Structure and dynamics of stands of primeval character composed of the little-leaf linden (*Tilia cordata* Mill.) in the "Las lipowy Obrożyska" reserve (southern Poland)

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ABSTRACT: The little-leaf linden stand, investigated in this study, is a relict of the Atlantic period. On three permanent sample plots, situated in a strictly protected reserve, trees were measured and classed in 1990 and 2000. Stands in these areas represented the growing up stage in transition to the optimum stage (Obrożyska 1), the optimum stage (Obrożyska 2), and the growing up stage, the selection structure phase (Obrożyska 3). In 2000 the percentage of linden by volume was 97% in Obrożyska 1 and 2, and 77% in Obrożyska 3, while the stand volume was 768, 861, and 761 m^3/ha, and basal area 60, 62, and 55 m^2/ha, respectively. These stands have the highest per hectare volume among stands of primeval character in the Polish part of the Carpathians.

Keywords: development stages and phases; stand volume; basal area; regeneration; volume of necromass

STUDY AIM

In Poland the little-leaf linden (*Tilia cordata* Mill.) belongs to the tree species that are scattered throughout the whole country. It is a characteristic tree of mesophilous broad-leaved forests composed of many species. With some exceptions it does not form pure stands. Depending on ecological conditions and geographic location the little-leaf linden, similarly like the big-leaf linden (*Tilia platyphyllos* Scop.), occurs together with beech (*Fagus sylvatica* L.), oaks (*Quercus robur* L. and *Q. petraea* Liebl.) and maples (including *Acer pseudoplatanus* L., *A. platanoides* L., and *A. campestre* L.). However, it is mainly associated with hornbeam (*Carpinus betulus* L.), and also spruce (*Picea abies* [L.] Karst.), fir (*Abies alba* Mill.) and pine (*Pinus sylvestris* L.) (Faliński, Pawlaczyk 1991).

One of the most interesting forest complexes with the little-leaf linden, the "Las lipowy Obrożyska" reserve, is located in the valley of the Poprad river, near the town of Muszyna in the Beskid Sądecki Mts. Środoń (1991) assumed that this little-leaf linden forest is a relict of linden stands abundantly occurring in this part of the Carpathians in the postglacial climatic optimum (Atlantic period, 7700–5100 B.C.). Relatively late, i.e. in the second half of the XIX century, it was mentioned in literature for the first time (Böhm 1866; Grzegorzek 1868). Raciborski (1910) also reported the occurrence of linden stands in forests of the Muszyna church estate. Several years later a more detailed publication concerning this interesting forest appeared in Sylwan (Malitowski 1916).

The reserve, 17.80 ha in area, was created in 1919 in order to protect the stand where the little-leaf linden was a dominant tree. At the present moment the reserve covers 101.74 ha, including 98.25 ha of forest, with 26.68 ha of stands of primeval character put under a strict protection (Plan Urządzania – Management Plan 1999).

A short floristic description of the linden forest of the Poprad river valley was published for the first time by Pawłowski (1921, 1925).

Subsequent studies concerning this forest included diameter measurements only (Witowski 1933, 1956 – unpublished data) and a stem analysis of two linden trees. A geobotanic study carried out in the reserve was completed in 1959 (Fabijanowski 1961).

In 1990 regular investigations of this linden stand were initiated by the Department of Silviculture, Agricultural University of Cracow. Measurements were carried out on three permanent sample plots at that time. They were repeated in 2000 in order to determine changes in selected characteristics of the stand, including d.b.h. distribution, storied structure and volume, which took place during a 10-year period. The analysis of the morphological characteristics of trees, tree recruitment, loss and increment will be discussed in another paper.

CHARACTERISTICS OF THE STUDY AREA AND SAMPLE PLOTS

Site conditions

The "Las lipowy Obrożyska" reserve is located in the Beskid Sądecki Mts. near the town of Muszyna, south west of the Jaworzyna mountain range (Obrębska-Starklowa 1967). It is situated on western and south-western slopes of Mikowa Mt. (641 m above sea level). A difference in the elevation of different parts of the reserve is 160 m (from 450 to 610 m) (Fabijanowski 1961).

A depressed area surrounding Muszyna is characterized by more moderate temperature conditions in comparison with the hills of Krynica situated farther northward. The mean annual temperature for Muszyna was 6.7°C for the period 1957–1962. July was the warmest month with mean temperature of 16.2°C while January was the coldest one (–3.8°C). The mean annual temperature amplitude was 20.0°C. There were 141 days per year without frosts, and the growing season lasted for 210 days (Obrębska-Starklowa 1967).

The annual total precipitation, which depends on the elevation and exposure to rainy winds, was 757 mm. The maximum (144 mm) occurred in June and minimum (23 mm) in February. Days with snowfall comprised 28% of all days with precipitation. The period without snow cover was 210 days (Obrębska-Starklowa 1967).

The reserve is situated within the Magura series. Tertiary Magura sandstone is composed of thick sandstone layers and conglomerates separated by clay shale. Acid brown soils prevail, while ridges are covered with typical leached brown soils, and in the stream valley there are fragments of grey brown soils (Plan Urządzania 1999).

Tilio-Carpinetum is the main forest association (Table 1), described as the subcontinental

Table 1. Location of sample plots and their site and stand characteristics

Name of plot	Obrożyska 1	Obrożyska 2	Obrożyska 3
Area (ha)	0.25	0.5	0.5
Geographic coordinates	49°20´54.5´´N 20°52´20.5´´E	49°20´56.3´´N 20°52´23.6´´E	49°20´07.1´´N 20°52´21.7´´E
Exposure	W	W	SW
Slope (°)	16	11–30	14–19
Elevation (m)	510	520	515
Species composition by volume (%)			
Tilia cordata	97.4	96.9	76.8
Abies alba	1.6	1.6	17.8
Carpinus betulus	0.8	1.2	4.3
Picea abies	0.2	0.1	1.1
Fagus sylvatica	–	0.1	–
Acer pseudoplatanus	–	0.1	–
Plant association		*Tilio-Carpinetum*	
Development stage and phase	Growing up stage /optimum stage	Initial phase of optimum stage	Growing up stage selection phase
Volume (2000) (m^3/ha)	768	861	761
Maximum age of linden trees (years)	180	200	230[1]

[1]breast height age

broad-leaved forest, the Małopolska variety, the submontane form (Matuszkiewicz 1982). There are fragments of *Dentario glandulosae-Fagetum* association in the upper part of the reserve while *Alnetum incanae carpaticum* and also moist and wet meadow communities occur along the stream (Staszkiewicz 2000).

The sample plots are located at 510–520 m above sea level in the *Tilio-Carpinetum* association.

Stand characteristics

The 1995 survey, based on a statistical-mathematical forest inventory system (26 4-are circular plots), covering the whole area of a strictly protected reserve, showed that about 80% of the area was covered by the stand in the growing up stage, about 20% by the stand in the optimum stage, and the break-up stage occurred sporadically (unpublished data). The stand species composition by volume was as follows: little-leaf linden – almost 60%, silver fir – about 15%, and the remaining species (hornbeam, Norway spruce, sycamore maple, common beech, Norway maple, Polish larch, and others) – 25%. The results obtained by this method will be published after control measurements in 2005.

This paper presents the results of research conducted on permanent classical sample plots according to methods similar to those used by Korpeľ (1989, 1995) during his studies on primeval forests. They enable to fully characterize a homogeneous fragment of a primeval stand representing a definite development stage.

Three permanent sample plots established in the reserve represented the predominating stand stages: the growing up stage in transition to the optimum stage on the plot Obrożyska 1, the initial phases of the optimum stage on the plot Obrożyska 2, and the growing up stage in selection phase on the plot Obrożyska 3

Table 2. Species composition by volume, basal area and the number of trees (d.b.h. ≥ 8) in 1990 and 2000

Plot	Species	Number of trees/ha		Volume (m^3/ha)		Basal area (m^2/ha)		Species composition (%)			
		N		V		G		V		G	
		1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
	Tilia cordata	432	408	679.85	747.90	52.62	56.92	97.2	97.4	94.9	95.1
	Abies alba	36	40	11.13	12.06	1.52	1.62	1.6	1.6	2.7	2.7
Obrożyska 1	*Carpinus betulus*	84	100	4.84	6.20	0.81	1.01	0.7	0.8	1.5	1.7
	Others	20	20	3.69	1.61	0.48	0.3	0.5	0.2	0.9	0.5
	Total	572	568	699.51	767.77	55.43	59.85	100.0	100.0	100.0	100.0
	Tilia cordata	446	418	773.30	833.89	56.36	59.57	97.0	96.9	95.8	95.7
	Abies alba	50	52	11.02	13.55	1.23	1.45	1.4	1.6	2.1	2.3
Obrożyska 2	*Carpinus betulus*	38	42	9.20	10.12	0.80	0.9	1.1	1.2	1.4	1.4
	Others	16	12	3.82	2.98	0.43	0.32	0.5	0.3	0.7	0.5
	Total	550	524	797.34	860.54	58.82	62.24	100.0	100.0	100.0	100.0
	Tilia cordata	190	186	532.10	584.93	36.85	40.13	76.5	76.8	73.1	73.3
	Abies alba	262	276	121.36	135.62	9.87	11.16	17.4	17.8	19.6	20.4
Obrożyska 3	*Carpinus betulus*	58	58	33.48	32.44	3.01	2.92	4.8	4.3	6.0	5.3
	Others	14	8	9.11	8.22	0.69	0.56	1.3	1.1	1.3	1.0
	Total	524	528	696.05	761.21	50.42	54.77	100.0	100.0	100.0	100.0

