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DYNAMICS OF TREE STANDS IN THE GORCE NATIONAL PARK (SOUTHERN POLAND) DURING THE PERIOD 1992–1997

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Abstract: The work presents the dynamics of tree stands in the Gorce National Park during the period 1992–1997. Special attention was given to the intensity of such processes as: tree mortality, tree recruitment, volume increment and natural regeneration, as well as to mutual relationships among these processes. In the field work a statistical approach to forest inventory was employed. Altogether 400 permanent circular sample plots were established and classified in respect to climatic and vegetation zones, species composition and developmental phase of tree stand. On the basis of these features 16 stand types were identified and described. Most of the analysed characteristics of tree stands (species composition, stand volume, tree density and natural regeneration) were spatially variable. Significant quantitative and qualitative changes in forest structure were ascertained in line with a substantial increase in the share of beech and silver fir in tree stands and in natural regeneration, and the decline of Norway spruce both in tree number and in tree volume.

Key words: species composition, developmental phases of tree stand, tree mortality, tree recruitment, volume increment, forest dynamics, Gorce National Park, southern Poland.

INTRODUCTION

The fulfilment of the main goal of nature conservation in national parks – i.e. "maintaining and studying all natural systems in a given area" (as defined by the law of nature conservation of December 7, 2000) is among the main tasks of the national park and should be conducted, among others, by "carrying out scientific investigations focusing upon documentation, monitoring and prediction of changes taking place in ecosystems" (& 5 and 8 of the statute of the Gorce National Park, 1992).

The binding rules of monitoring and inventory of forest resources (Instrukcja.... 1993), developed for commercially managed forests, are not suitable for the description of complex, mixed stands and their dynamics, and thus are not useful in national parks. Methods of monitoring and inventory in national parks should be adapted for permanent monitoring in large areas, taking into account the entire complexity of forest stands and their dynamic character (Przybylska 1993b, 2000).

A key problem in investigations of forest structure, strongly affecting the results and their interpretation, is the method of field data collection (Szwagrzyk 1988). Most investigators studying primeval forests in Western Carpathians (Korpel 1989, 1994; Jaworski 1991; Jaworski and Karczmarski 1991; Jaworski et al. 1994, Jaworski and Skrzyszewski 1995; Karczmarski 1995; Holeksa 1998) were strongly influenced by the concepts of developmental phases proposed by Leibundgut (1959) and presented a largely subjective approach to the selection of study plots. This is reflected by the vaguely defined criteria of "uniformity" and "representativity" of sample plots. The size, shape and number of sample plots differ strongly; usually the size of sample plots is less than 1 hectare, but sometimes a sample plot can be as large as fourteen hectares (Holeksa 1998).

A fully objective method of choosing research sites (so-called "representative method") is based upon distributing randomly or regularly a large number of relatively small plots (Bracha 1996). One of these methods, adapted for studying forest stands, is the so-called "statistical-mathematical" method of forest inventory, employing small, circular sample plots (Schmidt 1969; Rutkowski 1989). This method has been widely applied in Poland, both in protected areas (Rutkowski et al. 1972; Dziewolski 1991; Dziewolski and Rutkowski 1991; Przybylska et al. 1995) and in managed forests (Żuchowski 1981; Przybylska 1987; Rutkowski 1988). Recently, this method has frequently been employed in national parks. Sets of permanent, circular sample plots have been established in forests in the following national parks: Babia Góra NP, Bieszczady NP, Gorce NP, Karkonosze NP, Ojców NP, Pieniny NP, and – partly – of Magura NP and Roztocze NP (Przybylska 2000).

The process of employing the statistical-mathematical method of forest inventory for monitoring the forest dynamics in selected areas subjected to strict protection regime began in the Gorce mountains in 1969 (Rutkowski et al. 1972). That process continued after the establishment of the Gorce National Park (Przybylska et al. 1995). However, before this study started the set of permanent sample plots covered only 3% of the forests in the Gorce National Park. Therefore, it would be difficult to extrapolate the results for the entire park area. Lack of the reliable knowledge about the forest dynamics resulted in several wrong decisions, such as the "renaturalization" of already natural forest stands, application of certain management practices to strictly protected areas, neglecting natural forest regeneration and forcing artificial regeneration by tree planting (Chwistek 1996a, b; Loch 1996).

The studies presented in this paper are an example of practical realisation of one of the principal functions of the national park (scientific research). The main goal of the work was to describe the dynamics of forest stands in the Gorce National Park, with special emphasis on mutual relationships among tree mortality, recruitment, volume increment and natural regeneration of tree stands.

STUDY AREA

The Gorce mountains (49°26'–49°40'N, 19°53'–20°26'E) are a separate mountain range in the western Beskidy, part of Western Carpathians. The total area of the Gorce range is about 550 km^2; the topography is gentle, with flat ridges and rounded tops; only the valleys are characterised by steep slopes, landslides and rocky outcrops.

The Gorce National Park, set up in 1981, covers the area of 7,030 ha. It is situated in the central part of the Gorce range and includes most of the highest peaks: Jaworzyna Kamienicka (1,288 m a.s.l.), Kiczora (1,282 m) and Kudłoń (1,273 m). The main part of the park (6,823 ha) is situated between 650 and 1,288 m a.s.l.

The Gorce range is built of rocks representing the so-called Carpathian flysh (Magura type), up to 2,000 m thick. The bedrock can be divided into two distinct series; the richer one, built of silicates and marls, and the poor one, built of silicates and quartz. The most common soil types are: brown soils, cryptopodzolic soils, and podzolic soils (Adamczyk 1966).

The climate of the Gorce mountains is characterised by distinct climatic zones, strongly related to elevation, and locally modified by exposure and inclination of slopes. The mean annual temperature is 6–7°C in the foothills, while on the mountain ridges it is only about 3°C (Hess 1965). The annual precipitation amounts to 750–800 mm in the valleys, and up to 1,200 mm in the upper parts of the mountains.

Among the 14 forest communities described from the Gorce National Park (Michalik et al. 1988) the most common is Carpathian beech forest *Dentario glandulosae-Fagetum*, covering about 58% of the park area. The other common forest associations are: montane spruce-fir forest *Abieti-Piceetum montanum* (14%), subalpine spruce forest *Plagiothecio-Piceetum* (19%) and forest communities of transitional character (7%). Among the forest communities covering small areas there are: fir forests *Galio-Abietetum*, beech forests *Luzulo luzuloides-Fagetum*, alder forests *Alnetum incanae* and *Caltho-Alnetum* (Loch and Tomasiewicz 1998). In most cases forest communities have retained their natural character. Secondary forest stands dominated by trees not adjusted to local habitats are rare; for example, the area of artificially planted Norway spruce stands in the potential habitats of Carpathian beech forest amounts to only 0.13 ha (Loch and Tomasiewicz 1998).

During the 20 years since the establishment of the Gorce National Park protection regimes in certain areas have been changing frequently and profoundly. Four times (in 1982, 1986, 1991 and 1998) the area subjected to strict nature protection was diminished, and twice (in 1987 and 1998) it was enlarged. As a result, only 12.4% of the total park area has been subjected to strict nature protection for the whole period of 20 years. During the study period (1992–1997) strict protection encompassed an area of 2,802 ha (44.5% of all the tree stands in the Gorce National Park), while 3,488 ha was subjected to partial protection.

MATERIAL AND METHODS

For the inventory of forest resources and analysis of forest dynamics (tree mortality, tree recruitment, volume increment, changes in species composition and density of seedlings and saplings) the statistical-mathematical method (Rutkowski 11989) of forest inventory and monitoring on permanent circular plots was employed.

Two consecutive inventories were conducted in 1992 and 1997; each of them was carried out on 400 permanent sample plots, distributed in a regular spacing of 400 x 400 m (Fig. 1). All tree stands owned by the Gorce National

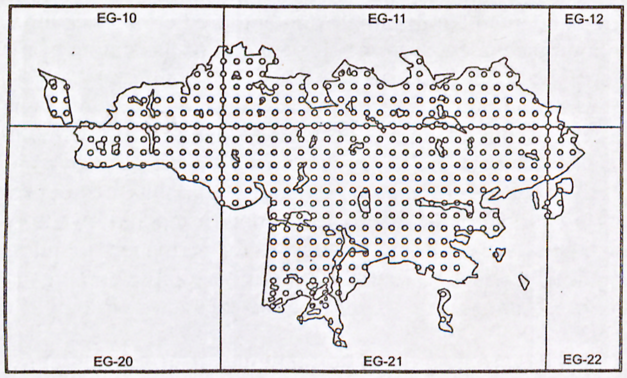

Fig. 1. The sampling scheme in the Gorce National Park; sample plots were distributed regularly at 400 x 400 m spacing, nested within a 10 x 10 km ATPOL grid.

