VEGETATION OF THE SELECTED FOREST STANDS IN THE POLISH CARPATHIAN MOUNTAINS – CHANGING IN TIME

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Abstract

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In the Carpathian Mountains within the framework of the two international cooperative projects carried out in the years 1996 and 1999 26 permanent study sites were established for description of forest vegetation in the vicinity of ambient ozone monitoring sites. Six of monitoring sites were located in southern part of Poland in forest ecosystems typical of each area. Five of them were located in national parks, and one in area of protected landscape. Phytosociological records were done in 1998 in each of the monitoring plots in 5 subplots (5x500 m^2) using the Braun-Blanquet's method. In 2005 in the frame of the international cooperative project „Biodiversity re-assessment and evaluation of trends in 26 forest sites in Carpathians" the phytosociological records in all forest permanent plots were repeated. The study sites located in Poland represented various types of forest: *Picea abies* (Norway spruce) stands (3), *Fagus sylvatica* (European beech) stands (1), *Abies alba* (white fir) stands (1) and mixed *Fagus sylvatica-Abies alba* (1). In three monitoring sites (Brenna, Babia Góra NP, Tatra NP) the cover of tree layer during the period from 1998 to 2005 changed essentially due to cutting and strong windfall. In the Babia Góra NP forest stand the number of plants decreased (from 42 to 28), in Tatra NP was similar (53-54), and in Brenna increased (from 38 to 55). In other three investigated sites (Pieniny NP, Magura NP, Bieszczady NP) only small changes in plant composition were noticed in 2005 in comparison to 1998.

Key words: species diversity, changes in time, national parks, Carpathian Mts, forest permanent plots

Introduction

Changes in numbers of species are natural for nature, but diminishing diversity of the biological resources during the 20th century is the most connected with human impact. Anthropogenic stressors are responsible in modification of habitats due to input of toxic chemicals to the air, water and soil (Barker et al., 1991; Szaro, Johnston, 1996). During the

past half-century, large areas of forests in Eastern and Central Europe have come under the adverse influence of air pollutants. This has seriously affected forest sustainability (Godzik, Sienkiewicz, 1990) while effects on biodiversity are still unknown. The effects of environmental change on biodiversity including the impact of air pollution have been recognized as a high priority for future research (Szaro, Johnston, 1996).

The Carpathian Mountains belong to the most beautiful natural areas in Europe. Forests of the Carpathians represent unique reservoirs of many endemic, rare and unusual plant and animal species. Numerous national parks and nature reserves have been established in the Carpathians two of them created bilateral (PL, SK) Biosphere Reserves (Babia Góra and Tatra National Parks of Western Carpathians) and trilateral (PL, UA, SK) Biosphere Reserve of Eastern Carpathians (Bieszczady National Park).

Forests in the Carpathian Mountains have been under human impacts for many centuries, however, most of those impacts have been quite local. In the last 40 50 years the long-range transport of pollutants from various European industrial areas has resulted in the high deposition of sulphur, nitrogen and heavy metals in the Carpathian forests (Grodzińska, Szarek-Łukaszewska, 1997). The industrial air pollutants have caused an extensive decline of the Carpathian forests (Godzik, Sienkiewicz, 1990; Grodzińska et al., 1995; Oszlányi, 1997). It is known that air pollutants cause changes in chemical composition of soil and tree foliage in the Carpathians (Maňkovská et al., 2002, 2004; Niemtur et al., 2002). The toxicity of sulphur and nitrogen oxides (SO_2 and NO_x, respectively) can be enhanced by the presence of ozone (O_3) (Guderian et al., 1989). Recently, the rapidly growing number of cars in Central and Eastern Europe resulted in an increase of NO_x and hydrocarbons emissions, which lead to higher rate of photochemical-smog formation. The long-range transport of ozone from Western Europe and O_3 generated locally are likely to result in elevating concentrations of this highly phytotoxic pollutant in Central and Eastern Europe, including the Carpathian Mountains (Bytnerowicz et al., 2002a, b; 2004; Godzik, Grodzińska, 2002, 2003; Godzik et al., 2004; Godzik, 2006; Fleischer et al., 2005, 2006). An increase in O_3 concentrations is possibly a major factor in continued mountain forest decline of the region, despite the recent reduction in SO_2 and heavy metal concentrations.

In the Carpathian Mountains in 1996 and 1997 were started two international projects („Evaluation of ozone air pollution and its phytotoxic potential in the Carpathian forests" and „Effects of forest health on biodiversity with emphasis on air pollution in the Carpathian Mountains"). Twenty-six permanent study plots were established in the vicinity of the ozone monitoring sites. The study sites were located on the NW-SE transect from the Czech Republic through Slovakia, Poland and Ukraine to Romania (Bytnerowicz et al., 2002a, b; 2004). Twelve (12) sites were located in the Western Carpathians, eleven (11) in the Eastern Carpathians and three (3) sites in the Southern Carpathians; most of them lie in national parks, biosphere reserves and areas of protected landscape. Six of the forest permanent plots were located in Polish Carpathians.

The aims of the first two joint projects were: (1) to determine the levels of O_3, SO_2, NO_2 air pollutants, and (2) to describe forest vegetation and health status of selected forest stands in the Carpathian Mountains. In 2005 in the frame of the next international cooperative project

„Biodiversity re-assessment and evaluation of trends in 26 forest sites in Carpathians" the phytosociological records in all forest permanent plots were repeated.

In this paper species composition, as well as ecological and dendrological characteristics of selected forest stands located in Polish Carpathians and changes in species composition in time (1998, 2005) are described.

