we found that the average volume and basal area for the strict protected part of the linden forest were lower (568 and 43.86 m^3 ha^{-1}, respectively) than for the large, permanent plots (Tables 4 and 5). Except for the short-leaf linden, which was still dominating tree species, the percentages of other tree species in the species composition were significant in terms of volume and basal area (Table 5). Partitions of *Abies alba* and *Carpinus betulus* exceeded 10 % (15.3 % and 10.8 % by volume and 14.8 % and 13.2 % by basal area, respectively) (Table 5).

The highest volume and basal area increments were recorded on the Obrożyska 2 plot, where their values reached 95.78 m^3 ha^{-1} and 6.05 m^2 ha^{-1}, respectively, in the 10-year period (Table 6). In the remaining two stands the increments were

Table 4 Species composition by volume and basal area (DBH ≥ 8 cm) of stands with linden on three plots in the Obrożyska Reserve in 2000

Plot	Species	Number of trees·ha^{-1}	Volume [m^{3}·ha^{-1}]	Basal area [m^{2}·ha^{-1}]	Species composition [%]	
		N	V	G	V	G
Obrożyska 1	*T. cordata*	408	747.90	56.92	97.4	95.1
	A. alba	40	12.06	1.62	1.6	2.7
	C. betulus	100	6.20	1.01	0.8	1.7
	Others	20	1.61	0.30	0.2	0.5
	Total	568	767.77	59.85	100.0	100.0
Obrożyska 2	*T. cordata*	418	833.89	59.57	96.9	95.8
	A. alba	52	13.55	1.45	1.6	2.3
	C. betulus	42	10.12	0.90	1.2	1.4
	Others	12	2.98	0.32	0.3	0.5
	Total	524	860.54	62.24	100.0	100.0
Obrożyska 3	*T. cordata*	186	584.93	40.13	76.8	73.3
	A. alba	276	135.62	11.16	17.8	20.4
	C. betulus	58	32.44	2.92	4.3	5.3
	Others	8	8.22	0.56	1.1	1.0
	Total	528	761.21	54.77	100.0	100.0

Table 5 Species composition by volume and basal area (DBH ≥ 8 cm) on 26 plots (in 100 × 100 m grid) in the Obrożyska Reserve in 2005

Species	Number of trees·ha^{-1}	Volume [m^{3}·ha^{-1}]	Basal area [m^{2}·ha^{-1}]	Species composition [%]	
	N	V	G	V	G
T. cordata	219	335.83	25.55	59.1	58.3
A. alba	61	87.15	6.51	15.3	14.8
C. betulus	155	61.41	5.78	10.8	13.2
A. pseudoplatanus	50	33.32	2.52	5.9	5.7
F. sylvatica	21	20.96	1.31	3.7	3.0
P. abies	16	16.94	1.19	3.0	2.7
A. platanoides	10	5.50	0.43	1.0	1.0
Others (*Betula pendula, Larix europaea, Alnus glutinosa, Pinus sylvestris*)	5	6.88	0.57	1.2	1.3
Total	537	567.99	43.86	100.0	100.0

lower (Obrożyska 1: 79.98 m^{3} ha^{-1}, 5.48 m^{2} ha^{-1}; and Obrożyska 3: 81.75 m^{3} ha^{-1}, 5.54 m^{2} ha^{-1}) but still significantly high. Linden had the largest percentage of the total increments values. A relatively high partition of fir in the increments' values on the Obrożyska 3 was caused by its numerous occurrences in the second canopy stratum.

Table 6 Volume and basal area of the main tree species and total on studied plots in the Obrożyska Reserve in the 10-year control period

Sample plot	Species	Increment 1990–2000	
		Volume [$m^3 \cdot ha^{-1}$]	Basal area [$m^2 \cdot ha^{-1}$]
Obrożyska 1	*T. cordata*	77.17	5.2
	A. alba	1.73	0.2
	C. betulus	1.04	0.1
	Others	0.04	0.0
	Total	79.98	5.48
Obrożyska 2	*T. cordata*	91.81	5.7
	A. alba	2.69	0.2
	C. betulus	0.86	0.1
	Others	0.42	0.1
	Total	95.78	6.05
Obrożyska 3	*T. cordata*	53.77	3.4
	A. alba	24.46	1.9
	C. betulus	3.04	0.2
	Others	0.48	0.0
	Total	81.75	5.54
		Increment 1995–2005	
On the basis of 26 sample plots (0.04 ha)	*T. cordata*	25.81	2.20
	A. alba	10.22	1.28
	C. betulus	10.06	0.88
	A. pseudoplatanus	6.95	0.43
	F. sylvatica	6.42	0.24
	Others	3.57	0.26
	Total	63.03	5.29