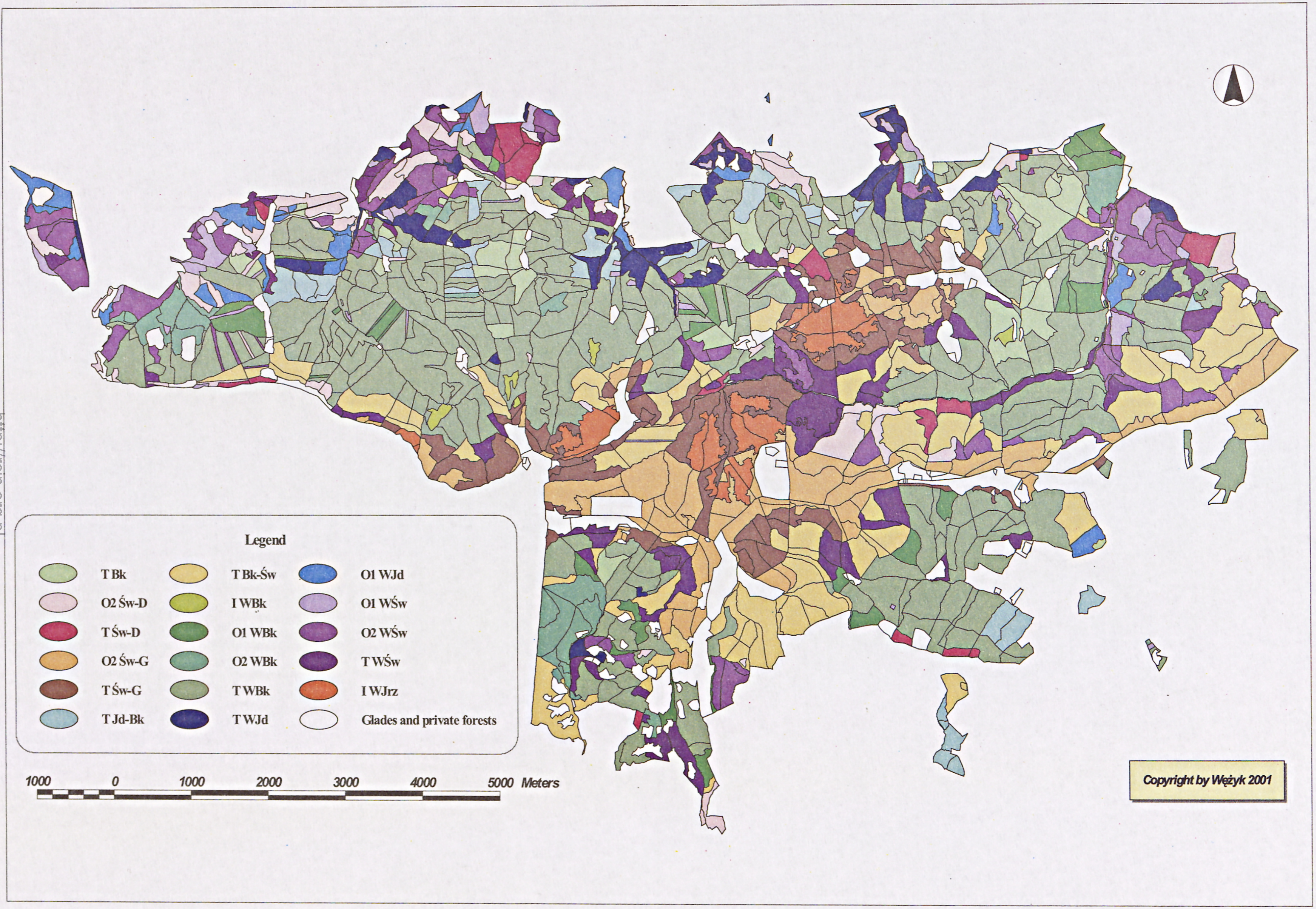

Fig. 2. Distribution of stand categories (distinguished on the basis of species composition and developmental phase) in the Gorce National Park in 1997: explanations as in Table 1.

Park (covering in total 6,290 ha) were subjected to the analysis.

The characteristics of forests in the Gorce National Park and description of their dynamics was based upon a system of the classification of tree stands according to the elevation zone, species composition an developmental phase of a tree stand. Two major vegetation zones were distinguished (montane zone and subalpine zone) with three types of species composition of forest stands :

1. Single-species stands, in which the share of admixtures (measured by volume) is less than 20%. The name of the category is given by the dominant tree species (for example, spruce stands, beech stands).
2. Mixed stands, in which the share of admixtures is greater than 20% by volume. The name of a category includes the term "mixed" in the beginning, for example: mixed beech stands.
3. Two-species stands, in which the share of both components is approximately the same (40–50%), for example: beech-spruce stands.

Four developmental phases of tree stands were distinguished in this study:

1. Initial phase, with the youngest tree stands (thickets, pole-stage stands).
2. Early optimal phase, with tree stands characterised by a high density of trees (usually thinner than 14 cm DBH) and low stand volume.
3. Late optimal phase, with tree stands characterised by a lower number of trees and relatively high stand volume.
4. Terminal phase, consisting of tree stands characterised by: low density of trees, wide range of size classes, a high percentage of trees with large DBH, high volume of tree stand, presence of advanced regeneration.

On the basis of the above mentioned criteria the forest stands in the Gorce National Park were divided into 17 categories (Table 1, Fig. 2). Forest dynamics was analysed only for those categories, in which at least 10 sample plots were located, i.e. in 16 categories. Classification of forest stands was made at the beginning of the study. The area and

Table 1. Stand categories distinguished on the basis of species composition and developmental phase of tree stand in areas subjected to different conservation regimes (numbers of sample plots per each category are given in parentheses).

Category of species composition		Developmental phase		Area [ha]	
Name	Acronym	Name	Symbol	Strict protection	Partial protection
Beech stands	Bk	Terminal	T	126.01 (8)	82.41 (2)
Mixed beech stands	WBk	Initial	I	16.04 (2)	-
		Early optimal	O1	52.32 (2)	111.4 (8)
		Late optimal	O2	8.57 (0)	160.08 (10)
		Terminal	T	1,111.7 (68)	1,208.09 (76)
Fir-beech stands	Jd-Bk	Terminal	T	5.42 (0)	168.76 (11)
Mixed fir stands	WJd	Early optimal	O1	4.62 (1)	115.05 (9)
		Terminal	T	11.71 (0)	182.20 (11)
Beech-spruce stands	Bk-Św	Terminal	T	463.66 (33)	235.63 (14)
Mixed spruce stands	WŚw	Early optimal	O1	6.41 (1)	84.10 (9)
		Late optimal	O2	61.02 (5)	324.07 (13)
		Terminal	T	235.97 (14)	121.51 (4)
Spruce stands of the montane zone	Św-D	Late optimal	O2	35.64 (1)	186.66 (17)
		Terminal	T	20.01 (1)	67.92 (10)
Mixed rowan stands	WJrz	Initial	I	25.68 (2)	142.76 (10)
Subalpine spruce forests	Św-G	Late optimal	O2	339.36 (17)	170.73 (11)
		Terminal	T	277.96 (21)	126.62 (9)
Total				2,802.10 (176)	3,487.99 (224)

boundaries of the initial phase were corrected on the basis of the aerial photographs taken in 1995.

In 1992, field measurements conducted in the permanent sample plots included: determination of species identity of each tree in the plot, measurement of DBH, and determination of the coordinates of all trees within the circle of the area of 0.05 ha. In addition, in the inner circle (of the area of 0.01 ha) heights of all trees were measured and all saplings (individuals taller than 0.5 m, with DBH less than 7 cm) were counted and measured. The measurements of seedlings (individuals shorter than 50 cm) of main tree species were conducted in 1993; at that time, there were 350 study plots distributed in regular spacing of 400 x 400 m. Seedlings were counted in three circular plots of size of 3.14 m^2 each, located at a distance of 5, 15 and 25 m from the plot centre to the north (Niemtur et al. 1994).

During the second inventory in 1997 the DBH of all living trees was re-measured. Trees, which had been removed or died between 1992 and 1997 were recorded as dead ones. Trees, which attained the DBH of 7 cm between 1992 and 1997 were recorded as "recruits". Seedlings and saplings were counted once again. Seedlings were counted in 4 subplots of a size of 1.25 m^2 each, situated at a distance of 3 m from the plot centre in four cardinal directions. All seedlings were divided into two categories: younger ones (not including germinants) less than 25 cm tall, and older ones, at least 25 cm tall.

The results of field measurements were analysed separately for each of the 16 categories of species composition. The analysis comprised:

1. Calculation of the average volume and densities of trees, saplings and seedlings per one hectare, as well as determination of the actual species composition of a tree stand and forest regeneration in 1992 and 1997.
2. Estimation of the intensity of tree mortality, recruitment and volume increment.
3. Statistical analysis of the exactness of the estimation of stand volume, volume increment and temporal changes in average stand volume.

The intensity of changes in number of trees per 1 ha and in stand volume was analysed using the indices of dynamics of chosen stand characteristics (Przybylska 1993a), according to the formulas:

$$W_{dN} = (N_{t2} - N_{t1}) \cdot N_{t1}^{-1} \cdot (t_2 - t_1)^{-1} \cdot 100\% \quad (1)$$

$$W_{dV} = (V_{t2} - V_{t1}) \cdot V_{t1}^{-1} \cdot (t_2 - t_1)^{-1} \cdot 100\% \quad (2)$$

where:

W_{dN} – index of annual dynamics of tree number;

W_{dV} – index of annual dynamics of average stand volume;

N_{t1}, N_{t2} – numbers of trees at the beginning and at the end of study period, respectively;

V_{t1}, V_{t2} – stand volume at the beginning and at the end of study period, respectively;

$t_2 - t_1$ – duration of the study.

In a similar way the indices of dynamics of recruitment (W_{dD_N}) and dynamics of tree mortality (W_{dU_N}) were calculated. In these cases, in the formula no (1) the expression ($N_{t2} - N_{t1}$) was replaced by the respective numbers of recruits and dead trees for the period 1992–1997. Similarly, by replacing in the formula (2) the expression $V_{t2} - V_{t1}$ with the volume of dead trees and the volume increment of trees, respectively, the dynamics were calculated of volume loss W_{dU_V} and volume increment (W_{dZ_V}).

All the field data and results of calculations (volume curves, tree volume, stand volume) are kept in printed and electronic forms at the research unit of the Gorce National Park.

RESULTS

Characteristics of the 16 categories of tree stands in the Gorce National Park, defined on the basis of species composition and developmental phase of a tree stand, are given in Table 2. The spatial distribution of these categories is presented in Figure 2.

The area covered by various categories of tree stands was greatly varied (Table 1, Fig. 3A). In the montane zone, covering 82.8% of the Park area (6,290 ha), the mixed beech stands (covering 51.2% of the montane zone) were the most widespread category. Next to them were the mixed spruce stands (16%) and beech-spruce stands (13.4%). The smallest area was covered by fir-beech forests (3.3%), pure beech stands (4%), pure spruce stands, and mixed fir stands (6% each). In the subalpine zone, 84.4% of the area was covered by pure spruce stands, while the remaining 15.6% were mixed rowan stands.