General characteristics of the Polish Carpathian Mts

The Carpathian mountain range is administered by five countries. Of the total area of the Carpathians (158,000 km^2) 52.9% is shared by Romania, 18.8% by Slovakia, 14.8% by Ukraine, 10.8% by Poland, and 2.7% by the Czech Republic. Geographically, the Carpathians are divided into three sections: Western, Eastern, and Southern (Transylvanian Alps) (Warszyńska, 1995; Vološčuk, 1999). The length of the Carpathian Mountains arch is about 1400 km while its width varies from about 170 km in the central sections of the Eastern and Western Carpathians to less than 80 km in the central part of the Southern Carpathians and the eastern part of the Western Carpathians.

The Polish Carpathians cover the area 19 600 km^2. They consist mostly of the Western Carpathians (17100 km^2) and small part of the Eastern Carpathians (2500 km^2) (Warszyńska, 1995). Polish Carpathians are generally medium elevated, except for the Tatra Mts, where the highest peak in the Polish part reaches the altitude of 2499 m (Mt Rysy, High Tatra Mts). The highest part of the Carpathians belongs to Slovakia (Tatra Mts with highest peak – Gerlach – 2655 m).

The Polish Carpathians are diversified of climate, geology, soil, vegetation and anthropogenic pressure (Dynowska, Maciejewski, 1991; Warszyńska, 1995). Mean annual temperature varies from above 8 °C to -4 °C, whereas mean annual precipitation from 700 mm to 1500 mm. The duration of the snow cover oscillates between 65 to 230 days. The Polish part of the Carpathians are composed mainly of sandstone and shales (Carpathian flysh) (Beskidy Mts) with small areas occupied by granite (Tatra Mts) and limestone (Pieniny Mts) (Starkel, 1991). Most common in the Beskidy Mts and in the granite part of the Tatra Mts are Dystric Cambisols and Luvisols. In the limestone part of the Tatra Mts and in the Pieniny Mts Podsols and Rendzina soils are formed. All Carpathians soils have shallow or medium deep soil profile with great amount of skeleton.

In the Polish Carpathians in the forest stand prevail beech (25.3%), fir (25%), spruce (21.7%) and pine (17%) (Fabijanowski, Jaworski, 1995). In the western part of the Polish Carpathians spruce dominates (> 70%), while in the eastern part the beech (27–40%) and fir (20–31%). The vegetation of the Polish Carpathians is found in elevational zones. In the western part the submontane (foothills) belt (up to 600–650 m a.s.l.) is occupied by deciduous and mixed forest. Originally, mostly *Quercus robur-Carpinus betulus* (oak-hornbeam) forests and mixed *Quercus robur-Pinus sylvestris* (oak-pine) forests covered this belt. The lower forest montane belt extends between 650 and 1250 m a.s.l. It is occupied by *Fagus sylvatica* (European beech) forests and in some ranges by *Fagus sylvatica-Abies alba* (European beech-white fir), *Abies alba-Picea abies* (white fir-Norway spruce) or

mainly artificial *Picea abies* forests. The upper forest montane belt ranges from 1250 to 1550 m a.s.l. and is dominated by *Picea abies* forests. The subalpine, alpine and subnival belts occupy the highest elevations in the Carpathian Mountains from 1550 to 2655 m a. s.l. (Mirek, Piękoś-Mirkowa, 1992).

Study area, material and method

Six permanent vegetation study sites were established in the vicinity of the ozone monitoring sites in the Polish Carpathian Mountains (Fig. 1). Five of the forest plots were located in the Western Carpathians (Brenna, Babia Góra NP, Tatra NP, Pieniny NP, Magura NP), and one in the Eastern Carpathians (Bieszczady NP). Five of them were located in national parks, and one in area of protected landscape (Brenna).

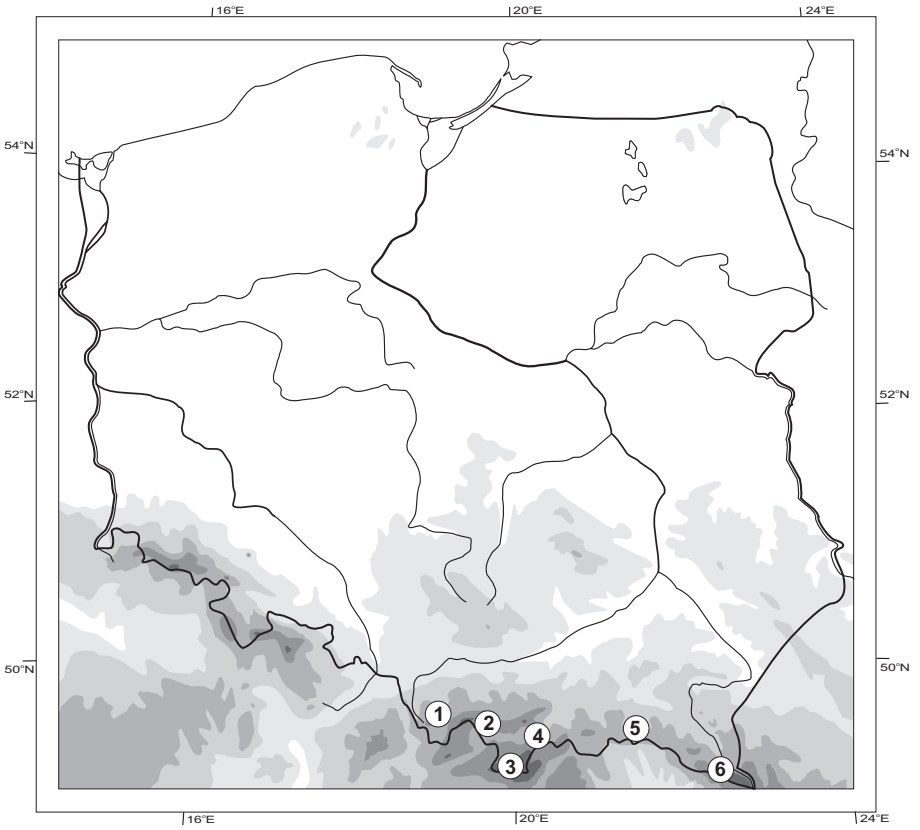

Fig. 1. Localization of forest monitoring sites in Poland. Legend: 1. Brenna, 2. Babia Góra National Park, 3. Tatra National Park, 4. Pieniny National Park, 5. Magura National Park, 6. Bieszczady National Park.