The values of volume and basal area increment, determined on the basis of 26 sample plots of 0.04 ha each, were lower than found in the stands growing on the large sample plots (Table 6). The highest volume and 10-year basal area increment were recorded for little-leaf linden (25.81 m^3 ha^{-1} and 2.20 m^2 ha^{-1}, respectively). The percentages of the remaining tree species in the increment values were higher than on the large sample plots (Table 6). The changes in volume and basal area in the control period depending on stand growth stage were analyzed by Grałek et al. (2009). The highest growing stock, volume, and basal area increment were in the stand on the Obrożyska 2 plot, where the initial phase of the optimum stage were determined by Jaworski et al. (2005) according to Korpel (1995) criteria. On the remaining plots, the transition from the growing-up stage to the optimum stage (the Obrożyska 1) and the selection structure phase (the Obrożyska 3) were determined (Jaworski et al. 2005).

The growing stock per hectare of the studied linden forests in the Obrożyska Reserve is one of the greatest (760–860 m^3 ha^{-1} on large sample plots or 568 m^3 ha^{-1} on 26 small sample plots) among primeval and natural stands in the Polish part of the Carpathians. The differences between the volume based on 3 large and

26 small sample plots could be explained by the fact that the large plots were established in subjectively selected homogeneous fragments of forest representing specified stage and phase of development (Korpel 1995). The volumes determined on large plots were higher than the volumes per hectare of pure beech and mixed stands with fir, beech, and spruce (Dziewolski and Rutkowski 1991; Jaworski et al. 1994; Przybylska et al. 1995; Jaworski and Paluch 2001; Jaworski et al. 2001a, b; Jaworski and Kołodziej 2002). Therefore, the high productivity of the stands may be an effect of the advantageous terrain configuration (mostly west and south slope aspects, protected against the north and east cold winds), fertile soil (brown soils), and mild climate (the Reserve is situated in the Poprad River valley along which warm air inflow from the south frequently occurs) (Fabijanowski 1961).

3.3 Pine Stands

Most of the investigated pine stands (75 %) grew at an altitude of 300–600 m, on a warm aspect (south, southeast, and southwest) and on rich or medium-rich forest site types characterized as mountain broad-leaved forest (LG) and mountain mixed broad-leaved forest (LMG) (Siedliskowe Podstawy Hodowli Lasu 2004). Due to the more favorable light and warmth conditions among pine trees and underneath pine canopies, many other tree species accompanying pine were recorded; among those *Abies alba*, *Fagus sylvatica* and *Picea abies* occurred most frequently (Fig. 1). Their participation in the number of trees, volume, and basal area ranged from 5 to 23 %. The remaining percentage belonged to pine and 12 other mostly broad-leaved, tree species.

Pine stands were mostly even-aged, and their average age ranged from 80 to 170 years between stands. The investigated pine stands were in most cases characterized by normal vitality, long crowns, low quality of the trunk, and high volume (up to 600 m^3 ha^{-1}). In each of the analyzed stands a high stability of Scots pines was observed, which was determined based on the ratio of height to DBH of trees.

On the basis of pinecone traits as morphological markers, pine stands were classified into three population groups named a lowland group, a mountain group, and a foothill group. The groups did not have any specific shape of the cone (morphotype), and they differed only in the proportion of three-cone morphotypes called “lowland” (L), “mountain” (M), and “foothill” (F). The cones of morphotype F were the largest, the least full, and had not numerous but long, wide, and thick scales. The L-type cones were the fullest, almost as wide as F-type, with flat and numerous scales. The M-type cones were the smallest, but similar in proportions to F-type. The morphotypes also varied in the percentage of scale forms (*plana*, *gibba*, *hamata*, *reflexa*). The setting angle of 1-year-old cones was smaller in the foothill and mountain groups of pines than in the lowland group. The spatial distribution of pine stands classified into the three population groups is shown in Fig. 2.