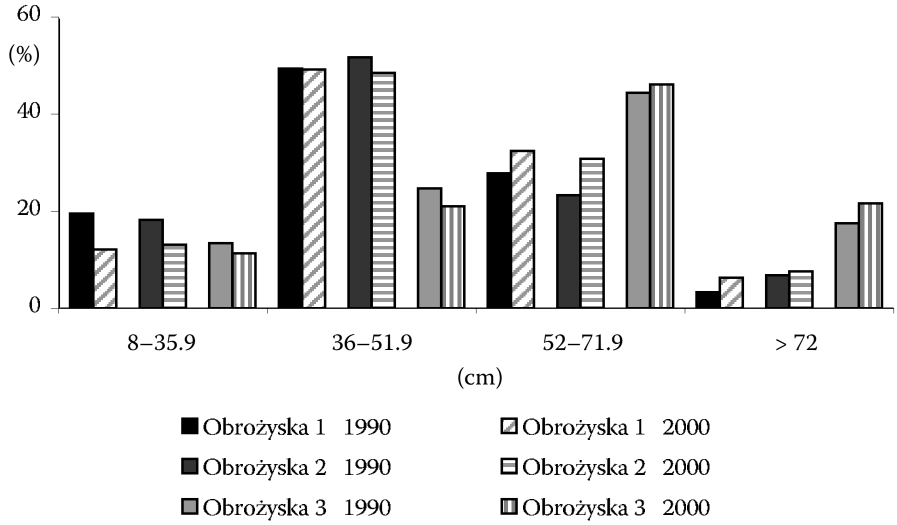

Fig. 1. Percentage of tree volume in individual size gradations according to Flury

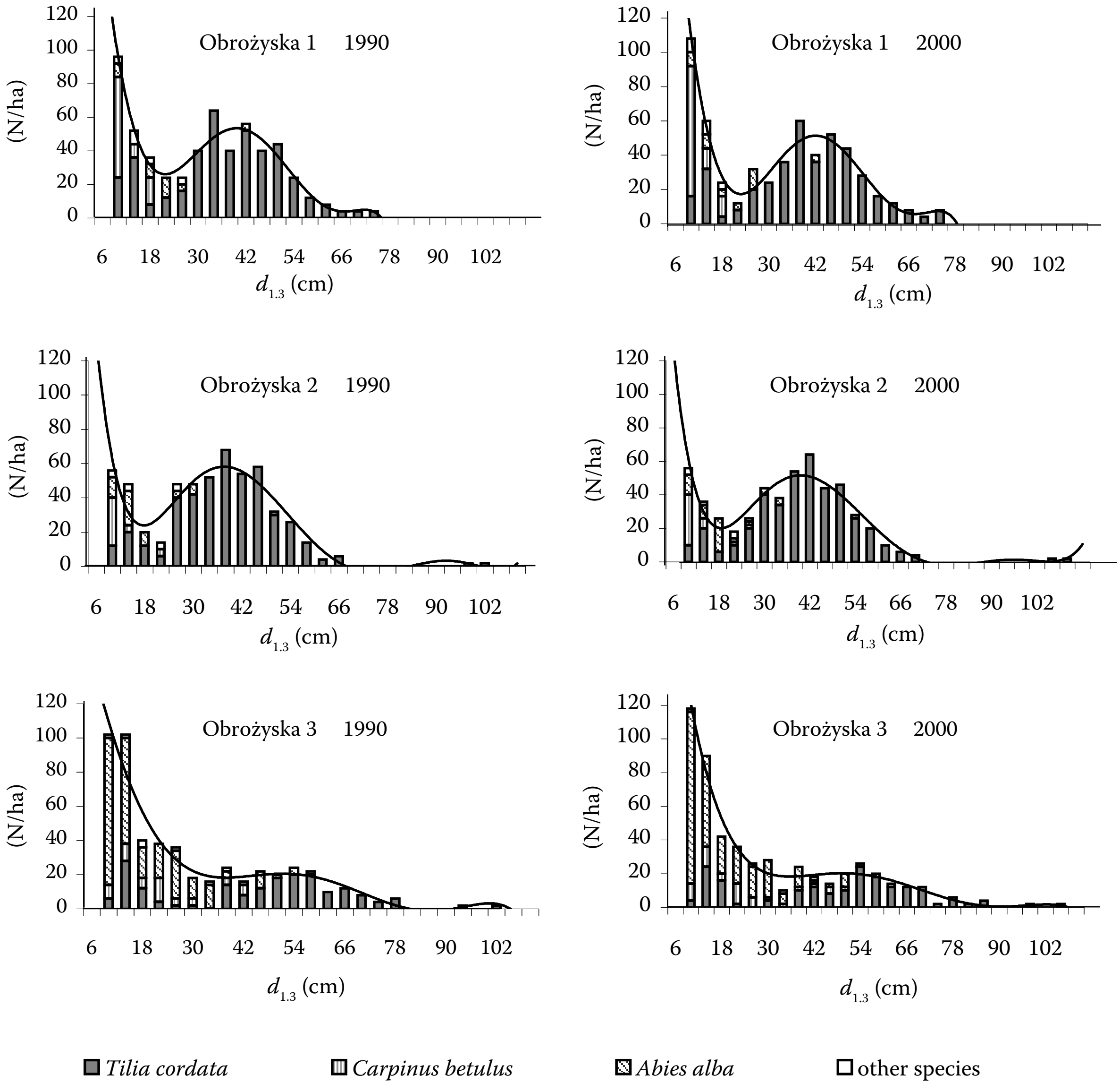

Fig. 2. d.b.h. distribution of all tree species together in 1990 and 2000

Table 3. Characteristics of stand d.b.h[1] distribution in 1990 and 2000

Plot		Species	Number of trees in a sample	Breast height diameter			Standard deviation	Coefficient of			Parameters of distribution[2] according to Pearson		Type of Person's distribution[3]
				min.	max.	mean		variation	skewness	excess	beta 1	beta 2	
							(cm)						
Obrożyska 1	1990	*Tilia cordata*	108	8.5	72.0	36.6	14.5	0.395	–0.134	–0.341	0.018	2.659	I
		Abies alba	6	10.0	25.0	17.3	×	×	×	×	×	×	×
		Carpinus betulus	21	8.0	19.0	10.6	3.1	0.292	1.425	0.881	2.030	3.881	?[3]
		Picea abies	5	8.0	27.5	16.2	×	×	×	×	×	×	×
		Stand	140	8.0	72.0	31.1	16.3	0.525	0.166	–0.927	0.027	2.073	I
	2000	*Tilia cordata*	101	8.5	74.0	39.8	14.5	0.366	–0.218	–0.226	0.047	2.774	I
		Abies alba	7	8.0	26.0	15.9	×	×	×	×	×	×	×
		Carpinus betulus	25	8.0	19.5	10.8	3.3	0.306	1.525	1.312	2.324	4.312	×
		Picea abies	4	9.5	18.5	12.3	×	×	×	×	×	×	×
		Stand	137	8.0	74.0	32.5	17.6	0.543	0.119	–1.071	0.014	1.929	I
Obrożyska 2	1990	*Tilia cordata*	222	8.0	102.0	37.9	13.4	0.353	0.634	3.285	0.402	6.285	?
		Abies alba	25	8.0	31.0	16.5	6.5	0.395	0.990	–0.115	0.979	2.885	I(J)
		Carpinus betulus	19	8.0	51.5	13.2	9.7	0.734	3.203	9.694	10.257	12.694	?
		Picea abies	5	8.0	27.0	16.1	×	×	×	×	×	×	×
		Fagus sylvatica	2	8.5	26.0	17.3	×	×	×	×	×	×	×
		Acer pseudoplatanus	1	×	×	×	×	×	×	×	×	×	×
		Stand	274	8.0	102.0	33.6	15.3	0.456	0.426	1.312	0.182	4.312	IV
	2000	*Tilia cordata*	206	8.0	110.0	40.2	14.4	0.358	0.650	3.442	0.422	6.442	?
		Abies alba	25	8.5	33.0	17.8	7.0	0.390	0.892	–0.093	0.795	2.907	I(J)
		Carpinus betulus	21	8.0	24.5	13.3	9.8	0.739	3.178	9.780	10.097	12.780	?
		Picea abies	3	9.5	22.5	14.6	×	×	×	×	×	×	×
		Fagus sylvatica	2	10.0	27.0	18.5	×	×	×	×	×	×	×
		Acer pseudoplatanus	1	×	×	×	×	×	×	×	×	×	×
		Stand	258	8.0	110.0	35.3	16.5	0.469	0.440	1.334	0.194	4.334	IV