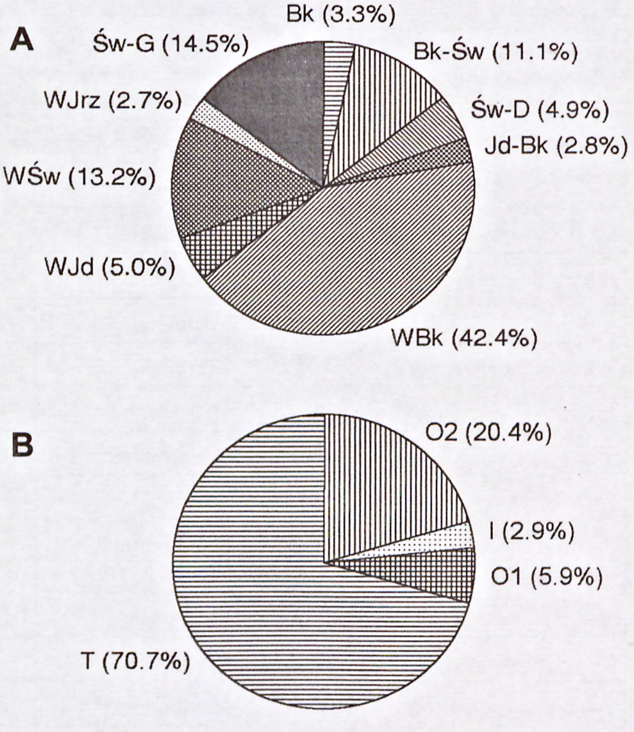

Fig. 3. The share of certain categories of species composition (A) and developmental phases (B) in the forests of the Gorce National Park in 1997. Explanations as in Table 1.

Table 2. Changes in species composition of tree stand and forest regeneration along with the intensities of tree mortality, tree recruitment and volume increment in various categories of tree stand composition and in various developmental phases of the Gorce Nartional Park in the years 1992–1997. Explanations: KSG – category of stand composition; names of categories and phases of development like in Table 1; Fs – *Fagus sylvatica*, Aa – *Abies alba*, Pa – *Picea abies*, Ap – *Acer pseudoplatanus*, Ld – *Larix decidua*, Sc – *Salix caprea*, Ai – *Alnus incana*, Sa – *Sorbus aucuparia*, Fe – *Fraxinus excelsior*, Pt – *Populus tremula*, Pav – *Prunus avium*, Bp – *Betula pendula*, Ug – *Ulmus glabra*, Ps – *Pinus sylvestris*, Ca – *Corylus avellana*; + – occurrence with frequency below 0.5%; [1] – data for seedlings are from 1993.

KSG	Phase	Year	NUMBER OF TREES		STAND VOLUME		SAPLINGS		SEEDLINGS		TREE MORALITY				TREE RE-CRUITMENT		VOLUME INCREM-MENT	
			ind./ha	%	m³/ha	%	ind./ha	%	ind./ha	%	ind./ha/year	%	m³/ha/year	%	ind./ha/year	%	m³/ha/year	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk	T	1992[1]	472	71Fs 18Aa 9Pa 1Ap 1Ld	453.4	79Fs 13Aa 6Pa 1Ld 1Ap	5,990	35Fs 31Aa 28Ap 5Pa 1Fc,Sa	8,276	63Fs 32Aa 5Pa	2.8	57Pa 43Fs	1.89	53Pa 47Fs	3.6	67Aa 33Fs	9.26	85Fs 11Aa 3Pa 1Ld,Ap
		1997	476 (+4)	70Fs 21Aa 7Pa 1Ap 1Ld	490.3 (+36.9)	80Fs 13Aa 5Pa 1Ld 1Ap	5,630 (-360)	59Fs 27Aa 10Ap 3Pa 1Fc,Sa	13,800	75Fs 12Aa 10Ap 3Pa								
WBk	O1	1992	968	60Fs 19Aa 17Pa 2Fc 1Ap 1Ai,Ld,Sc	168.8	41Fs 37Pa 18Aa 2Ai 2Fc +Ap,Ld,Sc	2,740	53Fs 25Aa 9Pa 6Ap 5Sc 1Sa 1Fc,Bp	1,667	55Pa 36Aa 9Fs	14.8	35Pa 33Fs 27Aa 5Ap	0.80	43Fs 29Pa 25Aa 3Ap	28.8	55Fs 28Aa 8Ap 6Pa 3Sc	8.85	47Fs 30Pa 19Aa 3Fc 1Ai +Ld,Ap, Sc
		1997	1,038 (+70)	61Fs 20Aa 14Pa 2Fc 2Ap 1Ai,Ld,Sc	212.0 (+43.2)	43Fs 35Pa 18Aa 1Fc 2Ai 1Ap,Ld,Sc	2,170 (-570)	55Fs 27Aa 9Pa 6Sc 1Sa 1Ap 1Bp	3,600	39Aa 39Fs 17Fc 5Ap								
WBk	O2	1992	706	73Fs 13Pa 8Ai 6Aa +Ap	295.4	69Fs 22Pa 7Aa 2Ai +Ap	1,770	59Pa 20Fs 12Aa 6Ai 3Sa	6,543	68Pa 27Aa 5Fs	6.4	50Pa 44Fs 6Ap	3.01	83Pa 17Fs +Ap	7.6	90Pa 5Aa 5Fs	8.16	80Fs 12Pa 4Ai 4Aa +Ap.
		1997	712 (+6)	71Fs 15Pa 8Ai 6Aa +Ap	321.9 (+26.5)	72Fs 18Pa 7Aa 3Ai +Ap	1,940 (+170)	45Pa 35Fs 11Aa 4Ai 4Sa 1Ap	26,400	81Fs 8Pa 6Ap 4Aa 1Sa								
WBk	T	1992	417	59Fs 21Pa 18Aa 1Ap 1Sc,Fc,Sa	390.8	57Fs 23Pa 19Aa 1Ap +Sc,Fc,Sa	3,556	41Fs 38Aa 11Pa 7Ap 2Sa 1Sc,Fc	8,200	49Aa 45Fs 6Pa	3.5	48Pa 29Fs 20Aa 3Ap +Sc	3.07	53Pa 27Fs 19Aa 1Ap,Sc	7.2	45Fs 32Aa 16Pa 3Ap 2Fc 1Sc 1Sa	7.93	60Fs 20Aa 19Pa 1Ap +Sc,Sa, Fc
		1997	436 (+19)	59Fs 19Pa 19Aa 1Ap 1Sc,Fc,Sa	415.6 (+24.8)	59Fs 22Pa 19Aa +Ap,Sc,Fc,Sa	3,386 (-170)	45Fs 38Aa 9Pa 6Ap 2Sa 1Sc,Fc +Bp	36,750	90Fs 5Aa 3Ap 1Pa 1Sa								
Jd-Bk	T	1992	505	43Aa 41Fs 15Pa 1Ld,Ap	419.4	44Fs 41Aa 14Pa 1Ld,Ap	4,173	53Aa 25Pa 21Fs 1Sa,Ap	12,202	89Aa 11Fs	5.1	49Aa 29Fs 22Pa	3.04	94Aa 6Fs +Pa	8.0	50Fs 41Aa 9Pa	9.25	50Fs 38Aa 11Pa 1Ld,Ap
		1997	520 (+15)	43Aa 42Fs 14Pa 1Ld,Ap	450.9 (+31.5)	46Fs 39Aa 14Pa 1Ld,Ap	3,673 (-500)	62Aa 22Fs 15Pa 1Sa	26,364	79Fs 16Aa 3Pa 1Sa 1Ap								
WJd	O1	1992	1,198	58Aa 30Pa 10Fs 1Sc 1Ai,Sa	147.8	50Aa 39Pa 10Fs 1Sc,Ai,Sa	4,140	38Aa 32Fs 17Pa 5Sc 4Sa 4Ap	1,910	89Aa 11Pa	23.6	63Pa 25Aa 9Fs 3Sc	1.82	73Pa 20Aa 6Fs 1Sc	48.0	55Aa 27Pa 10Fs 7Sc 1Ai	10.05	63Aa 29Pa 7Fs 1Sc,Ai
		1997	1,320 (+122)	60Aa 27Pa 10Fs 2Sc 1Ai,Sa	193.5 (+45,7)	55Aa 35Pa 10Fs +Sc,Ai,Sa	3,250 (-890)	32Fs 31Aa 16Pa 13Sa 6Ap 2Sc	5,200	50Aa 27Pa 19Fs 4Sa								