T a b l e 1. Characteristics of forest permanent plots in the Polish part of the Carpathian Mts.

Locality	Latitude	Longitude	Altitude (m a.s.l.)	Exposure	Inclination (°)
1. Brenna	49°40'07''	18°56'37''	600	W	15
2. Babia Góra NP	49°35'17''	19°35'00''	1100	NW	25
3 Tatry NP	49°17'07''	20°07'00''	1080	E	10–5
4. Pieniny NP	49°25'37''	20°21'32''	640	S	15–30
5. Magura NP	49°32'00''	21°30'00''	520	SW	3–10
6. Bieszczady NP	49°06'38''	22°35'40''	880	N	5–20

The study sites were situated at elevations ranging from 520 to 1100 m a.s.l. (Table 1). The study sites located in Poland represented various types of forest: *Picea abies* (Norway spruce) stands (3), *Fagus sylvatica* (European beech) stands (1), *Abies alba* (white fir) stands (1) and mixed *Fagus sylvatica-Abies alba* (1) (Tables 2, 3). The study sites differed in exposure, inclination of slopes and bedrock type. Each permanent study site was 0.7 ha in size. According to the criteria established by the European Intensive Monitoring Network for forest ecosystems, each site consisted of five 500 m^2 circular plots (C – centre, N – north, E – east, S – south, W – west subplot) (Fig. 2). In each plot all trees (> 7 cm in dbh) were marked permanently (number on a trunk) and their height and diameter at a breast height (DBH) were measured. In 1998 phytosociological records were done in each plot twice over the growing season (spring, summer) and ones in 2005 (summer), using the Braun-Blanquet's method (Szafer, Zarzycki, 1972). For the comparison of changes between 1998 and 2005 were used only phytosociological records done in summer. The phytosociological material comprised 60 records (5 records of each of the six permanent plots in 1998 and in 2005). In the tables each permanent plot (total area of 2500 m^2) is represented by 1 phytosociological record (Tables 2 and 3). Cover of each species in 5 small plots (area of 500 m^2) was determined using a six-grade scale (for explanation please see Table 2) (Szafer, Zarzycki, 1972). Species were listed according to their frequency of occurrence in the phytosociological material. Constancy of species was determined using a five-grade scale (for explanation please see Table 3) (Szafer, Zarzycki, 1972).

The nomenclature of vascular plant species follows Mirek et al. (1995, 2002) and the moss species Ochyra, Szmajda (1978), Ochyra et al. (2003).

To estimate tree age, cores were obtained with a 50-cm Suunto (Vantaa, Finland) tree borer. For each tree DBH and tree height were measured; the latter by trigonometric estimates with a Vertex III hypsometer (Haglof, Sweden). The volume of trees was estimated according to the volume tables referring indexed DBH and height (Czuraj, 1991). These tables contain data most valuable for Polish conditions.

Results

Species composition

List of plant composition occurred in forest permanent plots in the Polish Carpathians in 1998 was shown in Table 2, and in 2005 in Table 3.

Norway spruce (*Picea abies*) and common beech (*Fagus sylvatica*) are main tree species in the studied sites, while fir (*Abies alba*) is less frequently occurring. Forest stands are represented by pure spruce, pure beech and by mixed (fir-beech) stands. In 1998 the number of vascular plants registered in all records was 128 and number of bryophytes was 58. Pieniny NP forest stand was the richest in the species (88 vascular species and 25

T a b l e 2. Phytosociological data for selected forest permanent plots in Polish Carpathians (1998).

Site		Brenna	Babia Góra NP	Tatra NP	Pieniny NP	Magura NP	Bieszczady NP	
table no. of plot		1	2	3	4	5	6	
date		6.08	6.08	4.08	7.08	11.08	11.08	
altitude a.s.l. (m)		600	1100	1080	640	520	880	
exposition (Aspect)		W	NW	E	S	SW	N	
slope (o)		15	25	10	30	3–10	5–20	
cover of tree layer (A) %		30–60	10–40	40–70	70–90	70–90	50–95	
cover of shrub layer (B) %		80–90	30–50	5–50	25–40	10–20	10–20	
cover of herb layer (C)%		60–95	80–90	90	95–100	70–90	50–80	
cover of mosses (D)%		10–15	60–70	60–70	30–40	<3	<3	
area (m^2)		500	500	500	500	500	500	Constancy
Trees (A)								
Picea abies	A	4	3-4	4	+			III
	B	5		+-3				II
	C	+-4	+-2	+-2	+			III
Abies alba	A			+	4	3-4		II
	B	+		+		+		II
	C	+	+	+-2	+-1	+-1		III
Fagus sylvatica	A					2-4	3	I
	B	+-1	+	+		+	+-2	IV
	C	+				+	+-1	II
Acer pseudoplatanus	A						+-2	I
	B			+	+			I
	C				+	+	+	II
Sorbus aucuparia	B	+	3	+	+			II
	C	+	+-1	+	+	+		III
Shrubs (B)								
Corylus avellana	B				+-1	+		II
	C				+	+		I
Sambucus nigra	B			+	+-2		+	I
	C			+	+	+	+	II
Fraxinus excelsior	B				+			I
Lonicera xylosteum	B				2			I
Sambucus racemosa	B				+			I
Ribes uva-crispa	B				+			I
	C				+			I
Lonicera nigra	B				+			I
Larix decidua	B			+				I
Tilia cordata	B				+			I
Viburnum opulus	B				+			I
	C				+			I
Crataegus sp.	B					+		I
Herbs (C)								
Oxalis acetosella	C	+	+-1	2	3-4	1-2	+-2	V
Dryopteris dilatata	C	1-2	2-3	2-3	+-1	+-3	+-1	V
Maianthemum bifolium	C	+	+-2	1-2	+	+-1		IV
Athyrium filix-femina	C	+		+-2	1-2	+-2	+-2	IV
Vaccinium myrtillus	C	2-4	4-5	3-4		+	+	III
Rubus idaeus	C	+	+-2	1-2	1-4			III
Gymnocarpium dryopteris	C	+	+-1	+-1	+	+	+	III
Calamagrostis arundinacea	C	2-4	+	+-3	+	+		III
Dryopteris filix-mas	C	+			2	+-2	+-2	III
Rubus hirtus	C	+				3-4	2-3	III
Deschampsia flexuosa	C	+	+-1	+-2				III
Galeobdolon luteum	C	+		+	2-3	+	1-2	III
Senecio fuchsii	C				+-3	+-3	+	III