Table 3 to be continued

Plot	Species	Number of trees in a sample	Breast height diameter			Standard deviation	Coefficient of			Parameters of distribution[2] according to Pearson		Type of Person's distribution[3]
			min.	max.	mean		variation	skewness	excess	beta 1	beta 2	
			(cm)									
Obrożyska 3 1990	*Tilia cordata*	95	8.5	103.0	44.8	21.5	0.479	−0.061	−0.647	0.004	2.353	I
	Abies alba	130	8.0	56.5	18.8	11.1	0.592	1.380	1.364	1.904	4.364	?
	Carpinus betulus[1]	29	8.0	49.5	23.0	11.3	0.491	0.727	−0.460	0.528	2.540	I(J)
	Picea abies	6	8.5	39.0	23.6	×	×	×	×	×	×	×
	Acer pseudoplatanus	1	×	×	×	×	×	×	×	×	×	×
	Stand	261	8.0	103.0	28.9	19.8	0.688	0.982	0.169	0.965	3.169	I(J)
2000	*Tilia cordata*	92	8.5	106.0	47.8	22.2	0.464	−0.072	−0.548	0.005	2.452	I
	Abies alba	124	8.0	62.5	19.2	12.2	0.638	1.507	1.717	2.271	4.717	?
	Carpinus betulus	28	8.0	51.0	22.9	11.6	0.506	0.887	−0.175	0.786	2.825	I(J)
	Picea abies	4	8.0	40.5	27.1	×	×	×	×	×	×	×
	Stand	248	8.0	106.0	30.3	21.4	0.704	0.936	0.022	0.877	3.022	I(J)

[1]Broken trees were not included in the calculation of distribution parameters
[2]A type of Pearson's distribution was determined when the number of trees of a given species in a sample was at least 15
[3] ? does not fit to types of Pearson's distribution

(Table 1). The remaining stand characteristics are summarized in Table 1, and discussed in the chapter entitled "Results".

METHODS

Three permanent sample plots were established in a strictly protected part of the reserve in 1990. They were selected subjectively, taking into account stand characteristics such as species composition, height and age structure and crown closure, so that they would correspond to characteristics of individual development stages of a primeval forest described by Korpeľ (1989, 1995). Stand measurements were carried out in the same year, and they were repeated 10 years later. Their scope and methods in the main were the same as those presented in other papers concerning primeval forests of the Carpathians (including Jaworski, Kołodziej 2002). It should however be mentioned that in 1990 the height of only 64% of trees on plot 1, 70% on plot 2, and 87% on plot 3 was measured with the Blume-Leiss hypsometer, while in 2000 the height of all trees was measured with the Vertex hypsometer, with the exception of strongly bended ones when only the vertical height was measured, not the tree length. These data were used to determine the location of trees in three stand layers. Parameters to determine the types of Pearson's distribution were calculated on the basis of d.b.h. (≥ 8 cm) and height measurements (Zieliński 1972).

Stand volume was calculated using the "Zasoby" computer program based on Ukrainian and Moldavian volume tables for standing linden trees (Anonym 1987) and Czuraj's tables (1991) for the remaining tree species. In the poster published earlier (Jaworski et al. 2003), stand volume was calculated on the basis of Czuraj's tables only. But these tables allowed to determine the volume of linden trees up to 30 m in height and 65 cm in d.b.h. only. For larger trees the volume was determined using the form factor. Thus the per-hectare volume calculated in this manner was greater (Jaworski et al. 2003) than that given in the present paper. To calculate stand volume at the beginning (1990) and at the end (2000) of the period smoothed height curves according to Michajlov's function (Korf et al. 1972) were used. They were developed on the basis of measurements carried out in 2000 since they included more trees than in 1990, and they were more accurate thanks to the more precise hypsometer used.

RESULTS

Stand volume, basal area, number of trees, and species composition

Per-hectare stand volume increased in all three stands during the control period (Obrożyska 1: from 700 to 768 m^3/ha; Obrożyska 2: from 797 to 861 m^3/ha; Obrożyska 3: from 696 to 761 m^3/ha) (Table 2). At the beginning of the control period, as well as at its end, diameter classes ranging from 36 to 71.9 cm, and in Obrożyska 3 also above 72 cm, decided on the stand volume (Fig. 1). Basal area increased on all three plots during the 10-year period from about 3.4 to 4.4 m^2/ha, reaching in 2000 from about 55 m^2/ha (Obrożyska 3) to a little over 62 m^2/ha (Obrożyska 2) (Table 2). The number of trees decreased in Obrożyska 1 and Obrożyska 2 by 4 and 26 trees/ha, respectively (Table 2), and slightly increased in Obrożyska 3 by 4 trees/ha (Table 2). The species composition determined on the basis of volume and basal area percentages did not basically change (Table 2).

d.b.h. distribution

There was no change in d.b.h. distribution of all tree species together, and the same types of Pearson's curves were maintained with modes at the beginning and in the middle of distribution (Obrożyska 1 and 2), and at the beginning of distribution (Obrożyska 3) (Fig. 2, Table 3).

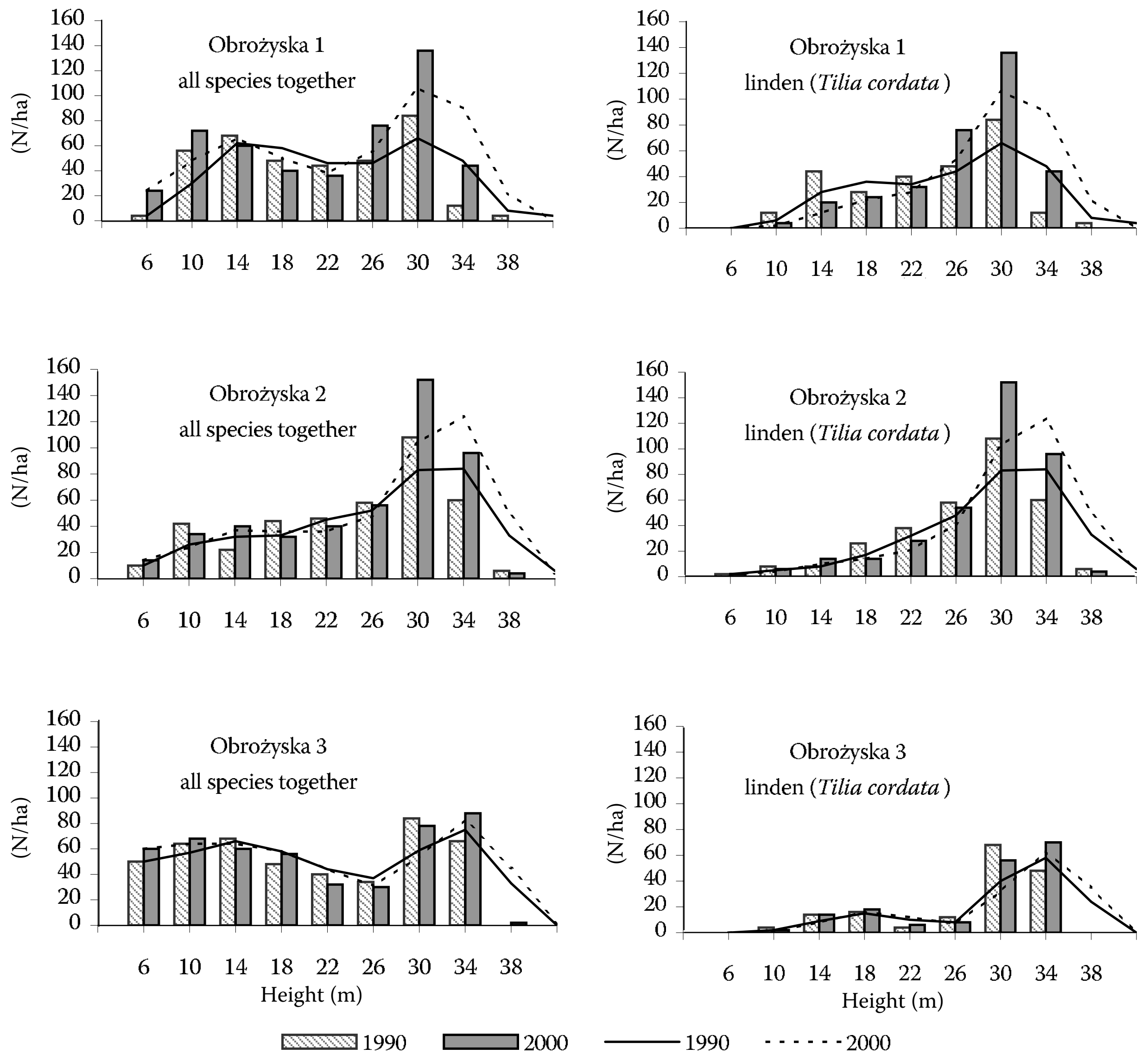

Fig. 3. Height distribution of all tree species together and linden in 1990 and 2000