Table 2 cont.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
WJd	T	1992	473	57Aa 24Fs 17Pa 1Ld 1Sa	380.6	55Aa 34Fs 7Pa 4Ld +Sa	3,127	39Aa 30Fs 17Pa 13Sa 1Ap,Sc	6,077	78Aa 16Fs 6Pa	3.6	48Aa 41Pa 11Fs	0.71	61Pa 38Aa 1Fs	25.1	64Aa 25Fs 10Pa 1Sc	10.27	63Aa 26Fs 6Pa 5Ld +Sa
		1997	580 (+107)	59Aa 24Fs 15Pa 1Ld 1Sa,Sc	429.4 (+48.8)	56Aa 33Fs 6Pa 4Ld +Sa,Sc	2,845 (-282)	36Aa 33Fs 16Sa 13Pa 2Ap	17,818	83Fs 10Aa 5Sa 2Pa								
Bk-Św	T	1992	462	51Fs 42Pa 6Aa 1Ap,Sa	455.4	49Pa 44Fs 6Aa 1Ap,Sa	1,628	50Fs 30Aa 7Ap 7Pa 6Sa	7,946	57Fs 30Pa 13Aa	3.9	82Pa 15Fs 3Aa	3.41	68Pa 31Fs 1Aa	2.6	71Fs 15Pa 11Aa 3Sc	8.27	47Pa 45Fs 7Aa 1Ap
		1997	455 (-7)	53Fs 40Pa 6Aa 1Ap,Sa,Sc	480.0 (+24.6)	48Pa 45Fs 6Aa 1Ap,Sa,Sc	2,570 (+943)	60Fs 25Aa 6Pa 5Sa 4Ap	35,702	83Fs 8Pa 5Ap 4Aa								
WŚw	O1	1992	732	64Pa 18Aa 7Sc 6Fs 3Ld 1Ap 1Pt,Bp,Sa,Fc	155.4	55Pa 21Fs 9Aa 8Ap 6Ld 1Sc, Bp,Pt,Sa,Fc	4,660	57Pa 17Aa 9Fs 7Sc 4Ap 3Sa 2Ld 1Bp,Fc	4,598	58Pa 38Aa 4Fs	17.6	91Pa 7Fs 2Fc	5.01	80Pa 20Fs +Fc	42.0	37Aa 28Pa 27Sc 7Fs 1Ap	5.71	52Pa 18Fs 18Aa 5Ld 3Ap 3Sc 1Bp,Pt
		1997	854 (+122)	53Pa 25Aa 12Sc 6Fs 2Ld 1Ap 1Pt,Bp,Sa	163.3 (+7.9)	50Pa 20Fs 12Aa 8Ap 7Ld 2Sc 1Bp,Pt,Sa	4,230 (-430)	51Pa 19Aa 9Fs 7Ap 6Sa 5Sc 2Ld 1Bp	12,400	82Fs 8Pa 6Ap 2Aa 2Sa								
WŚw	O2	1992	634	62Pa 26Fs 10Aa 1Ap 1Sa,Pt	270.2	65Pa 23Fs 11Aa 1Ap,Pt,Sa	2,417	32Sa 31Aa 21Pa 11Fs 3Ap 1Sc 1Pt,Fc	9,398	44Pa 36Fs 20Aa	9.3	86Pa 12Fs 2Aa	2.17	94Pa 4Aa 2Fs	7.3 ·	45Pa 30Fs 25Aa	7.98	61Pa 22Fs 15Aa 1Ap 1Pt,Sa
		1997	624 (-10)	59Pa 27Fs 12Aa 1Ap 1Sa,Pt	299.6 (+29.4)	63Pa 23Fs 12Aa 1Ap 1Pt,Sa	2,272 (-144)	39Sa 24Aa 21Pa 13Fs 2Ap 1Pt,Sc	12,889	63Fs 24Pa 7Sa 5Aa 1Ap								
WŚw	T	1992	381	56Pa 33Fs 8Aa 2Ap 1Ug,Sa	473.6	72Pa 20Fs 7Aa 1Ap +Ug,Sa	3,372	62Aa 17Fs 11Pa 7Sa 3Ap +Sc	9,962	51Pa 36Aa 13Fs	3.6	57Pa 32Fs 11Aa	3.30	81Pa 10Aa 9Fs	8.9	53Fs 35Aa 5Ap 5Ug 2Pa	8.10	67Pa 23Fs 9Aa 1Ap +Ug
		1997	408 (+27)	50Pa 36Fs 11Aa 2Ap 1Ug,Sa	498,4 (+24.8)	71Pa 21Fs 7Aa 1Ap +Ug,Sa	2,639 (+267)	55Aa 18Fs 14Sa 12Pa 1Ap	23,778	37Pa 29Fs 22Aa 11Ap 1Sa								
Św-D	O2	1992	570	87Pa 9Fs 3Aa 1Ld,Ap,Pav,Bp	237.6	87Pa 8Fs 4Aa 1Ld,Ap,Pav,Bp	2,400	80Pa 6Fs 6Aa 3Sa 3Sc 2Bp +Ps	6,897	64Pa 28Aa 8Fs	7.8	94Pa 3Aa 3Ld	1.38	98Pa 2Ld +Aa	15.6	66Pa 15Aa 10Fs 7Sc 1Brz 1Ca	6.36	86Pa 8Fs 4Aa 1Pav 1Ap,Ld, Bp
		1997	609 (+39)	84Pa 9Fs 5Aa 1Sc 1Ld,Bp, Ap,Pav,Ca	263.9 (+26.3)	87Pa 8Fs 4Aa 1Ld,Ap,Pav,Sc, Bp,Ca	1,585 (-815)	70Pa 15Fs 9Aa 2Sa 2Sc 1Bp 1Ug	6,667	71Pa 15Fs 10Aa 2Ap 2Sa								
Św-D	T	1992	335	77Pa 16Fs 6Aa 1Ap,Sa	337.3	88Pa 10Fs 2Aa +Ap,Sa	3,400	39Aa 33Pa 18Fs 8Sa 1Ap 1Sc	9,196	70Pa 17Aa 13Fs	4.0	90Pa 10Fs	2.27	99Pa 1Fs	7.6	58Pa 24Fs 14Aa 4Ap	7.04	85Pa 13Fs 2Aa +Ld,Ap
		1997	353 (+18)	74Pa 17Fs 7Aa 1Ap 1Sa	361.4 (+24.1)	87Pa 11Fs 2Aa +Ap,Sa	3,909 (+509)	38Aa 31Fs 21Pa 9Sa 1Ap	20,182	55Fs 39Pa 5Aa 1Sa								

WJrz	I	1992	129	80Pa 12Fs 8Sa	84.6	95Pa 3Fs 2Sa	1,617	60Sa 13Aa 13Pa 5Fs 3Bp 3Sc 2Ld 1Pt	1,680	84Pa 16Aa	4.3	100Pa	2.68	100Pa	0.7	100Bp	1.83	86Pa 10Fs 4Sa
		1997	110 (-19)	74Pa 14Fs 9Sa 3Bp	80.4 (-4,2)	93Pa 4Fs 3Sa +Bp	3,877 (+2260)	64Sa 17Pa 10Aa 4Sc 2Fs 2Bp 1Ld,Pt	3,667	100Pa								
Św-G	O2	1992	672	90Pa 9Fs 1Sa,Aa,Ap	333.5	98Pa 2Fs +Sa,Aa,Ap	307	47Pa 38Sa 14Fs 1Sc	8,449	97Pa 2Aa 1Fs	8.0	99Pa 1Sa	3.32	100Pa +Sa	1.6	62Fs 38Pa	7.71	96Pa 3Fs 1Sa,Ap, Aa
		1997	640 (-32)	89Pa 10Fs 1Sa,Aa,Ap	355.7 (+22.2)	97Pa 2Fs 1Sa,Aa,Ap	321 (+14)	39Sa 37Pa 23Fs 1Sc	15142	92Pa 7Fs 1Aa,Sa								
Św-G	T	1992	434	83Pa 13Fs 3Sa 1Aa	424.0	90Pa 8Fs 2Aa +Sa	700	57Sa 14Pa 14Aa 12Fs 3Ap	11,141	89Pa 8Aa 3Fs	4.5	87Pa 11Sa 2Fs	2.73	95Pa 3Fs 2Sa	0.4	75Fs 25Pa	7.52	88Pa 10Fs 2Aa +Sa
		1997	414 (-20)	83Pa 14Fs 2Sa 1Aa	447.9 (+23.9)	90Pa 8Fs 2Aa +Sa	967 (+267)	70Sa 11Fs 10Pa 8Aa 1Ap	40,800	48Fs 48Pa 3Aa 1Sa,Ap								
Total		1992	498	44Pa 38Fs 16Aa 1Ap 1Sc,Ai,Sa,Ld,Fc , Pt,Bp,Ug,Pav	358.6	46Pa 39Fs 14Aa 1Ap,Ld,Sa,Ai, Fc,Pt,Sc,Pav,Bp, Ug	2,750	35Aa 32Fs 18Pa 7Sa 6Ap 1Sc1Fc,Ld,Bp, Ai, Pt +Ps	8,072	36Pa 33Aa 31Fs	5.7	68Pa 16Fs 12Aa 2Ap 1Sa 1Sc,Ld, Fc	2.79	69Pa 19Fs 12Aa +Ap,Sa, Sc,Ld,Fc	8.9	35Aa 31Fs 25Pa 5Sc 2Ap 1Fc 1Ai,Sa, Bp,Ug, Ca	8.11	42Pa 40Fs 17Aa 1Ap,Ld, Sc,Ai, Sa,Fc,Pt, Pav,Bp, Ug
		1997	514 (+16)	40Pa 39Fs 18Aa 1Ap 1Sc 1Ai,Sa,Ld,Fc, Pt,Bp,Ug,Pav,C a	385.8 (+27.2)	45Pa 40Fs 14Aa 1Ap, Ld,Ai,Sa,Sc,Fc, Pt,Pav,Bp,Ug, Ca	2,806 (+56)	37Fs 33Aa 14Pa 10Sa 4Ap 1Sc 1Fc,Bp,Ld,Ai, Ug	27,130	74Fs 15Pa 6Aa 4Ap 1Sa +Fc								

In all categories (with the exception of pure spruce stands and mixed spruce stands) the dominant role was played by tree stands representing the terminal phase. They cover 70.7% of the total forest area in the Gorce National Park (77.6% of the montane zone and 44.2% of the subalpine zone) (Fig. 3B). The smallest area was covered by tree stands representing the initial phase (2.9%). The initial phase consisted mainly of the mixed beech stands and mixed rowan stands.

SPECIES COMPOSITION

In the tree layer, 13 species were recorded in the Gorce National Park in 1992. These were: Norway spruce, European beech, silver fir, sycamore, European larch, goat willow, grey alder, rowan, ash, aspen, bird cherry, silver birch, and elm. The main tree species were: spruce, beech and fir, which in total made up 97.6% of the tree number and 99% of the stand volume. In the period 1992–1997 to the list of species hazel was added; it attained the DBH of over 7 cm. The share of minor species (expressed by tree numbers) had increased from 2.4 to 3.1%. The highest diversity of species composition of the canopy layer (6–10 species) characterised: mixed beech stands, mixed fir stands, and mixed spruce stands representing the early optimal phase, as well as the spruce stands of the montane zone representing the late optimal phase of development. In the tree stands representing the terminal phase both the number of minor tree species and their share in tree stands were lowest (Table 2).