T a b l e 2. (Continued)

Polygonatum verticillatum	C		+	+-1	+		+	II
Homogyne alpina	C		1-3	1-3				II
Impatiens noli tangere	C				2-3	+-1	+	II
Galium odoratum	C				+-2		+-3	II
Prenanthes purpurea	C		+	+-1			+-1	II
Dentaria glandulosa	C				+-2	+	+-3	II
Stellaria nemorum	C		+		+	+	+-1	II
Luzula sylvatica	C		+-1	+				II
Mercurialis perennis	C				+-2		+-1	II
Dryopteris carthusiana	C	+-1	+	+	+	+		II
Anemone nemorosa	C	4	3-4	4	+			II
Bryophytes (D)								
Dicranum scoparium	D	+	+	+			+	III
Dicranum montanum	D	+	+	+	+	+	+	III
Polytrichastrum formosum	D	+-2	4	+		+	+	III
Tetraphis pellucida	D	+	+	+	+	+		III
Herzogiella seligieri	D	+			+	+	+	II
Hypnum cupressiforme	D	+			+	+	+	II
Pholia nutans	D	+				+	+	II
Plagiothecium curvifolium	D	+	+	+		+	+	II
Plagiothecium laetum	D	+	+	+	+	+	+	II
Rhizomnium punctatum	D				+	+	+	II
number of vascular plant species		23	26	38	88	38	57	
incl. sporadic species								
number of bryophytes		15	16	15	25	18	26	
incl. sporadic species								
Total number of species		38	42	53	113	56	83	

Sporadic species – Herbs: *Actaea spicata* 4: +-1, 6: +; *Adoxa moschatellina* 6: +; *Aegopodium podagraria* 4: +-2; *Ajuga reptans* 4: +, 6: +; *Alliaria officinalis* 4: +; *Asarum europeum* 4: +-1; *Asplenium trichomanes* 4: +; *Athyrium alpestre* 2: +; *Athyrium filix-mas* 2:+-2; *Blechnum spicant* 1: +, 2: +; *Brachypodium sylvaticum* 4: +-1; *Caltha palustris* 4: +, 6: +; *Campanula trachelium* 4: +; *Cardamine amara* 4:+, 6:+; *Cardamine impatiens* 4:+; *Cardamine pratensis* 6:+; *Carex alba* 4:+; *Carex digitata* 4:+, 5: +-1; *Carex pilulifera* 1:+; *Carex remota* 6:+; *Carex sylvatica* 4:+, 6:+; *Carpinus betulus* 6:+; *Chaerophyllum hirsutum* 4: +-1, 6:+; *Chelidonium majus* 4:+; *Chrysosplenium alternifolium* 4:+, 6:+; *Circaea alpina* 4: +-1, 6: 1; *Circaea lutetiana* 4:+, 6: +-1; *Dentaria bulbifera* 4:+, 6: +-1; *Digitalis grandiflora* 4:+; *Epilobium montanum* 4:+; *Epipactis helleborine* 2:+, 3:+; *Equisetum arvense* 4:+, 5:+; *Euphorbia amygdaloides* 4:+, 6:+; *Festuca gigantea* 4:+; *Festuca silvatica* 5:+; *Fragaria vesca* 4:+; *Galeopsis tetrahit* 5:+, 6:+; *Galium rotundifolium* 1: +-1, 3:+; *Galium schultesii* 4:+, 6:+; *Gentiana asclepiadea* 2:+, 3: +-1; *Geranium robertianum* 4:+; *Glechoma hirsuta* 4:+, 5:+, 6:+; *Hieracium murorum* 3:+, 4:+; *Huperzia selago* 2:+, 3:+, 6:+; *Hypericum hirsutum* 4:+; *Hypericum perforatum* 3:+; *Isopurum thalictroides* 6:+; *Lamium sp.* 4:+; *Lapsana communis* 4:+; *Lathyrus vernus* 4:+; *Leontodon hispidus subsp. hastilis* 1:+; *Luzula luzuloides* 6:+; *Luzula nemorosa* 3: 1-2; *Luzula pilosa* 3:+, 4:+, 5:+; *Lycopodium annotinum* 2:+, 3:+; *Lysimachia nemorum* 5:+, 6: +-1; *Melandrium rubrum* 4:+; *Melica nutans* 4: +-1; *Milium effusum* 4:+, 5:+; *Moehringia trinervia* 4:+; *Mycellis muralis* 4: +-1; *Myosotis palustris* 6:+; *Myosotis sylvatica* 4:+; *Paris quadrifolia* 4:+, 5:+, 6:+; *Petasites albus* 3:+, 4:+, 6:+; *Phegopteris connectilis* 1:+, 3:+; *Phyteuma spicatum* 3:+, 4:+, 6:+; *Poa nemoralis* 4:+, 5:+; *Polygonatum multiflorum* 4:+; *Polystichum aculeatum* 6:+; *Primula elatior* 6:+; *Pteridium aquilinum* 5: +-3; *Ranunculus lanuginosus* 4:+, 6:+; *Ranunculus repens* 6:+; *Ribes alpinum* 4:+; *Salvia glutinosa* 4: 1-2; *Sanicula europaea* 4:+, 6:+; *Senecio nemorensis* 6:+; *Soldanella carpatica* 3: 1-2; *Solidago virgaurea* 3:+, 6:+; *Stachys sylvatica* 4: +-1; *Stellaria media* 6:+; *Streptopus amplexifolius* 2:+, 5:+; *Symphytum cordatum* 5:+, 6: +-1; *Urtica dioica* 1:+, 4:+, 6:+; *Valeriana tripteris* 4:+; *Veronica montana* 3:+, 5:+, 6:+; *Viola reichenbachiana* 4:+.