Table 4. Characteristics of stand height[1] distribution in 1990 and 2000

Plot		Species	Number[1] of trees in a sample	Height (m)			Standard deviation	Coefficient of			Parameters of distribution[2] according to Pearson		Type of Person's distribution[3]
				min.	max.	mean		variation	skewness	excess	β_1	β_2	
Obrożyska 1	1990	*Tilia cordata*	67	8.0	36.5	23.4	7.0	0.298	–0.439	–0.838	0.193	2.162	I(J)
		Abies alba	5	6.0	19.6	13.2	×	×	×	×	×	×	×
		Carpinus betulus	13	8.5	22.5	11.7	×	×	×	×	×	×	×
		Picea abies	3	9.5	18.0	13.5	×	×	×	×	×	×	×
		Stand	88	6.0	36.5	20.8	8.0	0.385	–0.082	–1.273	0.007	1.727	I(U)
	2000	*Tilia cordata*	85	8.5	35.0	26.6	5.7	0.216	–1.102	0.616	1.215	3.616	I(J)
		Abies alba	7	5.8	19.6	11.8	×	×	×	×	×	×	×
		Carpinus betulus	23	7.7	22.5	11.9	3.5	0.291	1.363	1.555	1.859	4.555	?
		Picea abies	4	6.0	14.2	9.4	×	×	×	×	×	×	×
		Stand	119	5.8	35.0	22.3	8.6	0.386	–0.431	–1.250	0.186	1.750	I(U)
Obrożyska 2	1990	*Tilia cordata*	151	7.5	37.0	26.8	6.1	0.227	–0.983	0.702	0.966	3.702	I
		Abies alba	22	6.0	22.0	12.5	4.6	0.364	0.715	–0.599	0.511	2.401	I(J)
		Carpinus betulus	12	9.5	20.0	14.0	×	×	×	×	×	×	×
		Picea abies	4	5.5	17.5	10.9	×	×	×	×	×	×	×
		Fagus sylvatica	2	11.0	18.0	14.5	×	×	×	×	×	×	×
		Acer pseudoplatanus	1	×	×	×	×	×	×	×	×	×	×
		Stand	192	5.5	37.0	23.9	8.1	0.338	–0.552	–0.826	0.305	2.174	I(J)
	2000	*Tilia cordata*	185	7.4	36.7	28.2	5.9	0.208	–1.487	1.911	2.212	4.911	?
		Abies alba	25	6.0	24.2	13.6	5.2	0.379	0.609	–0.600	0.371	2.400	I(J)
		Carpinus betulus	17	8.4	23.0	15.0	3.8	0.255	0.381	–0.384	0.145	2.616	I
		Picea abies	3	6.9	18.5	11.8	×	×	×	×	×	×	×
		Fagus sylvatica	2	10.0	23.0	16.5	×	×	×	×	×	×	×
		Acer pseudoplatanus	1	×	×	×	×	×	×	×	×	×	×
		Stand	233	6.0	36.7	25.3	8.0	0.315	–0.815	–0.587	0.663	2.413	I(J)

Table 4 to be continued

Plot		Species	Number[1] of trees in a sample	Height (m)			Standard deviation	Coefficient of			Parameters of distribution[2] according to Pearson		Type of Person's distribution[3]
				min.	max.	mean		variation	skewness	excess	β_1	β_2	
Obrożyska 3	1990	*Tilia cordata*	83	9	34.75	27.4	6.8	0.247	–1.211	0.096	1.467	3.096	I(U)
		Abies alba	115	4.5	34.5	15.3	8.4	0.548	0.799	–0.533	0.638	2.467	I(J)
		Carpinus betulus	22	9	25.5	18.1	5.0	0.274	–0.182	–1.171	0.033	1.829	I(J)
		Picea abies	6	6.5	31.25	22.5	×	×	×	×	×	×	×
		Acer pseudoplatanus	1	×	×	×	×	×	×	×	×	×	×
		Stand	227	4.5	34.75	20.2	9.4	0.466	0.003	–1.460	0.000	1.540	I(U)
	2000	*Tilia cordata*	87	10.8	35.5	28.3	6.7	0.237	–1.186	–0.026	1.406	2.974	I(U)
		Abies alba	124	4.9	36.4	15.3	8.8	0.574	0.830	–0.541	0.689	2.459	I(J)
		Carpinus betulus	22	9.1	29.1	19.1	5.2	0.275	–0.044	–0.684	0.002	2.316	I
		Picea abies	4	4.8	32.5	23.3	×	×	×	×	×	×	×
		Stand	237	4.8	36.4	20.5	9.9	0.482	–0.015	–1.493	0.000	1.507	I(U)

[1]Broken and leaning trees were not included in the calculation of distribution parameters
[2]A type of Pearson's distribution was determined when the number of trees of a given species in a sample was at least 15
[3]? does not fit to types of Pearson's distribution

On two plots (Obrożyska 1 and 3) the d.b.h. distribution curve for linden maintained Pearson's distribution of I type, i.e. with a mode in medium diameter classes. In Obrożyska 2 the d.b.h. distribution curve did not fit to the types of Pearson's distribution (Fig. 2, Table 3).

In Obrożyska 2 and 3 the biggest linden trees reached 110 and 106 cm in d.b.h., respectively (Fig. 2, Table 3). The coefficient of variation indicated an increase of d.b.h. variability during the control period when all tree species were considered jointly, and a decrease in the case of linden alone in Obrożyska 1 and 3, and a slight increase in Obrożyska 2 (Table 3).

Due to processes of tree recruitment, dying, and transfer within diameter classes there were tendencies to decrease or increase the number of linden trees in individual size gradations during the control period analyzed (Fig. 2).

When all tree species were taken into consideration jointly, it was evident that the change in the shape of d.b.h. distribution curves in comparison with linden was due to the presence of trees in the smallest size gradations, hornbeam and fir in Obrożyska 1 and 2, and fir in Obrożyska 3 (Fig. 2).

Tree height distribution

Height distributions of all measured tree species together did not change significantly in Obrożyska 1 and 2, maintaining the modes in a 30-metre height class, while the stand in Obrożyska 3 maintained the shape of the curve close to a bimodal curve (Fig. 3). The value of the coefficient of variation for the height of all tree species together increased in Obrożyska 1 and 3, and decreased in Obrożyska 2 (Table 4).

At the beginning and at the end of the control period height distribution curves of all species together (Obrożyska 1 and 3) showed Pearson's distribution of I(U) types, i.e. a bimodal curve, while in Obrożyska 2 the curve with a single mode – I(J) (Fig. 3, Table 4).

It should be mentioned that tree height distribution curves for 1990 were computed taking into account the measured trees as well as those for which heights were not measured (see methods) but were determined on the basis of the stand height curve.

Table 5. Volume of dead-wood, standing dead trees and stand (living trees) in 2000