STAND VOLUME

The average stand volume had increased between 1992 and 1997 from 358.6 m^3/ha to 385.8 m^3/ha. The stand volumes for various stand categories ranged from 80 m^3/ha in the initial phase (almost all of that was made by old trees remaining from the earlier generation) to almost 500 m^3/ha in the mixed spruce stands representing the terminal phase. The relationship between tree density and stand volume was presented in Figure 4. The largest variability of stand volume occurred in the terminal phase and amounted in 1992 from 337.3 m^3/ha in pure spruce stands of the montane zone to 473.6 m^3/ha in mixed spruce stands.

The net change in stand volume from 1992 to 1997, a result of volume increment, volume loss due to tree mortality, and volume gain due to tree recruitment, was in most of the stand categories (except for the initial phase) positive, and ranged from 7.9 m^3/ha/5 years in mixed spruce stands in the early optimal phase to 48.8 m^3/ha/5 years in mixed fir stands in the terminal phase (Table 2, Fig. 4). The average volume increment for the tree stands in the entire Park amounted to 27.2 m^3/ha/5 years. The dynamics of changes in mean stand volume for the entire stands and, separately, for the main tree species (spruce, beech and fir), expressed as a ratio of the actual value of particular characteristics to their value at the beginning of the study period and given in percent, was presented in Figure 5.

During the period 1992–1997 the index of annual

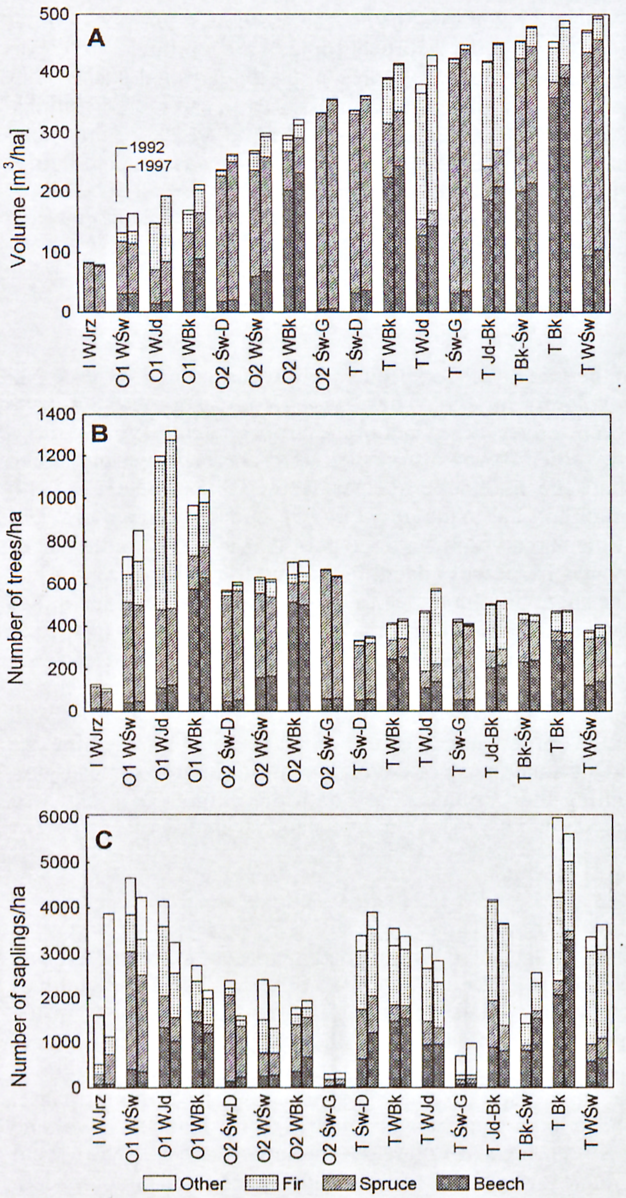

Fig. 4. Comparison of the species composition, mean stand volume (A), tree number per 1 ha (B), and density of saplings (C) in various stand categories, and changes of these characteristics during the period 1992–1997. Explanations as in Table 1.

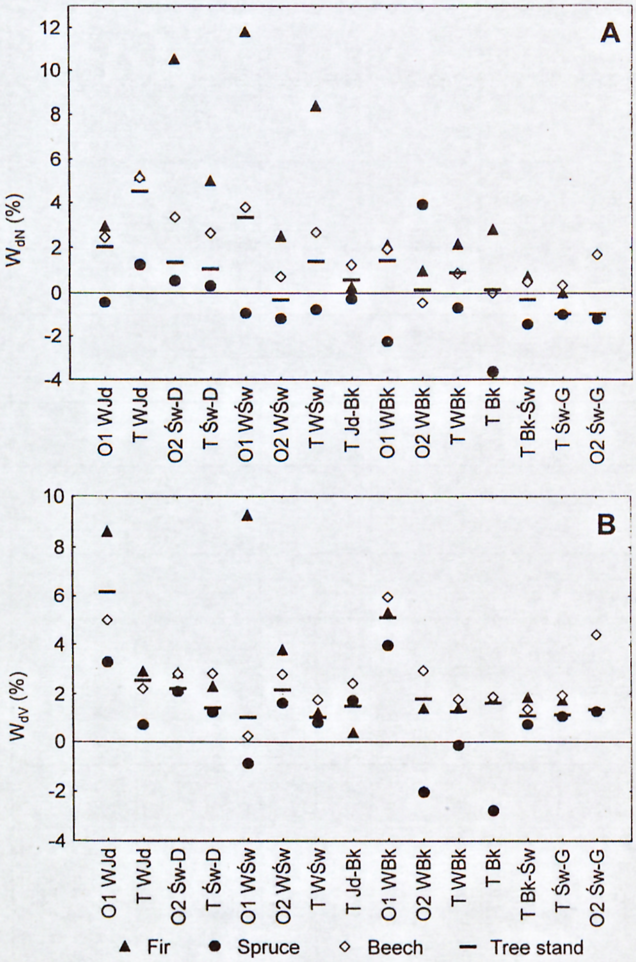

Fig. 5. Annual indices of change in tree density W_{dN} (A) and in stand volume W_{dV} (B) for the entire stand and for beech, fir and spruce separately, calculated for chosen stand categories for the period 1992–1997. Explanations as in Table 1.

change in stand volume amounted to 1.5%. The biggest differences in volume increment were ascertained in the early optimal phase between the mixed fir stands (6.2% per annum) and mixed beech stands (5.1%) on the one hand, and mixed spruce stands (1.0%) on the other. The reason for such big differences was the high mortality rate in mixed spruce stands (5.01 m^3/ha/year, i. e. 3.2% annually), related mostly to the dieback of the oldest spruces. The positive net change in stand volume was a result of a high increment in silver fir and in beech, compensating largely for the negative or low positive respective indices for spruce (Fig. 5).

In the four categories: mixed beech stands in the late optimal and terminal phases, as well as in beech stands and mixed spruce stands in the early optimal phase, covering in total 2,579 ha (i.e. 41% of the entire forest area within the boundaries of the Gorce N. P.) the volume of spruces went down. The process was most pronounced in beech stands in the terminal phase, amounting there to 2.8% annually (0.72 m^3/ha/year).

The highest indices of the intensity of volume increment were attained by silver fir in mixed spruce stands (9.3% annually) and in mixed fir stands (8.6%). In both cases it occurred in tree stands representing the early optimal phase of stand development. The average intensity of volume increment in silver fir (2.2%) was slightly higher than in beech (1.9%).

NUMBER OF TREES

The density of trees in various stand categories was strongly variable, depending primarily on the developmental phase of a forest stand. The average density of trees in the late optimal phase was usually lower than in the early optimal phase, but higher than in the terminal phase of stand development (Table 2, Fig. 4). In the initial phase there were either no trees above 7 cm DBH or few of them, scattered throughout the stand.

During the period 1992–1997 the average number of trees per 1 ha had increased in most of the stand categories. The only exceptions were the subalpine spruce forests, beech-spruce forests and mixed spruce forests in the late optimal phase, where the number of trees per 1 ha has actually decreased (Table 2, Fig. 4). The highest increase in tree number (122 trees/ha/5 years) took place in mixed fir and mixed spruce forests in the early optimal phase, and the most rapid decline of tree density (32 trees/ha/5 years) occurred in the subalpine spruce forests representing the late optimal phase. The average tree density for the entire forest area had increased from 498 trees/ha in 1992 to 514 trees/ha in 1997.

During the period 1992–1997 an increase in the average number of silver fir amounted to 12 tree/ha, which (expressed as the index of intensity) was 3.1%. In beech it amounted to 10 tree/ha (1%). That quite rapid increase in silver fir was especially pronounced in mixed fir and mixed spruce forests and in spruce forests of the montane zone. For example, in mixed spruce forests in the early optimal phase, because of an increase in the number of silver fir by 59.1% (78 trees/ha/5 years) the share of silver fir in a tree stand had increased from 18.0% to 24.6%.

The number of spruces had declined in 11 stand categories covering in total 5,617 ha (89% of the total area of the Park). The intensity of changes ranged from 0.3% annually in beech-fir stands to 3.6% annually in beech dominated stands (Fig. 5). In the spruce stands of the montane zone and in mixed fir forests the number of spruces had increased, but the dynamics of that increase was very low when compared to increases in beech and silver fir. Only in mixed beech forests in the late optimal phase the intensity of an increase in the spruce number (3.9% annually, i.e. 3.6 trees/ha/1 year) was higher than the intensity of an increase in the silver fir and beech (Fig. 5a). The mixed beech forests of the late optimal phase are the only stand category in which the share of spruce (determined on the basis of tree numbers) had increased from 13.0% in 1992 to 15.4% in 1997. However, at the same time the share of spruce estimated on the basis of tree volume had declined from 22.4% to 18.5%. The average decline in the number of spruces over the entire Park area amounted to 10 trees/ha/5 years, i.e. 4.6% in five years.