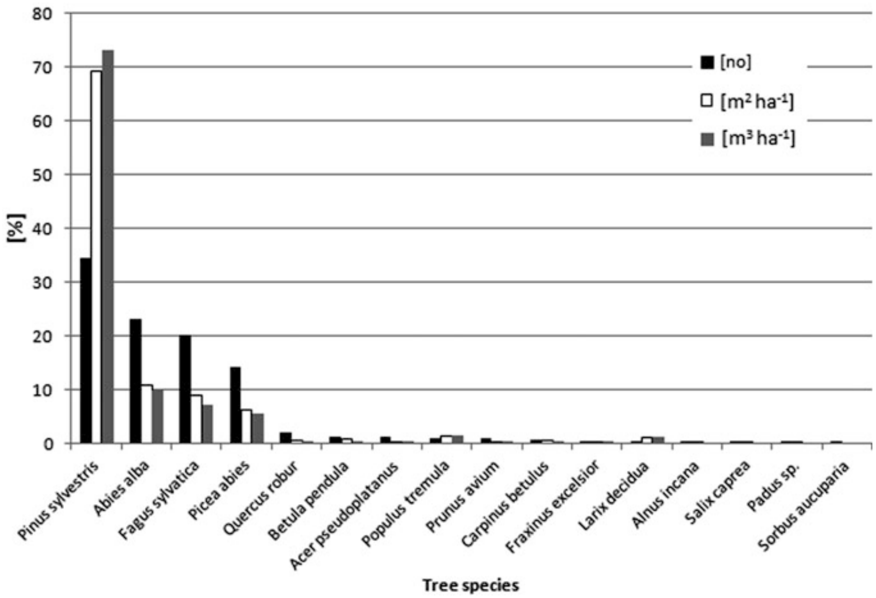

Fig. 1 Number, volume, and basal area percentage of tree species found among pine trees and underneath pine canopies

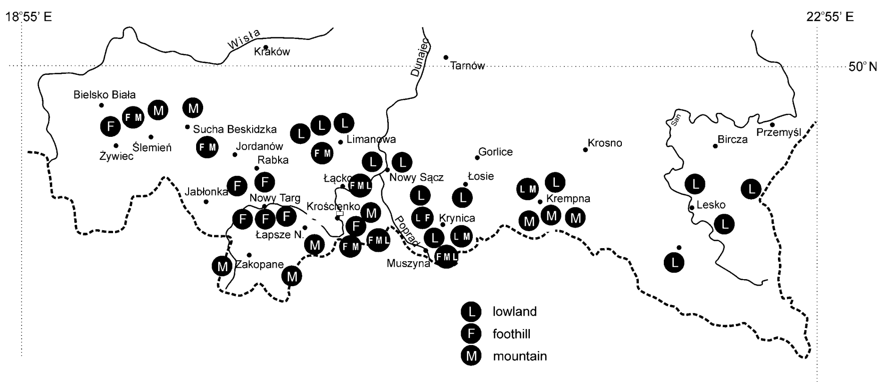

Fig. 2 Spatial distribution of pine stands classified into the three population groups (L, F, M) within the range of the Polish Carpathians

The lowland pine can create stands producing wood of high quality and commercial value if they grow on less fertile microsites and/or have a higher canopy density (Skrzyszewski 2004). When the sites are more fertile and/or the canopy density is lower, the lowland pine achieves high DBH increment and forms very stable stands, but the trees have thick branches and a limited ability for self-pruning (high branch age) (Table 7).

Table 7 Pine branch thickness, their age, and appearance of knots in population groups

Branch traits	Population group[a]	Adjusted mean	Homogeneous groups[b]		
Branch thickness [mm]	L	66	●		
	M	54		●	
	F	53		●	
Branch age [years]	L	53	●		
	M	45		●	
	F	40			●
Number of burl knots per tree	L	3.1	●		
	F	2.1		●	
	M	2.2		●	
Number of open knots per tree	M	2.5	●		
	L	2.3	●		
	F	1.0		●	

[a] L: lowland; M: mountain; F: foothill; [b] homogeneous groups are joined vertically by dots

Diameter increment of branches is very significantly correlated to the DBH increment (Skrzyszewski 2004). With respect to the future quality of the stem, the DBH of a tree should not exceed 7 cm at the age of 16 years and 30 cm at 80 years (diameter increment should be limited) (Skrzyszewski 2004).

The needles of lowland pines showed the highest Cu and Fe content (Table 8). This suggests that their photosynthesis process is more efficient (Starck 2002).

The age of the thickest branches (the lowest branches) showed that the lowland pines are the most shade tolerant (Table 7). The foothill pine has thin branches, a narrow crown, and smaller DBH increment, but the greatest height and quality of stem (number of burl and open knots) (Tables 7 and 9). Furthermore, these traits are maintained on fertile sites (mountain broad-leaved forest site) and at a low canopy density (Skrzyszewski 2004). The mountain pine forms stands of very good quality on part of the sites, but it exhibits the greatest needle loss (Table 9).