Plot	Species	Volume of dead trees (necromass) lying dead-wood V_L		standing dead trees V_p		Total necromass $V_L + V_P$		Stand volume V		Total $V_L + V_P + V$		Percentage of necromass volume in volume of living and dead trees $\frac{V_L + V_p}{V_L - V_P + V} \times 100$	Ratio of necromass ($V_L + V_P = 1$) to stand volume (V)
		(m³/ha)	(%)	(m³/ha)	(%)	(m³/ha)	(%)	(m³/ha)	(%)	(m³/ha)	(%)	(%)	
Obrożyska 1	*Tilia cordata*	17.92	55.0	14.29	81.5	32.21	64.3	747.90	97.4	780.11	95.4	4.1	1:23.2
	Abies alba	2.82	8.7	0.49	2.8	3.31	6.6	12.06	1.6	15.37	1.9	21.5	1:3.6
	Carpinus betulus	0.04	0.1	–	×	0.04	0.1	6.20	0.8	6.24	0.8	0.6	1:155.0
	Picea abies	2.76	8.5	2.76	15.7	5.52	11.0	1.61	0.2	7.13	0.9	77.4	1:0.3
	Decomposed wood	9.01	27.7	–	×	9.01	18.0	–	×	9.01	1.1	×	×
	Total	32.55	100.0	17.54	100.0	50.09	100.0	767.77	100.0	817.86	100.0	6.1	1:15.3
Obrożyska 2	*Tilia cordata*	27.70	55.3	7.74	84.8	35.44	59.8	833.89	96.9	869.33	94.5	4.1	1:23.5
	Abies alba	1.06	2.1	0.15	1.6	1.21	2.0	13.55	1.6	14.76	1.6	8.2	1:11.2
	Carpinus betulus	3.06	6.1	–	–	3.06	5.2	10.12	1.2	13.18	1.4	23.2	1:3.3
	Picea abies	1.86	3.7	1.24	13.6	3.10	5.2	0.94	0.1	4.04	0.4	76.7	1:0.3
	Fagus sylvatica	–	×	–	×	–	×	1.38	0.1	1.38	0.2	×	×
	Acer pseudoplatanus	–	×	–	×	–	×	0.66	0.1	0.66	0.1	×	×
	Decomposed wood	16.46	32.8	–	×	16.46	27.8	–	×	16.46	1.8	×	×
	Total	50.14	100.0	9.13	100.0	59.27	100.0	860.54	100.0	919.81	100.0	6.4	1:14.5
Obrożyska 3	*Tilia cordata*	10.60	22.0	0.56	6.1	11.16	19.5	584.93	76.8	596.09	72.8	1.9	1:52.4
	Abies alba	7.42	15.4	5.19	56.9	12.61	22.0	135.62	17.8	148.23	18.1	8.5	1:10.8
	Carpinus betulus	1.86	3.9	1.93	21.1	3.79	6.6	32.44	4.3	36.23	4.4	10.5	1:8.6
	Picea abies	0.88	1.8	0.95	10.4	1.83	3.2	8.22	1.1	10.05	1.2	18.2	1:4.5
	Acer pseudoplatanus	–	×	0.50	5.5	0.50	0.9	–	×	0.50	0.1	×	×
	Decomposed wood	27.40	56.9	–	×	27.40	47.8	–	×	27.40	3.4	×	×
	Total	48.16	100.0	9.13	100.0	57.29	100.0	761.21	100.0	818.50	100.0	7.0	1:13.3

Table 6. Numbers and species composition of regeneration (2000)

Species	Young natural regeneration								Underwood						
	seedlings		younger saplings height ≤ 20 cm	older saplings height 21–50 cm	total younger and older saplings		total seedlings, younger and older saplings		height 51–80 cm	height 81–130 cm	from 130 cm in height to 1.9 cm in d.b.h.	diameter class (cm)		total underwood	
												2.0–3.9	4.0–5.9		
	(trees/ha)	(%)	(trees/ha)			(%)	(trees/ha)	(%)	(trees/ha)						(%)
Obrożyska 1			9												
Tilia cordata	1,000	18.3	455	182	637	2.1	1,637	4.6	527	164	109	–	–	800	78.6
Abies alba	91	1.7	2,091	–	2,091	6.9	2,182	6.1	–	–	–	–	–	–	–
Carpinus betulus	1,455	26.7	15,364	1,364	16,728	55.3	18,183	50.9	–	–	–	36	164	200	19.6
Picea abies	–	–	–	91	91	0.3	91	0.2	–	–	18	–	–	18	1.8
Fagus sylvatica	–	–	–	91	91	0.3	91	0.2	–	–	–	–	–	–	–
Acer pseudoplatanus	2,909	53.3	10,273	182	10,455	34.5	13,364	37.4	–	–	–	–	–	–	–
Acer platanoides	–	–	182	–	182	0.6	182	0.6	–	–	–	–	–	–	–
Total	5,455	100	28,365	1,910	30,275	100	35,730	100	527	164	127	36	164	1,018	100
Obrożyska 2															
Tilia cordata	938	20.8	938	375	1,313	6.4	2,251	8.9	875	163	50	25	13	1,126	81.7
Abies alba	313	7.0	1,000	–	1,000	4.8	1,313	5.3	–	–	–	–	–	–	–
Carpinus betulus	1,875	41.6	12,313	3,438	15,751	76.1	17,626	70.0	–	–	–	50	100	150	10.9
Picea abies	63	1.4	–	–	–	–	63	0.2	–	13	13	63	13	102	7.4
Fagus sylvatica	–	–	313	63	376	1.8	376	1.5	–	–	–	–	–	–	–
Acer pseudoplatanus	1,313	29.2	2,188	63	2,251	10.9	3,564	14.1	–	–	–	–	–	–	–
Total	4,502	100	16,752	3,939	20,691	100	25,193	100	875	176	63	138	126	1,378	100
Obrożyska 3															
Tilia cordata	143	0.9	214	4,000	4,214	7.9	4,357	6.3	386	14	14	–	14	428	91.0
Abies alba	12,214	77.4	11,285	71	11,356	21.4	23,570	34.1	–	–	–	–	14	14	3.0
Carpinus betulus	1,857	11.8	19,786	1,500	21,286	39.9	23,143	33.5	–	–	–	–	–	–	–
Picea abies	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fagus sylvatica	71	0.4	143	71	214	0.4	285	0.4	14	–	–	–	–	14	3.0
Acer pseudoplatanus	1,143	7.2	11,786	1,286	13,072	24.5	14,215	20.6	–	–	–	–	–	–	–
Acer platanoides	357	2.3	2,857	214	3,071	5.8	3,428	5.0	–	–	–	–	14	14	3.0
Fraxinus excelsior	–	–	–	71	71	0.1	71	0.1	–	–	–	–	–	–	–
Total	15,785	100	46,071	7,213	53,284	100	69,069	100	400	14	14	–	42	470	100

Table 7. Numbers of advanced undergrowth (d. b.h. 6.0–7.9 cm) in 1990 and 2000

Species	1990		2000	
	(trees/ha)	(%)	(trees/ha)	(%)
Obrożyska 1				
Tilia cordata	4	5.6	8	5.4
Abies alba	4	5.5	–	×
Carpinus betulus	48	66.7	120	81.1
Picea abies	16	22.2	20	13.5
Total	72	100.0	148	100.0
Obrożyska 2				
Tilia cordata	10	20.0	4	8.7
Abies alba	2	4.0	–	×
Carpinus betulus	38	76.0	38	82.6
Picea abies	–	×	4	8.7
Total	50	100.0	46	100.0
Obrożyska 3				
Abies alba	64	74.4	54	69.2
Carpinus betulus	16	18.6	18	23.1
Picea abies	4	4.7	2	2.6
Fagus sylvatica	2	2.3	4	5.1
Total	86	100.0	78	100.0

The dynamics of height distribution in linden in individual height classes showed a considerable variation. There was a distinct increase in linden percentage in 2000 in comparison with 1990 in 26, 30, and 34 m height classes in Obrożyska 1, in 30 and 34 m classes in Obrożyska 2, and in the 34 m class in Obrożyska 3 (Fig. 3).

The height variability of linden decreased during the 10-year period, which was indicated by a lower coefficient of variation in 2000 than in 1990 (Table 4). In Obrożyska 1 the I(J) type of height distribution in linden was retained, and in Obrożyska 3 the I(U) type, while in Obrożyska 2 the I type changed into distribution not fitting to Pearson's distributions.

Volume of necromass (dead standing trees and dead wood on the ground)

On all three plots linden dominated in dead wood lying on the ground (from 22 to about 55% of total dead wood) (Table 5). Probably this percentage was higher since linden wood also likely contributed considerably to unidentified decomposed wood. In Obrożyska 3 lying fir wood (7.42 m^3/ha) was almost as abundant as that of linden (10.6 m^3/ha) (Table 5).

In Obrożyska 1 and 2 linden also dominated among standing dead trees (82 and 85%, respectively) (Table 5). On both these plots a relatively high percentage of standing dead spruce trees also occurred (about 16 and 14%) (Table 5). In Obrożyska 3 fir dominated among standing dead trees (57%), followed by hornbeam (21%), spruce (about 10.5%) and linden (about 6%) (Table 5).

The volume of necromass in total volume of living and dead trees together was from 6.1 to 7.0%. This percentage for linden ranged from 1.9 to 4.1% (Table 5).

Regeneration

Hornbeam dominated (2000) in the regeneration of Obrożyska 1 (51% of young natural regeneration and over 81% of advanced underwood) and Obrożyska 2 (almost 70% of young natural regeneration and 83% of advanced underwood) (Tables 6 and 7), while fir dominated in regeneration in Obrożyska 3 (over 34% of young natural regeneration and 69% of advanced underwood) (Tables 6 and 7).

The percentage of linden young regeneration ranged from 4.6% (Obrożyska 1) to 8.9% (Obrożyska 2) of the total amount of young regeneration. Linden dominated in the underwood, and its percentage varied from 79% (Obrożyska 1) to 91% (Obrożyska 3) (Table 6). The advanced underwood occurred on Obrożyska 1 (5.4%) and Obrożyska 2 (8.7%) plots only (Table 7).