TREE MORTALITY

Tree mortality in the Park was caused primarily by natural factors (of the 25,000 m^3 of timber removed from the Park in 5 years, over 92% were dead trees or trees already dying for natural reasons). Tree mortality occurred in all size classes; the highest intensity of tree mortality was ascertained for smaller trees (DBH below 15 cm). The highest numbers of dead trees were found in the early optimal phase (18.7 dead trees/ha/1 year on average). For the entire Park area the average mortality was 5.7 tree/ha/1 year (the volume loss of about 2.79 m^3/ha/1 year). The intensity of mortality was estimated at 1.1% annually (as compared to the tree number in 1992), or 0.8% annually (as compared to the tree volume in 1992). The most intense mortality occurred in spruce – over 70% of the dead trees were spruces, and the figures for tree volume were almost the same. The dynamics of tree mortality (expressed in terms of tree numbers as well as in tree volume) for spruce was higher than those for beech and fir in most of the stand categories (Fig. 6). No losses of silver fir were ascertained in five stand categories, and no beech mortality – in two of them (Table 2).

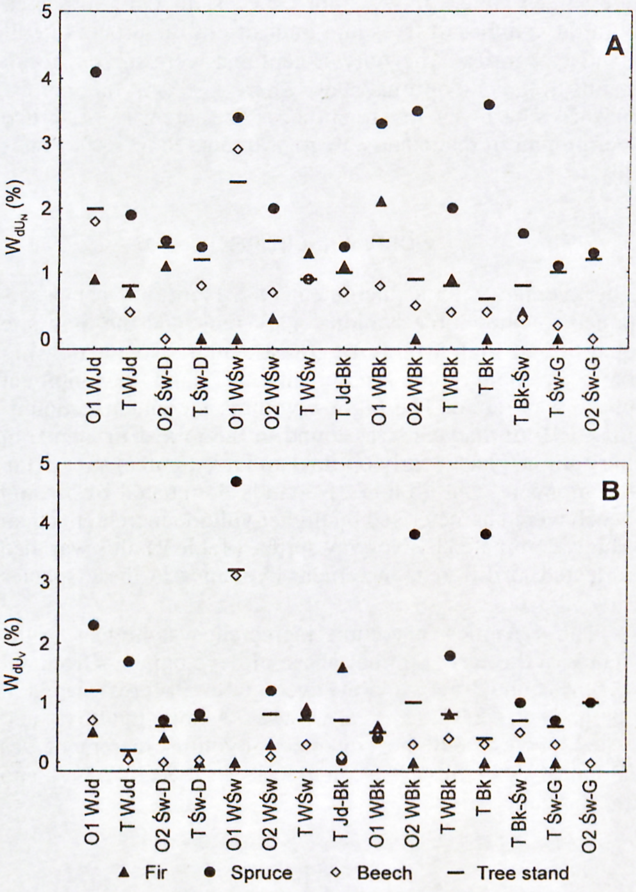

Fig. 6. Annual indices of tree mortality estimated by tree number W_{dU_N} (A) and by timber volume W_{dU_V} (B) for the entire stand and for beech, fir and spruce separately, for the period 1992–1997. Explanations as in Table 1

TREE RECRUITMENT

The process of recruitment of canopy trees attained the intensity of 8.9 trees/ha/1 year, i.e. 1.8% annually, and was very uneven spatially. The highest intensity of canopy tree recruitment was found in tree stands in the early optimal phase in the montane zone (on average 39.6 trees/ha/1 year, i. e. 4.1% annually). The lowest intensity of recruitment was ascertained in subalpine spruce forests – less than 1 tree/ha/1 year. In the montane zone the most numerous species among recruits was silver fir (3.7 trees/ha/1 year, average intensity 3.9% annually). The second numerous species among recruits was beech with 3.3 trees/ha/1 year (1.5%) and the third, Norway spruce with 2.6 trees/ha/1 year (1.5%).

In the process of turning from the sapling stage into canopy trees silver fir was more successful than spruce in both the number of trees and intensity of the process in all stand categories. The only exceptions were mixed beech stands in the late optimal stage where 89.5% of the recruits (6.8 trees/ha/1 year) were spruces. The intensity of spruce recruitment in that stand category amounted to 7.4% annually (Fig. 7).

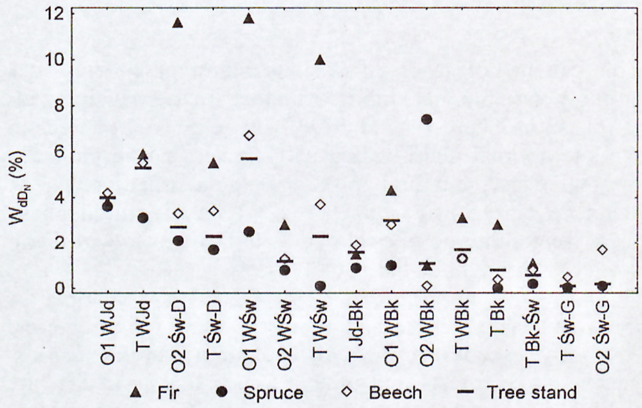

Fig. 7. Annual indices of tree recruitment W_{D_N} for the entire stand and for beech, fir and spruce separately, for the period 1992–1997. Explanations as in Table 1

VOLUME INCREMENT

The average volume increment of 8.11 m^3/ha/year ascertained for the Gorce National Park indicated the high site quality and high vitality of forest stands. No relationship between the volume increment and stand development phase was found. The highest volume increment, amounting to 10 m^3/ha/year, was found in the mixed fir stands in the optimal phase (early optimal and late optimal as well) in the montane zone (Table 2). Stands dominated by fir and beech were characterised by higher volume increments than stands dominated by Norway spruce (Table 2); this was also reflected in different increment dynamics in these species (Fig. 8).

The dynamics of volume increment was highest in the stands in the early optimal phase of development (from 3.7 to 6.8% annually), while the average for all forest stands of the park was 2.3% per year (Fig. 8). Among the three analysed species the highest intensity of volume increment was found in silver fir (2.8%), next to it was beech (2.3%), and the last one spruce (2.1%).

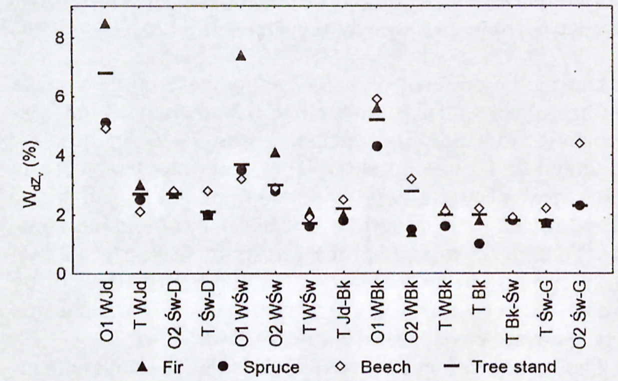

Fig. 8. Annual indices of volume increment W_{dZ_v} for the entire stand and for beech, fir and spruce separately, for the period 1992–1997. Explanations as in Table 1.

REGENERATION

Among young trees the biggest changes occurred in the density and species composition of seedlings. In 1993 the shares of major tree species: beech, spruce and fir (only these species had been recorded) were similar, and the average density of seedlings amounted to 8,000 individuals/ha (Table 2). The highest densities of seedlings were recorded in forest stands in the terminal phase, especially in fir-beech stands (12,000 ind./ha) and in subalpine spruce forests (over 11,000 ind./ha). The lowest densities were recorded in stands representing the initial phase and in mixed beech stands in the early optimal phase (about 1,600 ind./ha).

Till the year 1997 the average density of seedlings in the entire Park area had increased to more than 27,000 ind./ha, and their species composition was dominated by beech (74.2%) (Table 2). That was a result of the establishment of the extremely large cohort of beech seedlings in spring 1996, after a mast year (1995) (most of the beech seedlings recorded in 1997 were 2-year old ones). On average, in 1997 more than 94% of all the recorded seedlings were below 25 cm tall. Among the taller seedlings (25–50 cm tall), whose density reached 1,605 ind./ha, five species were recorded: beech (49.8%), fir (22.8%), spruce (11.8%), sycamore (8.1%) and rowan (7.5%). Like in 1993, the highest densities of seedlings were found in tree stands in the terminal phase of development – up to 41,000 ind./ha in subalpine spruce forests. The lowest densities of seedlings (about 3,600 ind./ha) were recorded in the initial and early optimal phases of development (Table 2).

The average density of saplings (individuals taller than 50 cm, with DBH less than 7 cm) did not changed much between the two censuses. In 1992 it amounted to 2,750 ind./ha, and in 1997 – to 2,806 ind./ha. However, the spatial distribution of saplings was very uneven (Table 2, Fig. 4). Generally, the density of saplings declined along the elevation gradient; the density of saplings in the subalpine zone was about 700 ind./ha in 1992 and increased to 1,247 ind./ha in 1997. At the same time the densities in the montane zone were: 3,185 ind./ha and 3,137 ind./ha, respectively. The substantial increase in the density of saplings in the subalpine zone was a result of a rapid increase in the number of saplings (by 140% in five years) in mixed rowan stands representing the initial phase of forest development. During the same period, the density of saplings declined slightly in the forest stands in the montane zone, especially in the early optimal phase (by 16.5% on average). In the year 1992 the species composition of saplings was: fir 34.5%, beech 32.2%, spruce 18%, rowan 6.6%, and sycamore 6.4%. At the second census saplings were dominated by fir and beech (over 70% of the younger saplings and 73% of the older saplings). The ratios of the number of canopy trees to the number of saplings and to the number of older seedlings (1: 5: 4 in beech and 1:10:4 in silver fir) suggest that a further recruitment of canopy trees of these species is almost certain and that beech and fir will be able to maintain dominance for a longer time.