Bryophytes: *Amblystegium serpens* 6:+; *Anomodon attenuatus* 4:+, 6:+; *Atrichum undulatum* 4:+, 5:+; *Blepharostoma trichophyllum* 2:+, 3:+; *Brachythecium populeum* 6:+; *Brachythecium reflexum* 6:+; *Brachythecium rutabulum* 4:+, 5:+, 6:+; *Brachythecium salebrosum* 1:+, 4:+, 6:+; *Brachythecium starkei* 3:+; *Brachythecium velutinum* 4:+, 5:+; *Bryum capillare* 4:+; *Bryum flaccidum* 6:+; *Calypogeia azurea* 2:+; *Calypogeia integristipula* 1:+; *Cephalozia bicuspidata* 2:+; *Ceratodon purpureus* 1:+; *Cirriphyllum piliferum* 4:+; *Cirriphyllum tommasinum* 4:+; *Ctenidium molluscum* 4:+; *Dicranella heteromalla* 1:+, 5:+; *Dicranodontium denudatum* 6:+; *Dicranum tauricum* 1:+; *Eurhynchium angustirete* 1:+, 4:+; *Isothecium alopecuroides* 4:+, 6:+; *Lepidozia reptans* 3:+, 5:+; *Lophocolea heterophylla* 2:+, 3:+, 5:+; *Metzegeria furcata* 6:+; *Mnium hornum* 5:+; *Oxystegus tenuirostris* 6:+; *Paraleucobryum longifolium* 6:+; *Plagiochila asplenioides* 4:+; *Plagiomnium affine* 3:+, 4:+; *Plagiomnium cuspidatum* 6:+; *Plagiomnium denticulatum* 4:+; *Plagiomnium rostratum* 3:+, 4:+, 5:+; *Plagiomnium undulatum* 2:+, 4:+; *Plagiothecium denticulatum* 5:+, 6:+; *Plagiothecium nemorale* 4:+, 6:+; *Plagiothecium undulatum* 2:+; *Pleurozium schreberi* 3:+; *Porella platyphylla* 6:+; *Pseudotaxiphyllum visgrili* 4:+; *Ptilidium ciliare* 2:+; *Rhytidiadelphus loreus* 2:+, 3:+; *Sanionia uncinata* 2:+, 6:+; *Sphagnum girgensonii* 2:+; *Tortella tortuosa* 4:+; *Tritomaria quinquedentata* 3:+.

Scale of coverage: 5 – 75–100%; 4 – 50–75%; 3 – 25–50%; 2 < 25%; 1 – abundant but coverage low; + – few numerous. Scale of constancy: V – present in 80–100 % of records; IV – 60–80 %; III – 40–60%; II – 20–40 %; I – sporadic species < 20%.

T a b l e 3. Phytosociological data for selected forest permanent plots in Polish Carpathians (2005).