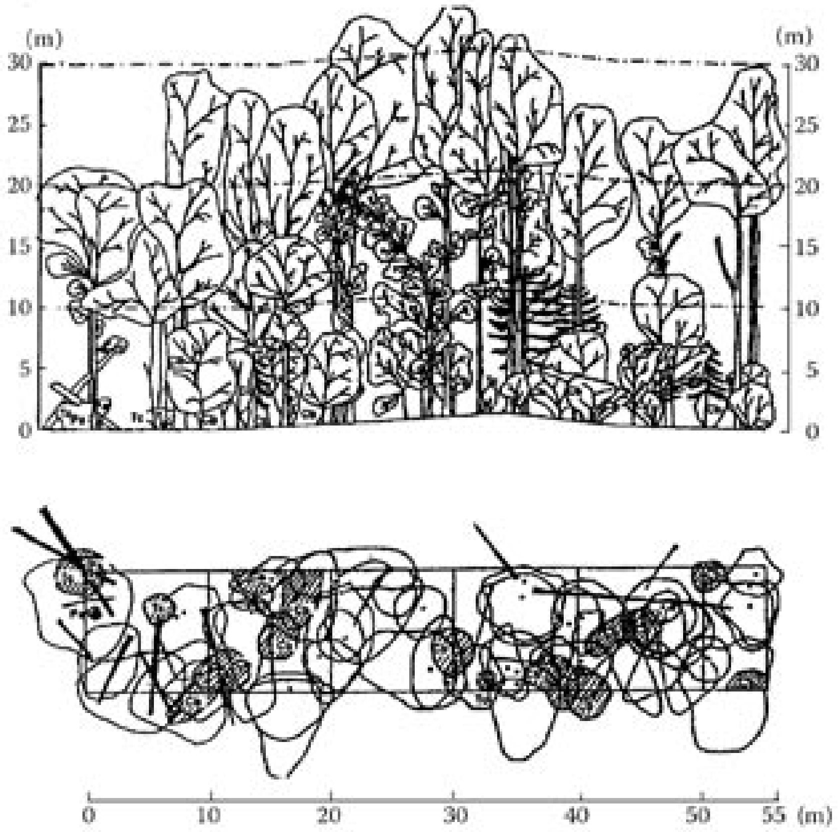

Fig. 4. Obrożyska 1 stand profile

Development stages and phases

Obrożyska 1

This stand was in the advanced growing up stage, in transition to the optimum stage (Figs. 4 and 5). It was indicated by domination of trees of the growing up generation (over 59% of trees of all species) and a lower percentage of trees of the optimum growth generation (over 40%). Trees of the living up generation occurred sporadically (about 1%). Among linden trees the generation B (almost 55%) dominated over the generation C (over 44%) (Table 8). Trees of these two generations reached the age from about 155 to 180 years, and from about 50 to 130 years, respectively (Table 9). The transition stage, mentioned above, was also indicated by a high percentage of trees in the upper layer-100 (50%), as well as in the middle layer-200 (almost 32%), and low percentage in the lower layer-300 (over 18%) (Table 10).

The domination of the upper layer in respect of volume (about 96% of total volume in 2000) indicated the development of the optimum stage (Table 11).

Obrożyska 2

In 2000 this stand was in the initial phase of the optimum stage (Figs. 6 and 7). It was indicated by a

Fig. 5. Stand fragment in Obrożyska 1

Table 8. Percentage of tree categories (2000) according to Řehák's (1964) classification

Species		Categories of trees			Total
		A	B	C	
Obrożyska 1					
Tilia cordata	(trees/ha)	4.0	224.0	180.0	408
	(%)	1.0	54.9	44.1	100
Abies alba	(trees/ha)	–	4.0	36.0	40
	(%)	–	10.0	90.0	100
Carpinus betulus	(trees/ha)	–	–	100.0	100
	(%)	–	–	100.0	100
Picea abies	(trees/ha)	–	–	20.0	20
	(%)	–	–	100.0	100
Total	(trees/ha)	4.0	228.0	336.0	568
	(%)	0.7	40.1	59.2	100
Obrożyska 2					
Tilia cordata	(trees/ha)	28.0	238.0	152.0	418
	(%)	6.7	56.9	36.4	100
Abies alba	(trees/ha)	–	–	52.0	52
	(%)	–	–	100.0	100
Carpinus betulus	(trees/ha)	2.0	–	40.0	42
	(%)	4.8	–	95.2	100
Fagus sylvatica	(trees/ha)	–	–	4.0	4
	(%)	–	–	100.0	100
Picea abies	(trees/ha)	–	–	6.0	6
	(%)	–	–	100.0	100
Acer pseudoplatanus	(trees/ha)	–	–	2.0	2
	(%)	–	–	100.0	100
Total	(trees/ha)	30.0	238.0	256	524
	(%)	5.7	45.4	48.9	100
Obrożyska 3					
Tilia cordata	(trees/ha)	10.0	122.0	54.0	186
	(%)	5.4	65.6	29.0	100
Carpinus betulus	(trees/ha)	–	10.0	48.0	58
	(%)	–	17.2	82.8	100
Abies alba	(trees/ha)	–	28.0	248.0	276
	(%)	–	10.1	89.9	100
Picea abies	(trees/ha)	–	6.0	2.0	8
	(%)	–	75.0	25.0	100
Total	(trees/ha)	10.0	166.0	352.0	528
	(%)	1.9	31.4	66.7	100

Tree development classes: A – 1iving up generation, B – optimum growth generation, C – growing up generation

high volume (861 m^3/ha) (Table 2) and the highest percentage of trees in the upper layer (over 63% of the total number of trees), a considerably smaller number in the middle layer (about 26%), and a relatively low percentage in the lower layer (over 11%) (Table 10). Stand volume was concentrated in the upper layer (96% of the total volume in 2000) (Table 11). Trees of the optimum growth and living up generations accounted for 51.1% of the total number, while trees of the growing up generation for 48.9% (Table 8). The Obrożyska 2 stand was characterized by the smallest d.b.h. (coefficient of variation 0.469

Table 9. Age of linden and fir (2000)

Tree number	Species	Tree categories[1] according to Řehák's (1964) classification	d.b.h. (cm)	Height (m)	Age (years)
Obrożyska 1					
40	*Tilia*	C_1	31.5	27.2	79
18	*Tilia*	C_1	37.0	29.0	89
51	*Tilia*	C_1	37.5	22.8	107
72	*Tilia*	C_1	36.5	29.9	129
119	*Tilia*	C_2	15.0	14.5	51
19	*Tilia*	B_1	68.5	29.8	154
130	*Tilia*	B_1	48.5	32.5	163
86	*Tilia*	B_1	51.5	33.9	163
36	*Tilia*	B_1	52.0	32.6	179
37	*Tilia*	B_2	72.5	29.3	159
Obrożyska 2					
211	*Tilia*	C_1	44.5	30.5	114
171	*Tilia*	C_2	14.5	16.4	59
50	*Tilia*	C_3	10.5	8.0	26
289	*Tilia*	B_1	52.0	32.1	119
267	*Tilia*	B_1	41.5	31.0	159
182	*Tilia*	B_2	41.5	22.2	119
266	*Tilia*	B_2	40.0	23.5	139
172	*Tilia*	A_1	64.0	31.4	105
260	*Tilia*	A_1	67.0	33.0	146[2]
213	*Tilia*	A_2	60.0	32.0	101
Obrożyska 3					
268	*Abies*	C_1	38.5	30.2	63
242	*Abies*	C_2	15.5	10.8	79
158	*Abies*	C_2	12.5	12.7	89
153	*Abies*	B_1	62.5	36.4	99
79	*Abies*	B_2	37.5	22.7	82
17	*Abies*	B_2	38.5	22.5	129
288	*Tilia*	C_1	23.0	23.0	64[2]
157	*Tilia*	C_1	39.0	30.4	104
264	*Tilia*	C_2	11.0	10.8	34
198	*Tilia*	C_2	17.5	14.3	37
294	*Tilia*	C_2	12.5	15.4	55
275	*Tilia*	B_1	78.5	33.0	151
169	*Tilia*	B_1	77.0	34.7	134
186	*Tilia*	A_2	106.0	33.9	229[2]

[1]Description as in Table 8; Vitality: 1– luxuriant, 2 – normal, 3 – weakened
[2]Age at breast height

in 2000) and height (0.315) diversification between the three studied areas (Tables 3 and 4).