Spruce saplings started from a density of 495 ind./ha at the first census, and their density had declined till 1997 by 19.2% (95 ind./ha/5 years). That decline was four time faster than the decline in canopy trees of that species. The relatively low survivorship rate of spruce regeneration caused the ratio of densities of canopy trees to saplings and to older seedlings to be as low as 1: 2: 1, which – compared to the ratios in beech and silver fir – suggests, that spruce will be probably unable to maintain its current share in tree stands for a longer time.

STATISTICAL EXAMINATION OF THE RELIABILITY OF ESTIMATES OF STAND VOLUME AND VOLUME INCREMENT

The volume of different stand categories was estimated with various exactness, depending on the variability of forests belonging to that category and on the number of selected sample plots. The average stand volume was estimated for the entire Park area with an error of 8.1 m^3/ha (2.3%) in 1992 and 8.4 m^3/ha (2.2%) in 1997. In the montane zone the highest reliability of results was attained for tree stands in the terminal phase of development; except for the beech-fir stands, the relative error of volume estimation did not exceed 10% for any stand category (Table 3). Stand volume for mixed beech forests (represented by 144 sample plots) was estimated with the lowest average error of 3.4%; the second lowest was the relative error of 4.2% for beech-spruce forests, represented by 47 sample plots.

The coefficient of variability of stand volume in sample plots representing the terminal phase of stand development was strongly variable, ranging from 22.5% to 41.7% in the year 1992. Among the stand categories with the lowest values of the coefficient of variability (below 30%) were mixed fir stands, pure beech stands, pure spruce stands and beech-spruce stands. Among those with the highest values of coefficient of variability were: mixed spruce stands, mixed beech stands, and beech-fir forests. The highest errors of stand volume estimation at the first census, ranging from 16.5 to 23.2%, occurred in the early optimal phase of stand development. These high relative errors resulted from a small number of sample plots in those categories and from the highest coefficients of variability in the Park, which amounted to 52.4% in mixed fir stands and 73.5% in mixed beech stands. That high variability was caused by the very uneven distribution of few large trees, exceeding much the volume of an average tree in those stands. In the stands in the late optimal phase the relative errors were lower and attained the values of 11.6% and 13.7%, respectively. The coefficient of variability was also lower and amounted to 47.2%.

The relative errors of stand volume estimation during the second census were in most cases lower than in 1992 (Table 3). That was caused by the lower coefficient of variability in sample plots; compared to 1992, the coefficients declined by 5.8% on average in the early optimal phase and by 4.4% in the late optimal phase. The coefficient of variability increased slightly in beech stands, pure spruce stands, beech-spruce forests and mixed spruce forests in the terminal phase, as well as in the subalpine spruce forests.

In the Gorce National Park the average volume increment for all stands was estimated with an average error of 0.17 m^3/ha/year, i.e. 2.1%. In various stand categories average errors of volume increment estimation ranged from 0.26 m^3/ha/year (3.3%) in mixed beech stands in the terminal phase to 1.58 m^3/ha/year (17.8%) in mixed beech stands in the early optimal phase of development.

In all stand categories the change of stand volume was a positive one. The values of average error of volume estimation were lowest in stand categories represented by a large number of sample plots, characterised by a low coefficient of variability and high coefficients of autocorrelation of stand volume in sample plots. In general, the values of autocorrelation of stand volume in 1992 and in 1997 ranged from 0.864 to 0.983, indicating an almost linear increase in stand volume. In 11 out of 16 stand categories the change in volume was statistically significant (with significance level of 0.05) (Table 3).

DISCUSSION

Each of the 16 stand categories consisted of at least several tens of separate forest stands, characterised by a given combination of climatic zone, tree stand species composition, and developmental phase. This method of analysis was chosen because of the large size of the area under study (6,290 ha) and relatively low density of sample plots (each plot represented about 16 ha of forest). The correctness of the division of the entire Park area into stand categories was supported by relatively low values of the coefficients of variability for stand volume in various stand categories, as well as by relatively low errors of estimation of stand volume and volume increment (most of the relative errors were

Table 3. Statistical examination of the reliability of estimates of stand volume and volume increment. Names of categories and phases of development like in table 1; S_V, S_{ZV} – standard deviation; $S_V\%$, $S_{ZV}\%$ – coefficient of variability; ΔV, ΔZ_V, $\Delta(V_2\text{-}V_1)$ – average error; $\Delta V\%$, $\Delta Z_V\%$ – relative error in percent; r – coefficients of autocorrelation of stand volume in sample plots; $V_2\text{-}V_1$ – change in stand volume; "+" – statistically significant ("-" not significant) change in stand volume (analyzed by a t-test at, with significance level of 0.05).

Phase	Category of stand composition	Number of plots	Stand volume in 1992				Stand volume in 1997				Volume increment				r	Change of stand volume			
			S_V	$S_V\%$	ΔV	$\Delta V\%$	S_V	$S_V\%$	ΔV	$\Delta V\%$	S_{ZV}	$S_{ZV}\%$	ΔZ_V	$\Delta Z_V\%$		$V_2\text{-}V_1$	$\Delta(V_2\text{-}V_1)$		
			m^3/0.05 ha	%	m^3/ha	%	m^3/0.05 ha	%	m^3/ha	%	m^3/0.05 ha	%	m^3/ha/year	%		m^3/ha	m^3/ha	%	
O1	WBk	10	6.2	73.5	39.2	23.2	7.2	67.9	45.5	21.5	0.25	56.4	1.58	17.8	0.897	43.2	20.2	46.8	+
O1	WJd	10	3.9	52.4	24.5	16.6	4.0	41.8	25.6	13.2	0.21	40.8	1.30	12.9	0.886	45.8	12.0	26.3	+
O1	WŚw	10	4.5	58.4	28.7	18.5	4.2	51.0	26.3	16.1	0.09	31.9	0.58	10.1	0.864	7.9	14.5	184.5	-
O2	Św-D	18	5.9	49.9	27.9	11.8	6.3	47.6	29.6	11.2	0.13	39.7	0.60	9.4	0.938	26.3	10.2	38.9	+
O2	WBk	10	6.4	43.5	40.6	13.7	5.9	37.0	37.6	11.7	0.13	30.7	0.79	9.7	0.887	26.5	18.8	71.0	-
O2	WŚw	18	6.6	49.0	31.2	11.6	6.5	43.6	30.8	10.3	0.14	34.6	0.65	8.1	0.934	29.3	11.2	38.4	+
T	Bk	10	5.3	23.2	33.3	7.3	5.8	23.8	36.9	7.5	0.14	29.2	0.85	9.2	0.887	37.0	17.1	46.2	+
T	Św-D	11	4.3	25.5	25.9	7.7	5.0	27.6	30.1	8.3	0.14	39.0	0.83	11.8	0.886	24.1	14.0	57.9	-
T	Jd-Bk	11	8.7	41.7	52.7	12.6	8.8	38.9	52.9	11.7	0.14	30.3	0.84	9.1	0.897	31.5	24.0	76.2	-
T	Bk-Św	47	6.6	28.9	19.2	4.2	7.1	29.5	20.6	4.3	0.14	35.0	0.42	5.1	0.967	24.5	5.3	21.6	+
T	WBk	144	7.9	40.7	13.2	3.4	8.1	39.0	13.5	3.3	0.16	40.0	0.26	3.3	0.959	24.8	3.8	15.4	+
T	WJd	11	4.3	22.5	25.8	6.8	4.2	19.7	25.5	5.9	0.18	34.8	1.08	10.5	0.883	48.8	12.4	25.5	+
T	WŚw	18	9.7	41.0	45.8	9.7	10.5	42.2	49.5	9.9	0.17	42.5	0.81	10.0	0.936	24.7	17.4	70.5	-
O2	Św-G	28	3.8	22.8	14.3	4.3	4.6	25.8	17.3	4.9	0.11	28.9	0.42	5.5	0.921	22.2	6.9	31.2	+
T	Św-G	30	4.6	21.6	16.7	3.9	5.3	23.8	19.5	4.3	0.13	35.2	0.48	6.4	0.933	24.0	7.2	30.0	+
Total		400	8.1	45.3	8.1	2.3	8.4	43.7	8.4	2.2	0.17	42.7	0.17	2.1	0.976	27.2	1.8	6.7	+

below 10%) (Table 3). The results were comparable with previous small-scale studies of that kind, conducted in chosen stands or compartments of the Gorce National Park (Rutkowski et al. 1972; Przybylska et al. 1995).

The division of the Park area into stand categories produced relatively uniform stand units; thus even in case, when the number of sample plots per stand category was relatively low, the estimations of stand characteristics is still reliable. Therefore, predictions concerning stand dynamics could be made with a relatively high confidence.

Dividing the Park area into stand categories, the Authors did not take into account the kind of conservation regime applied (strict reserves, partial reserves). Firstly, a division of the Park forests into a larger number of categories would inevitably cause problems with the low numbers of sample plots per category. Secondly, the spatial extent of protection regimes changed in the Gorce National Park so often that only 12.4% of the Park area has remained under the same conservation regime throughout the entire history of the Park. A very distinct pattern in the spatial structure of the areas under various conservation regimes is superimposed onto the climatic and vegetation zonation of the Park; thus some stand categories are confined to areas under strict protection, while the others – to areas under partial protection (Table 1). For example, in case of mixed beech stands in the late optimal phase and in mixed fir stands in the terminal phase all sample plots were located in areas under partial protection. One can expect, that in the next census the distribution of sample plots in areas of various conservation regimes would be different, as in the year 1998 the area under strict protection was enlarged in the Park by 750 ha.