Name of the site		Brenna	Babia Góra NP	Tatra NP	Pieniny NP	Magura NP	Bieszczady NP	
table no. of plot		1	2	3	4	5	6	
date		29.07	29.07	13.07	13.07	3.08	3.08	
altitude a.s.l. (m)		600	1100	1080	640	520	880	
exposition (Aspect)		W	NW	E	S	SW	N	
slope (o)		15	25	10	30	3–10	5–20	
cover of tree layer (A) %		30–60	10–40	40–70	70–90	70–90	50–95	
cover of shrub layer (B) %		80–90	30–50	5–50	25–40	10–20	10–20	
cover of herb layer (C)%		60–95	80–90	90	95–100	70–90	50–80	
cover of mosses (D)%		10–15	60–70	60–70	30–40	< 3	< 3	
Area (m^2)		500	500	500	500	500	500	Constancy
Trees (A)								
Picea abies	A	2-4	1-3	3-4	+			III
	B	5		+-3				II
	C	+-1	+	1-2	+			III
Abies alba	A			+	4	3-4		II
	B	+		+				II
	C	+		+	+	+-1		III
Fagus sylvatica	A					3-5		I
	B	+	+	+		+	+-1	IV
	C	+	+			+	+	II
Acer pseudoplatanus	A					+		I
	B			+	+			I
	C				+	+	+	III
Sorbus aucuparia	A							
	B		3	+	+			II
	C	+	+-1	+	+	+	+	IV
Shrubs (B)								
Corylus avellana	B				+-1	+		II
	C				+	+		II
Sambucus nigra	B				1-2			I
	C			+				I
Sambucus racemosa	B				+			I
	C					+	+	I
Lonicera xylosteum	B				2			I
	C				+-2			I
Fraxinus excelsior	B				+			I
	C					+		I
Ribes uva-crispa	B				+			I
	C				+			I
Lonicera nigra	B				+			I
Cornus sanquinea	B				+			I
Tilia platyphyllos	B				+			I
Crategus sp.	B					+		I
Herbs (C)								
Oxalis acetosella		+	+	2	3	1-2	2	V
Dryopteris dilatata		2	2-3	1-2	+-1	2-4	+	V
Athyrium filix-femina		+	+	+-2	1-2	+-2	+-2	V
Maianthemum bifolium		+	+	+-2	+	+		IV
Dryopteris carthusiana		+	+	+	+	+	+	IV
Vaccinium myrtillus		2-4	5	3-4		+	+	III
Rubus hirtus		+	+	+		4	2-3	III
Rubus idaeus		+	1-2	1-2	2-4			III
Calamagrostis arundinacea		2-4	+	1-3	+	+-1		III
Dryopteris filix-mas		+			+-2	+	+-2	III
Polygonatum verticillatum				+-1	+		+	III

T a b l e 3. (Continued)

Deschampsia flexuosa		+	+-1	1-2				II
Impatiens parviflora					3	1	+	II
Senecio nemorensis					+	+	+	II
Gymnocarpium dryopteris		+	+-1	1	+		+	II
Senecio ovatus					1-3	1-2	+	II
Carex sylvatica					+	+-1	+	II
Carex digitata		+			+	+		II
Homogyne alpina			1-3	2-3				II
Prenanthes purpurea				+-1			+	II
Galium odoratum					1-2		+-3	II
Mercurialis perennis					+-2		+	II
Ajuga reptans					+	+	+	II
Dentaria glandulosa					+		+-1	II
Urtica dioica		+			+		+	II
Luzula pilosa		+		+	+	+		II
Galeobdolon luteum ssp. montanum		+			+	+	1	II
Actaea spicata					+		+	II
Sanicula europaea					+		+	II
Anemone nemorosa					+	+	+	II
Lysimachia nemorum						+	+-1	II
Galeobdolon luteum					2-3		1-2	II
Glechoma hirsuta					+-1		+	II
Euphorbia amygdaloides					+		+	II
Stellaria nemorum					+		+	II
Dentaria bulbifera					+		+-1	II
Epilobium montanum		+			+			II
Brachypodium sylvaticum					+-1	+		II
Circaea lutetiana					+-1		+-1	II
Viola reichenbachiana					+			II
Chrysosplenium alternifolium					+		+	II
Bryophytes (D)								
Polytrichastrum formosum		2	4	2-4	1	+		III
Dicranum scoparium		+	+-2	2	1			II
Tetraphis pellucida		+	+	+	+	+		II
Hypnum cupressiforme		+		+	1	+	+	II
Herzogiella seligieri		+	+		+	+	+	II
Plagiothecium curvifolium		+	+	+	+	+		II
Plagiomnium affine				+	+-1	+		II
Rhizomnium punctatum				+	+	+	+	II
Eurhynchium angustirete				+	+			II
Plagiothecium denticulatum		+	+	+			+	II
Buckiella undulata			+-2	+				II
Atrichum undulatum		+			+	+		II
Plagiothecium laetum			+			+	+	II
number of vascular plant species incl. sporadic species		41	19	35	94	45	51	
number of bryophytes incl. sporadic species		14	9	19	21	13	18	
total number of species		55	28	54	115	58	69	

Sporadic species – Herbs: *Aegopodium podagraria 4:+-1; Agrostis gigantea 1:+; Agrostis stolonifera 5:+; Angelica sylvestris 4:+; Anthoxanthum odoratum 1:+; Asarum europaeum 4:+; Asplenium trichomanes 4:+; Athyrium distentifolium 2:+-1; Betula pendula 1:+, 5:+; Bromus benekenii 4:+; Caltha laeta 4:+, 6:+; Caltha palustris 6:+; Campanula trachelium 4:+; Cardamine amara 4:+, 6; Cardamine hirsuta 1:+; Cardamine impatiens 4:+; Cardamine trifolia 4:+; Carex alba 4:+; Carex remota 4:+, 5:+, 6:+; Carex sp. 3:+; Chaerophyllum aromaticum 4:+; Chaerophyllum hirsutum 6:+; Chamaenerion angustifolium 1:+, 3:+-1; Circaea alpina 1:+, 4:+, 6:+; Cirsium arvense 1:+; Crepis paludosa 4:+; Cruciata glabra 4:+; Dactylis glomerata 1:+, 5:+; Digitalis purpurea 1:+; Equisetum arvense 4:+, 5:+; Festuca drymeia 5:+-1, 6:+; Festuca gigantea 4:+; Fragaria vesca 4:+; Galeopsis speciosa 5:+, 6:+; Galium rotundifolium 1:+-1; Galium saxatile 3:+; Galium schultesii 4:+; Gentiana asclepiadea 2:+, 3:+-1; Geranium robertianum 4:+-1; Geum urbanum 4:+; Hieracium murorum 3:+; Huperzia selago 2:+, 3:+, 6:+; Hypericum hirsutum 4:+; Hypericum maculatum 1:+, 3:+, 5:+; Impatiens noli-tangere 6:+; Lapsana communis 4:+; Lathyrus vernus 4:+; Leontodon hispidus subsp.hastilis 1:+; Luzula luzulina 1:+, 3:1-2; Luzula luzuloides 3:+; Luzula sylvatica 2:+-1, 3:+; Melandrium rubrum 4:+; Melica nutans 4:+; Milium effusum 3:+, 4:+; Monotropa hypopitys 5:+; Mycelis muralis*