Linden trees of the living up generation on this plot reached from over 100 (at the ground level) to about 150 (at breast height) years in age, while those of the optimum growth from about 120 to about 160 years, and the growing up generation from about 25 to almost 115 years (Table 9). Trees

Table 10. Percentage of the number of trees in stand layers (according to IUFRO classification) in 2000

Plot	Species	Layer							
		100		200		300		Total	
		(trees/ha)	(%)	(trees/ha)	(%)	(trees/ha)	(%)	(trees/ha)	(%)
Obrożyska 1	*Tilia cordata*	284	100	112	62.2	12	11.5	408	71.9
	Abies alba	–	–	24	13.3	16	15.4	40	7.0
	Carpinus betulus	–	–	36	20.0	64	61.6	100	17.6
	Picea abies	–	–	8	4.5	12	11.5	20	3.5
	Stand	284	100	180	100.0	104	100.0	568	100
Percentage of trees in a layer (%)		×	50	×	31.7	×	18.3	×	×
Obrożyska 2	*Tilia cordata*	332	100	76	56.7	10	17.2	418	79.8
	Abies alba	–	–	26	19.4	26	44.8	52	9.9
	Carpinus betulus	–	–	26	19.4	16	27.6	42	8.0
	Picea abies	–	–	2	1.5	4	6.9	6	1.1
	Fagus sylvatica	–	–	2	1.5	2	3.5	4	0.8
	Acer pseudoplatanus	–	–	2	1.5	–	–	2	0.4
	Stand	332	100	134	100.0	58	100.0	524	100.0
Percentage of trees in a layer (%)		×	63.3	×	25.6	×	11.1	×	×
Obrożyska 3	*Tilia cordata*	138	68.3	40	23.3	8	5.2	186	35.2
	Abies alba	50	24.7	92	53.4	134	87.0	276	52.3
	Carpinus betulus	8	4.0	40	23.3	10	6.5	58	11.0
	Picea abies	6	3.0	–	–	2	1.3	8	1.5
	Stand	202	100.0	172	100.0	154	100.0	528	100.0
Percentage of trees in a layer (%)		×	38.2	×	32.6	×	29.2	×	×

Table 11. Distribution of the number of trees and volume in height classes determined on the basis of smoothed heights

Height class (m)	Number of trees		Volume	
	(trees/ha)	(%)	(m^3/ha)	(%)
1990				
Obrożyska 1				
≤ 10.7	72	12.6	2.21	0.3
10.8–21.4	148	25.2	28.14	4.0
21.5–32.1	352	62.2	669.16	95.7
Total	572	100.0	699.51	100.0
Obrożyska 2				
≤ 12.1	52	9.1	2.66	0.3
12.2–24.1	118	21.8	32.46	4.1
24.2–36.2	380	69.1	762.22	95.6
Total	550	100.0	797.34	100.0
Obrożyska 3				
≤ 11.8	134	25.6	5.35	0.8
11.9–23.7	192	36.6	61.28	8.8
23.8–35.5	198	37.8	629.42	90.4
Total	524	100.0	696.05	100.0
2000				
Obrożyska 1				
≤ 10.8	84	14.9	2.21	0.3
10.9–21.5	136	23.9	24.74	3.2
21.6–32.3	348	61.2	740.82	96.5
Total	568	100.0	767.77	100.0
Obrożyska 2				
≤ 12.2	48	9.2	2.03	0.2
12.3–24.3	110	21.0	31.30	3.7
24.4–36.5	366	69.8	827.21	96.1
Total	524	100.0	860.54	100.0
Obrożyska 3				
≤ 11.9	132	25.0	4.75	0.6
12.0–23.9	196	37.1	62.23	8.2
23.9–35.7	200	37.9	694.23	91.2
Total	528	100.0	761.21	100.0

of the largest diameters reached the age of about 200 years (Table 1). It should be mentioned that the interior of some linden trees was decayed, and this made age measurements difficult. This was also true in the case of linden trees on the remaining plots.

Obrożyska 3

This stand was in the growing up stage, selection structure phase (Figs. 8 and 9). It was indicated by a single-armed curve of d.b.h. distribution being close to Liocourt-Meyer's distribution, domination of trees of the growing up generation (almost 67%) (Table 8), a relatively little diversified percentage of trees in the upper (38.2%), middle (32.6%) and lower (29.2%) layers of the stand (Table 10), and high values of the coefficients of variation of d.b.h. (0.704 – 2000) and height (0.482) (Tables 3 and 4). The volume of the middle layer was 9% in 1990 and 8% in 2000 (Table 11).

The age of linden trees of the generation of optimum growth B (increment cores were taken from only 2 trees) was about 135 and 150 years, of the growing up generation from almost 35 to 105 years, and of the living up generation 230 years (Table 9).

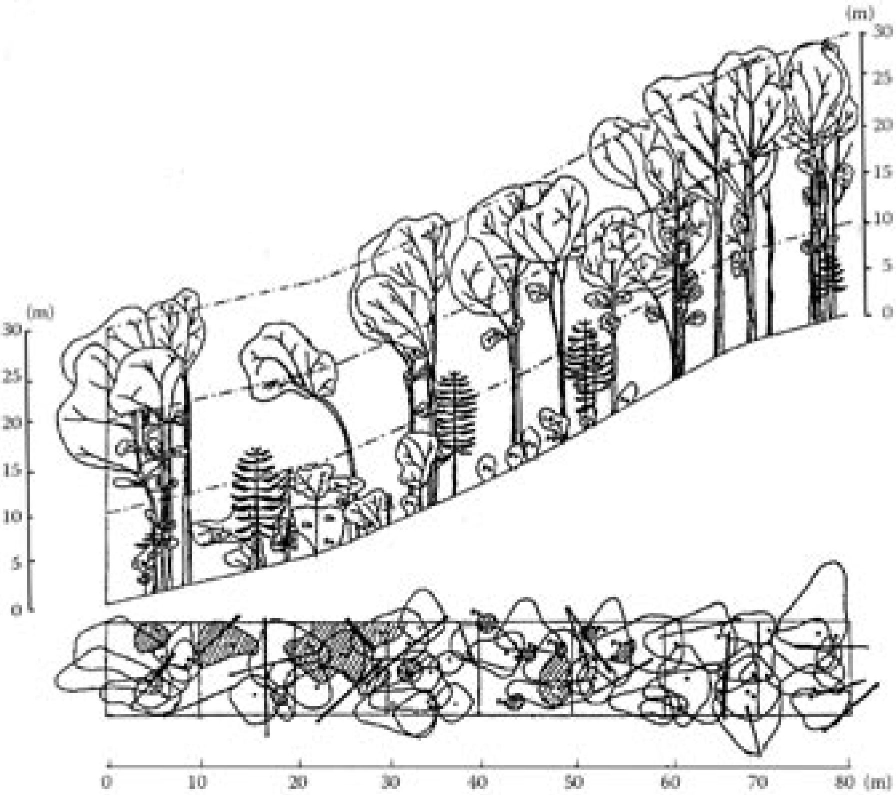

Fig. 6. Obrożyska 2 stand profile

Fig. 7. Stand fragment in Obrożyska 2

DISCUSSION

The little-leaf linden stands in the Obrożyska reserve have one of the greatest volumes per hectare among stands of primeval character in the Polish part of the Carpathians (761–861 m^3/ha). In this respect they are better than primeval as well as managed stands in Poland with the exception of some Norway spruce stands of Istebna (comp. Table 12). They are not as good as the best primeval stands in Slovakia with fir, beech and spruce in their species composition, nor as managed beech stands of the highest per-hectare volume known in literature (Oltarc – 1,067 m^3/ha, Freienwalde 945 m^3/ha) (Table 12).

Basal area on sample plots established in the Obrożyska reserve was very high (55–62 m^2/ha). It was greater than that in Polish primeval and managed forests as well as in stands of Oltarc and Freienwalde, and greater than values given in volume tables for beech, fir and spruce. However, it was smaller than that in primeval forests of Slovakia (Table 12).

The lack of earlier data on the volume of Obrożyska stands and a short period of time analyzed in this study do not allow to conclude that such a high per-hectare volume is a permanent characteristic, or it is the result of changes in site conditions for example.