The mountain and foothill pines are more resistant to frost and drought damages (Starck 2002) due to the higher K content (Table 8).

Table 8 Nutrient contents of 1-year-old pine needles by population groups

Nutrient	Population group[a]	Adjusted mean	Homogeneous groups[b]	
K [%]	F	0.661	●	
	M	0.66	●	
	L	0.549		●
Cu [ppm]	L	15.91	●	
	M	14.66		●
	F	14.02		●
Fe [ppm]	L	151	●	
	F	113		●
	M	102		●

[a] L: lowland; M: mountain; F: foothill; [b] homogeneous groups are joined vertically by dots

Table 9 Stem and crown traits of sample pine trees in population groups

Stem and crown traits	Population group[a]	Adjusted mean	Homogeneous groups[b]		
DBH, D [cm]	L	44.5	●		
	F	41.8		●	
	M	41.1		●	
Mean annual DBH increment [mm]	L	3.6	●		
	F	3.4		●	
	M	3.3		●	
Height, H [m]	F	29.4	●		
	M	28.1		●	
	L	27.6			●
Coefficient of slenderness, H/D	F	72	●		
	M	70	●		
	L	62		●	
Crown spreading degree (narrow crown)	L	20	●		
Crown width/H [%]	M	19		●	
	F	18			●
Needle loss [%]	M	24	●		
	F	20		●	
	L	17			●

[a] L: lowland; M: mountain; F: foothill; [b] homogeneous groups are joined vertically by dots

Pine tree as an admixture species can play a stabilizing role (coefficient of slenderness height/diameter [H/D] is lower than 80) (Table 9) in stands prone to wind damage and can be a productive admixture or a co-dominant species in silver fir or beech stands. Additionally, the site conditions created by Scots pine are conducive to the abundant appearance of the main and admixture climax species, mostly *Abies alba* Mill (Fig. 2). This role of pine stands as a nurse crop enables the prolongation of the transformation period and the attainment of multistory, uneven-aged silver fir stands (Jaworski 1988).

4 Conclusions and Practical Implications

The results of this study showed that sycamore maple appeared to be a high productive species (high volume and basal area increment) and can play a valuable role as a productive admixture in the stands of the Bieszczady Mountains. The little-leaf linden stands in the Obrożyska Reserve had the highest volume per hectare among managed and primeval character stands in the Polish part of the Carpathians. Where site conditions meet its requirements, especially in the lower part of the lower mountain zone at altitudes up to 600–700 m, these stands are a suitable admixture or even codominant species, increasing the productivity and biological diversity of stands.

In the Polish Carpathian forests three pine population groups were distinguished on the basis of morphological (cone) traits—lowland, foothill and mountain groups—which also varied according to timber quality, stem and crown traits, as well as Cu, Fe and K content in needles. The pine populations group (lowland, foothills and mountain) should be considered during Scots pine introduction to forests stands as a codominant or admixture tree of different percentages (productive or nurse role) and as a nurse crop tree in open areas (before climax species).

Based on the results of our study, we suggest that increased introduction of little-leaf linden and sycamore maple as an admixture in forest stands should be followed by flexible methods of regeneration. The Swiss irregular shelterwood system is recommended as the best method for creating favorable conditions of light and shelter for regeneration in gaps while maintaining a suitable partition of both species within the stand.

The lower light demands of lowland Scots pine allows for its cultivation in small groups within fir stands with the result that in forest stands managed by the Swiss irregular shelterwood system Scots pine can be introduced into unregenerated gaps. In the case of existing Scots pine regeneration that constitutes a nursing admixture, it should be free from the influence of other species before the Scots pine trees are 10 years old (Skrzyszewski 2004).

The foothill Scots pine should be used to a greater extent in establishing nurse stands. In such stands, with the early reduced density caused by restructure felling, the Scots pine has the capacity to maintain high stem quality, especially on fertile sites such as mountain broad-leaved forest and mountain mixed broad-leaved forest. In addition, the higher frost resistance of mountain Scots pine allows its populations to be introduced, especially at high elevations including afforestation near the upper timberline. Because the mountain Scots pine grows mostly in small populations in only a few places in the Carpathians (Fig. 2), it is necessary to reestablish the higher elevation stands in the lower mountain belt of the Carpathians on the basis of the remaining stands.

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