4:+, 5:+; Myosotis palustris 4:+, 5:+; Myosotis sylvatica 4:+; Neottia nidus-avis 4:+; Padus avium 4:+; Padus serotina 4:+; Paris quadrifolia 4:+, 5:+; Petasites albus 4:+, 5:+, 6:+; Phleum commutatum 1:+; Polygonatum multiflorum 4:+; Potentilla recta 1:+; Primula elatior 4:+; Pteridium aquilinum 5:1-3; Ranunculus lanuginosus 4:+; Ranunculus repens 5:+, 6:+; Ribes alpinum 4:+; Rosa sp. 4:+; Rubus sp. 1:+; Salix silesiaca 1:+; Salvia glutinosa 4:1-2, 6:+; Soldanella carpatica 2:+; Solidago virgaurea 3:+, 6:+; Stachys sylvatica 4:+-1; Symphytum cordatum 6:+; Taraxacum officinale 1:+; Tussilago farfara 1:+; Veratrum lobelianum 3:+; Veronica montana 6:+; Veronica officinalis 1:+, 4:+, 5:+; Viburnum opulus 4:+; Vincetoxicum hirundinaria 4:+.

Bryophytes: Anomodon attenuatus 4:+, 6:+; Brachythecium rutabulum 4:+, 6:+; Brachythecium salebrosum 1:+, 6:+; Cirriphyllum piliferum 1:+; Ctenidium molluscum 4:+, 6:+; Dicranella heteromalla 1:+, 5:+; Dicranodontium denudatum 3:+; Fissidens taxifolius 4:+; Hylocomium splendens 3:+; Isothecium alopecuroides 4:+, 5:+, 6:+; Mnium spinulosum 3:+, 4:+; Paraleucobryum longifolium 6:+; Plagiomnium cuspidatum 6:+; Plagiomnium undulatum 4:+-1; Plagiothecium nemorale 1:+, 4:+, 5:+, 6:+; Plagiothecium ruthei 6:+; Plagiothecium succulentum 1:+; 6:+; Pleurozium schreberi 1:+, 3:+; Polytrichastrum longisetum 1:+; Pterigynandrum filiforme 6:+; Rhytidiadelphus squarrosus 2:+, 3:+; Sanionia uncinata 1:+, 3:+, 6:+; Sciuro-hypnum populeum 5:+; Sciuro-hypnum reflexum 3:+, 6:+; Sphagnum girgensonii 3:+; Thuidium tamariscinum 3:+; Tortella tortuosa 4:+.

Scale of coverage: 5 – 7
5–100%; 4 – 50–75%; 3 – 25–50%; 2 < 25%; 1 – abundant but coverage low; + - few numerous. Scale of constancy: V – present in 80–100 % of records; IV – 60–80 %; III – 40–60%; II – 20–40 %; I – sporadic species < 20%.

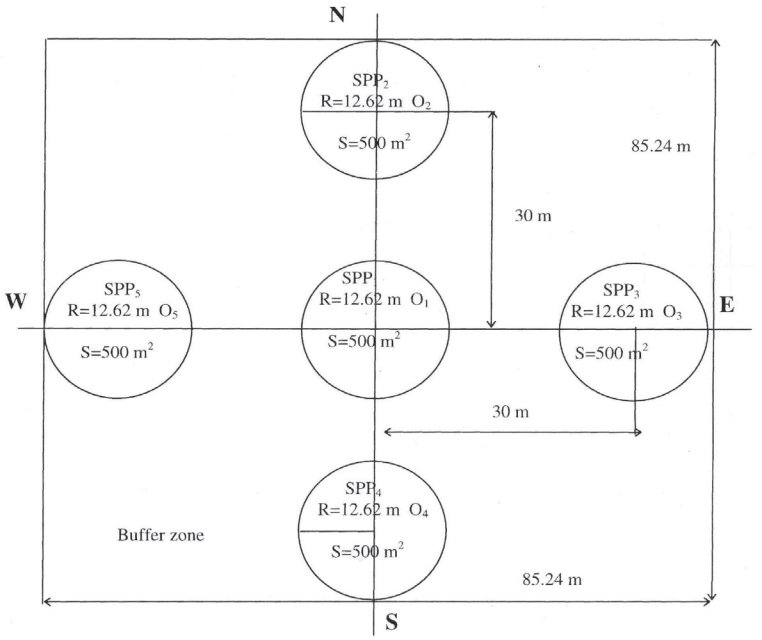

Fig. 2. Schematic of an intensive permanent observation plot with 5 subplots.

bryophytes) ranged from 51 to 78 plants in individual records (Tables 2 and 4). In 1998 the lowest number of plants was recorded from Brenna nad Babia Góra NP stands (38 and 42 species, accordingly) (Tables 2 and 4). The number of vascular plant species registered in all records in 2005 was 142, ranging from 11 to 74 species in individual records, the number

Table 4. Number of species in particular phytosociological records (500 m^2) in forest permanent plots located in Polish Carpathians – comparison between 1998 and 2005 (in brackets).