Examples of increased productivity of beech, oak and fir stands were reported by Pretzsch (1996),

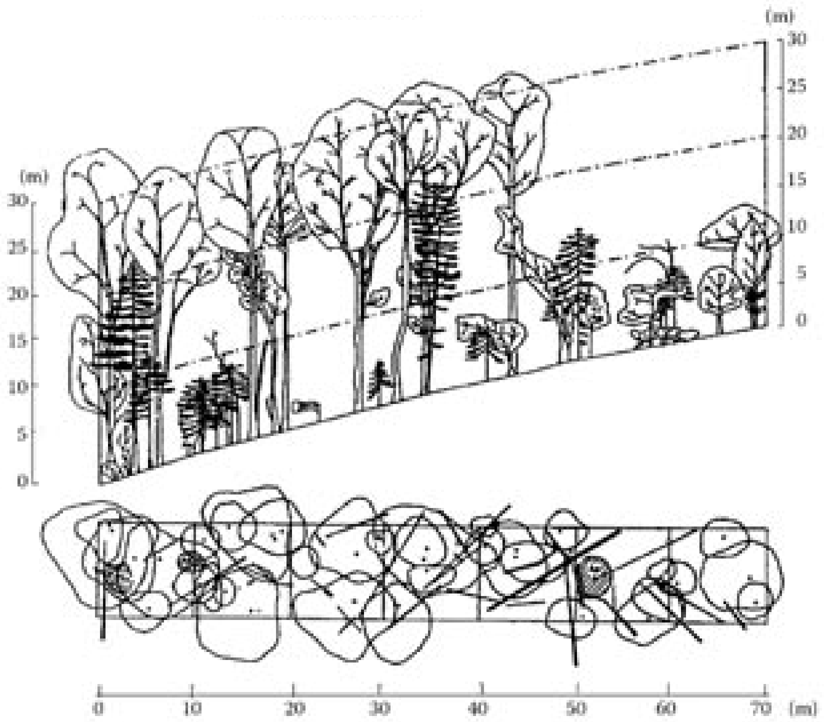

Fig. 8. Obrożyska 3 stand profile

who explained this phenomenon by various causes, including the effect of silvicultural treatments (e.g. soil fertilization and liming), changes in climatic conditions (especially global warming up), and also the effect of atmospheric deposits.

Fig. 9. Stand fragment in Obrożyska 3

In the case of forests of primeval character the latter two causes may be taken into consideration, but their explanation would require to undertake complex investigations. It is true, however, that the surroundings of Muszyna, including the Obrożyska reserve, have a warmer climate than the neighbouring areas (Obrębska-Starklowa 1967).

On all plots the species composition of regeneration differed from that of the parent stands (Tables 2, 6 and 7).

Linden underwood, especially that belonging to the class of an advanced underwood, was hardly noticeable on the study plots, i.e. in stand fragments with more or less uniform canopy, while it formed groups in openings.

The regeneration in openings also was discussed by Witowski (1933). He found that in fragments where the crown closure was 70–100% hornbeam and spruce regenerated well, while a linden pole-stage forest occurred at places of old openings. In his opinion "the survival of linden in the reserve without creation of groups at suitable places, i.e. without help of man, is impossible". However, in spite of such difficulties with regeneration, linden still dominates in the reserve at the present time, and it is not endangered.

Linden showed the ability to accumulate the underwood (bank of underwood from 51 cm in height to 1.9 cm in d.b.h.), and most likely to accumulate young natural regeneration which in the case of improvement of light conditions due to tree mortality in the upper story grew into advanced underwood, and later into the lower story.

Table 12. Volume and basal area from volume tables and selected managed and primeval stands

Research object, tables of volume	Stand characteristics			Source
	species, age (years)	volume (m^3/ha)	basal area (m^2/ha)	
Managed stands				
Carpathians (Poland)	linden 120–140	468	–	Głaz (1985)
Oltarc (Hungary)	beech 122	1,067	45.1	Šmelko et al. (1992)
Freienwalde (Germany)	beech 148	945	48.1	Šmelko et al. (1992)
Forêt de Berce (France)	oak	972	–	Šmelko et al. (1992)
Experimental plot of Schwappach	oak 191	837	54.7	Šmelko et al. (1992)
Istebna – Bukowiec (Poland)	spruce	1,056.11	55.08	unpublished data
Primeval stands				
Bieszczady National Park (Poland)	beech of many generations	578–610	33.0–35.0	Jaworski, Kołodziej (2002)
Babia Góra National Park (Poland)	fir, beech of many generations	505–693	34.7–43.6	Jaworski, Paluch (2002)
Białowieża National Park (Poland)	mixed stand with linden	–	52.4	Bernadzki et al. (1998)
Dobročský prales (Slovakia)	spruce, fir, beech of many generations	1,046–1,366	56.1–70.8	Korpeľ (1989)
Data from volume tables				
Zylkin's tables	linden 120	455	42.6	Czuraj (1990)
Schwappach's tables	beech 140	656	33.4	Czuraj (1990)
Hausser's tables	fir 120–160	843–881	49.8–49.0	Czuraj (1990)
Schwappach's tables	spruce 100	787	48.3	Czuraj (1990)

On the basis of long-term studies in the Białowieża Primeval Forest (Faliński, Pawlaczyk 1991) found that linden held its position in the forest environment thanks to its great vitality and ability to adapt itself (ecological plasticity) to changing conditions, especially thanks to "waiting strategy" and "persisting strategy" in conquered localities.

In spite of the fact that the growing up stage, including a storied structure phase, dominated in the reserve the selection phase, the most complex structure, developed rarely, and only in fragments with a high percentage of fir and hornbeam.

Linden trees often occur in groups (2–3 trees together), which indicates a great importance of their sprout regeneration (Fig. 7).

In the Obrożyska reserve the volume of necromass is small (Table 5). Much more dead wood was reported from stands mentioned above, i.e. stands with beech, fir, and spruce in the Gorce Mts., Babia Góra Mt., and Slovak reserves (Table 13). The ratio of dead wood to stand volume is associated with the rate of wood decomposition. In the case of beech, linden, sycamore maple, and ash this process takes 20–30 years, while decomposition of fir and spruce wood takes more than 50 years (Korpeľ 1995).

CONCLUSIONS

The research presented in this paper allowed to draw the following conclusions:

1. The little-leaf linden on the investigated plots showed a very high productive potentiality. Therefore, it would be proper to introduce it into stands where site conditions meet its requirements, especially in the lower part of the lower mountain zone (up to about 600–700 m above sea level) as an admixture increasing productivity and biological variability of stands.
2. A small percentage of the little-leaf linden in the young natural regeneration and advanced underwood, and a relatively abundant underwood in the classes from 51 cm in height to 1.9 cm in d.b.h. indicated a waiting strategy which should secure the dominant position of this tree species in future stands.
3. The regeneration process and the stand structure showed that in managed forests the regeneration

Table 13. Volume of necromass and ratio of necromass to stand volume in selected primeval stands of Poland and Slovakia

Research object	Species forming the stand	Volume of necromass (dead-wood on the ground and dead standing trees) (m^3/ha)	Ratio of volume of necromass to volume of living trees	Author
Babia Góra National Park (Poland)	fir, beech	279–358	1:2 to 1:1.5	Jaworski, Karczmarski (1990)
Gorce National Park (Poland)	beech, fir, spruce	132–191	1:3.4 to 1:5.8	Jaworski, Skrzyszewski (1995)
Dobročský prales (Slovakia)	fir, beech, spruce	439		Saniga, Schütz (2001b)
	– optimum stage	–	1:6	
	– growing up stage	–	1:2 to 1:3	
	– break-up stage	–	1:1.5	
Havešová (Slovakia)	beech	40–157		Saniga, Schütz (2001a)
	– optimum stage	–	1:4.5 to 1:18	
	– growing up stage	–	1:3.5 to 1 :5.5	
	– break-up stage	–	1.55 to 1:14	
Rožok (Slovakia)	beech	32–50		Saniga, Schütz (2001a)
	– optimum stage	–	1:18 to 1:25	
	– growing up stage	–	1:2.5 to 1:7.5	
	– break-up stage	–	1:3 to 1:3.5	

of the little-leaf linden in stands composed of many tree species would be most successful in groups with a side shelter. In the case of natural seeding on larger areas it would be necessary to assume a short, partial regeneration period allowing a fast exposure of the little-linden natural regeneration.

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Struktura a dynamika porostů pralesního charakteru tvořených lípou srdčitou (*Tilia cordata* Mill.) v rezervaci "Las lipowy Obrożyska" (v jižním Polsku)

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ABSTRAKT: Porost lípy srdčité, který jsme sledovali, je reliktem z doby atlantské. Na třech trvalých zkusných plochách, které se nacházejí v přísně chráněné rezervaci, jsme v r. 1990 a 2000 prováděli měření a klasifikaci stromů. Porosty v těchto oblastech představovaly stadium dorůstání na přechodu do stadia optima (Obrożyska 1), stadium optima (Obrożyska 2) a stadium dorůstání, fázi výběrné struktury (Obrożyska 3). V r. 2000 činil objemový podíl lípy 97 % na ploše Obrożyska 1 a 2 a 77 % na ploše Obrożyska 3, zatímco porostní zásoba na jednotlivých plochách dosahovala 768, 861 a 761 m^3/ha a výčetní plocha byla 60, resp. 62 a 55 m^2/ha. V polské části Karpat mají tyto porosty nejvyšší zásobu na hektar mezi porosty pralesního charakteru.

Klíčová slova: vývojová stadia a fáze; porostní zásoba; výčetní základna; obnova lesa; objem odumřelého dřeva

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