The dynamics of changes in the timber volume of forest stands depends on initial timber resources, on the intensity of mortality, recruitment and volume increment, as well as on mutual relationships between these processes. The knowledge of the amount and structure of timber resources and of the dynamics of volume changes during the period 1992–1997 allows us – under the assumption that the external factors remain more or less constant – to make predictions about the future dynamics of forest stands in the Gorce National Park. For making such predictions it is essential to know the direction and rate of changes in various stand categories and the dynamic tendencies of the main tree species. The validity of this approach is supported by high values of the autocorrelation (0.864–0.983) of stand volume in various stand categories (Table 3), indicating a constant rate of changes in the mean stand volume.

An analysis of the index of dynamics of the mean volume allows one to forecast the direction and rate of changes in timber resources in the future. During the period 1992–1997 the mean index of intensity of stand volume increment amounted to 1.5% annually. In the near future one can expect a further increase in timber resources in the Park, although the rate and intensity of that process could be more variable.

In all stand categories dominated by beech and fir one should expect an increase in timber volume. These stands are characterised by relatively high numbers of trees (including many young ones) with high rates of volume increment. In tree stands dominated by Norway spruce with large stand volume (like the mixed spruce stands of the montane zone or subalpine spruce forests) or with low timber volume (like pure spruce stands of the montane zone) where the entire timber volume is concentrated in relatively few trees (on average about 400 trees/ha) (Fig. 4), one can expect that the processes of tree mortality would offset volume increment and tree recruitment, which would eventually result in either very slow stand volume increment or even decline in timber resources.

The pure spruce stands of the montane zone, subalpine spruce forests, mixed beech stands and mixed spruce stands in the early and late optimal phases would probably get more similar in respect to timber volume, intensity of volume increment, and stand structure to the forests of terminal phase of development. Tree density in these stands could remain for some time at the present level of about 600 trees/ha or fluctuate within a narrow range, with a dominant downward trend. A further increase in the number and volume of minor tree species would eventually result in changes in stand category, from pure to mixed stands. In 1997, the minor tree species amounted in these stands to about 20% of the total number of trees.

Indices of the intensity of changes in tree number, stand volume, tree recruitment and mortality allow the comparison of dynamic tendencies in main tree species. This study has indicated a substantial decline in Norway spruce, expressed in the downward trends in the share of this species in forest stands of almost all categories, expressed both in tree number and in timber volume. The dynamics of volume increment in spruce is much lower than in silver fir or in beech. An analysis of stand structure showed, that tree recruitment in spruce had been maintained at a very low level for a quite long time, because the share of spruce in trees with lower DBH values is much lower than in other species, and much lower than the share of spruce in higher DBH classes (Chwistek 2000). Also in the nearest future one could expect a further decrease in the share of spruce in most stand categories, because – compared to fir and beech – spruce has relatively few saplings (saplings are most important for the process of tree recruitment in the future). Another indicators of the low vitality of spruce are lower indices of the dynamics of volume increment than in fir or beech, as already mentioned.

A very prospective character of the population of silver fir in the Gorce mountains is indicated by the highest values of recruitment, the highest indices of recruitment intensity, and the highest values of volume increment. Along with low mortality rates this would result in an increase in the share of silver fir in tree stands in the Gorce National Park. It is very likely that this high dynamics of silver fir will be maintained in the near future. Contrary to Norway spruce in the montane zone, the silver fir population does not show any signs of slowing down in the reproduction process or low survivorship of seedlings and saplings.

This study indicates also, that significant qualitative and quantitative changes in the structure and species composition of forests stands (most of them statistically significant) can take place even in short time periods. On the one hand, this suggests that the dynamics of forest stands is relatively high in the Gorce National Park. On the other hand, it points to a need to repeat the census after a comparably short time. Short inetravals between censuses increase the chances of detecting changes in the intensity of analysed processes (tree mortality, tree recruitment, volume increment, forest regeneration) and enhance the probability of recording rare events, which could affect strongly the entire forest dynamics for a longer time. A good example of a sudden event which had completely altered the course of forest stands dynamics in some parts of the Gorce mountains was a hurricane on August 12, 1986. Detailed measurements conducted in the "Turbacz" reserve (Dziewolski and Rutkowski 1991) indicated, that during the period of 17 years (from 1969 to 1986) the average stand volume had actually increased in the study site, but just after the hurricane the stand volume turned out to be lower than in 1969. Without measurements done before the hurricane the net result of volume changes would be a negative one, which could have lead to misinterpretations of stand dynamics.

The process of decline in Norway spruce and dynamic increase in beech, found in this study, had been reported repeatedly for a few decades from the Gorce National Park (Dziewolski 1985; Dziewolski and Rutkowski 1991; Przybylska et al. 1995). Similar tendencies were also found in other areas in Poland (Dziewolski 1991; Sokołowski 1991; Kowalski 1994; Bernadzki et al. 1997). On the other hand, silver fir – in the light of earlier findings – was considered to be a declining species. A decline in silver fir was also suggested in the Gorce mountains (Dziewolski and Rutkowski 1991; Jaworski and Skrzyszewski 1995; Przybylska et al. 1995), and in other areas of Polish Carpathians (Dziewolski 1987; Jaworski, Pach and Szar 1995; Jaworski et al. 1995). A decrease in the vitality of silver fir and its widespread dieback were interpreted as symptoms of air pollution (Schütt 1981; Bernadzki 1983; Ząbecki 1984). With the levels of air pollution by sulphur dioxide, nitrogen oxides and heavy metals decreasing since the early 1980s (Environment Protection 1997) the vitality of silver fir has improved substantially. In most areas of its natural distribution in Poland, silver fir showed an increased radial increment and a general increase in vigor (Jaworski, Pach and Szar 1995; Jaworski et al. 1995). Among the essential mechanisms causing the growth depression in silver fir could have been a joint influence of air pollution and climatic factors. For example, the sums of effective temperatures decreased during the growing seasons in the 1960s and 1970s (Kowalski 1991), which could negatively influence the vitality and growth potential in silver fir.

The earlier studies indicating a decrease in the share of silver fir in tree stands in the Gorce Mountains covered relatively small areas (up to several hundreds of hectares). In addition, these areas were situated (like the "Turbacz" and "Łopuszna Valley" reserves) at relatively high elevations, above 900 m, where the density of silver fir is much lower than in lower montane zone (Chwistek et al. 1997). Thus it is difficult to say if the observed decline of silver fir was only a local phenomenon, or a large-scale one, encompassing the entire Park area. The results of the most recent investigations (Kwinta 2000) concerning the dynamics of silver fir in the tree stands of the Łopuszna valley during the period 1992–1997 are similar to the results of our work, concerning this species.

The ascertained changes in species composition of forest stands can be also looked at in a wider context of the global climate change (Brubaker 1986; Kowalski 1994; Kullman 1995). During the present period of global warming of climate (Obrębska-Starklowa et al. 1994), due to an increase in the length of the growing season and in the sums of effective temperatures, the meso- and eutrophic deciduous tree species have now much better conditions for growth, regeneration and consecutive expansion, which gives them a competitive advantage over less demanding tree species (Kowalski 1994). In his studies on the influence of climatic conditions upon the radial growth of trees Feliksik (1993) ascertained that periods of warm weather enhanced the radial increment in silver fir and beech but affected the growth of spruce.

Another important issue in studies on forest dynamics is the influence of browsing by large herbivores upon the natural regeneration of forest. According to the common opinion, large densities of deer and associated with that pressure upon the forest regeneration and younger trees could endanger the very existence of silver fir in these forests (Szukiel 1994; Jaworski and Skrzyszewski 1995; Miścicki and Żurek 1995). A census of damage to forest regeneration, conducted in 1993 (using the same set of sample plots as employed in this work) indicated that one out of four individuals of silver fir had been browsed in the past; in 15% of the firs the terminal shoot had been browsed, in 10% the bark on the stem had been gnawed (Miścicki and Żurek 1995). According to the authors these figures show that the actual level of browsing is several times higher than that accepted for managed forests and that the high deer numbers and their intense pressure upon natural regeneration in the last 60 years are "unnatural' factors endangering the further existence of the forest.

In spite of that, silver fir turned out to be a species, which during the period 1992–1997 dominated in terms of the intensity of recruitment and growth of tree numbers (Table 2, Fig. 7) over beech and Norway spruce, which are browsed by deer only occasionally. That lack of detectable effect of deer damage upon the dynamics of silver fir can be explained by the high numbers of fir regeneration, relatively low intensity of damage, and large regeneration ability of fir saplings (Jamrozy 1987). While conducting the censuses of damage to forest regeneration, one should take into account such factors as timber volume and tree density of the entire forest stand. It is essential to note that only single individuals among the seedlings and saplings present under the forest canopy would eventually succeed in reaching the mature tree level. Conducting joint censuses of tree stand characteristics and inventory of damage to natural regeneration, following the fate of individual trees (which could be identified by determining their coordinates within the sample plot) would allow to evaluate the effects of deer browsing upon the intensity of tree recruitment as well as upon the height and volume increment of trees.

CONCLUSIONS

In the Gorce National Park forests show a big variability in terms of species composition, stand volume, tree density and stand structure. The differences result from variability in habitat conditions and various forest management regimes in the past. The majority of forest stands is now in a stage of intense growth, which is indicated by a statistically significant increase in mean timber volume, high current volume increment, tree recruitment rates higher than mortality rates, and an increase in the number of sub-canopy tree regeneration.

The results indicate a substantial decline in Norway spruce, especially in the montane zone. Symptoms of that process are as follows:

- a decrease in the share of spruce (by number as well as by timber volume) in tree stands over the entire Park area;
- low values of indices of dynamics of tree number and timber volume, of tree recruitment and volume increment, along with the highest index of tree mortality among major tree species;
- a decrease in regeneration density and in the share of spruce among young generation of trees in the montane zone.

In the subalpine spruce forests no evidence of a decline in natural spruce regeneration was found; actually and the number of spruce seedlings increased twofold from 1992 to 1997.

Beech and silver fir are very dynamic species, as shown by:

- an increase in their share in forest stands,
- a rapid increase in tree numbers and in timber volume,
- high rates of volume increment and high recruitment rates, associated with low mortality,
- dominance among sub-canopy regeneration.

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