Forest stand		C*	N	E	S	W
Brenna	vascular plants	18(24)	18(31)	15(13)	15(14)	18(24)
	mosses	7(5)	6(3)	6(5)	5(6)	9(5)
Babia Góra NP	vascular plants	15(14)	17(14)	18(14)	13(11)	17(14)
	mosses	7(6)	7(4)	7(5)	8(4)	8(5)
Tatra NP	vascular plants	29(24)	26(26)	24(23)	20(20)	20(21)
	mosses	7(10)	9(9)	7(5)	7(5)	10(14)
Pieniny NP	vascular plants	64(70)	66(74)	57(62)	47(63)	43(57)
	mosses	7(5)	12(8)	13(11)	4(6)	8(10)
Magura NP	vascular plants	23(19)	18(28)	24(30)	27(29)	20(18)
	mosses	11(5)	7(5)	7(6)	5(6)	4(7)
Bieszczady NP	vascular plants	30(27)	40(33)	25(23)	27(38)	40(39)
	mosses	10(7)	17(6)	10(6)	10(8)	12(9)

Notes: C* – centre, N – north, E – East, S – south, W – west subplot

of bryophytes is 40 ranging from 3 to 14 in individual records (Tables 3 and 4). The forest stand in Pieniny NP is the richest in the species (94 vascular species, 21 bryophytes), while the number of species in Babia Góra NP forest stand is the lowest (19 vascular species, 9 bryophytes) (Table 3).

Three stands (Brenna, Babia Góra NP, Tatra NP) represent coniferous forest, and another three stands (Pieniny NP, Magura NP, Bieszczady NP) deciduous and mixed forests (Tables 2, 3, and 5). In the first group of forest stands spruce (*Picea abies*) is the dominant species in tree and shrub layers. In shrub layer occur also fir (*Abies alba*), beech (*Fagus sylvatica*) and rowan (*Sorbus aucuparia*). Typical for these forests are species of nutrient-poorer habitats – *Vaccinium myrtillus, Homogyne alpina, Deschampsia flexuosa, Calamagrostis arundinacea, Polytrichastrum formosum, Dicranum scoparium, Plagiothecium curvifolium, Buckiella undulata*. In the Tatra NP forest only, appear *Soldanella carpatica*, *Galium saxatile* and *Luzula luzulina*; *Galium rotundifolium* occur only in Brenna forest stands and *Luzula sylvatica* and *Athyrium distentifolium* in Babia Góra NP (Table 2, 3). The coniferous stands are not rich in the species. The number of vascular plants reaches in 54 and 58 species, while the number of mosses 31 and 26 species (in 1998 and 2005, accordingly) (Table 5). Fifty and 48 species (in 1998 and 2005, accordingly) are sporadic, and only 14-15 accordingly to years are frequent components (Table 5). Coniferous forest stands represent *Plagiothecio-Piceetum* (Szaf. et al. 1923) J. Mat. 1977 association (Matuszkiewicz, 2002), which is included in *Vaccinio-Piceetea* class.

In the second group of forest stands beech (*Fagus sylvatica*) or fir (*Abies alba*) are the dominant species. Cover of tree layer is high (70–90%), shrub layer is rich in the species, especially in the site on the calcium carbonate substratum (Pieniny NP). Cover of herb layer fluctuates between 60 and 100%, moss layer is rich in the species, but their coverage is low

Table 5. Constancy* of species in two groups of forest stands in the Polish Carpathian Mountains – comparison between 1998 and 2005 (in brackets).

Forest stands	Scale of constancy					Total
	V	IV	III	II	I	
coniferous forest stands (Brenna, Babia Góra NP, Tatra NP) vascular plants mosses	7(4) 1(1)	5(8) 2(1)	6(2) 2(2)	9(13) 3(5)	27(31) 23(17)	54(58) 31(26)
deciduous and mixed forest stands (Pieniny NP, Magura NP, Bieszczady NP) vascular plants mosses	3(4) -(-)	9(17) -(-)	9(17) 3(3)	38(35) 7(10)	64(43) 35(19)	123(116) 45(32)

Notes: * scale of constancy: V – present in 81–100% of records; IV – 61–80%; III – 41–60%; II – 21–40%; I < 20%

(excl. Pieniny NP). Most of the recorded species represent plants of mesotrophic habitats, typical for deciduous forests (e.g. *Galeobdolon luteum, Dentaria glandulosa, D. bulbifera, Galium odoratum, Carex sylvatica, Mercurialis perennis, Rubus hirtus, Luzula pilosa, Glechoma hirsuta, Herzogiella seligeri, Rhizomnium punctatum* (Table 3). Deciduous and mixed forest stands are rich in species. In 2005 the number of vascular plants is 116 species, the number of bryophytes is 32 species (in 1998 123 and 45 species, accordingly). Sixty two (99 in 1998) species are sporadic, 21 (12 in 1998) species are frequent component (Table 5). Deciduous and mixed forest stands represent *Dentario glandulosae-Fagetum* (Klika 1927 em. W. Mat. 1964) (Matuszkiewicz, 2002).

Different geographical elements are represented among the plants growing on the study plots (coniferous, deciduous and mixed forests). *Dentaria glandulosa* and *Symphytum cordatum* represent the Western Carpathian sub-endemics, *Soldanella carpatica*, *Galium rotundifolium* and *Luzula luzulina* represent a Western Carpathian element. The invasion of foreign species to Polish flora – *Impatiens parviflora* has been observed in fir-beech and beech forest stands (Pieniny NP, Bieszczady NP, Magura NP).

Ecological and dendrological characteristics of forest stands

Three spruce stands developed on either a calcium carbonate deficient Flysch substratum (Brenna, Babia Góra NP) or on a crystalline granite substratum (Tatra NP). Three deciduous and mixed forest stands occurred on a limestone substratum (Pieniny NP) or on calcium-rich Flysch substratum (Magura NP, Bieszczady NP). The investigated stands were represented by 88 to 120 year old individuals of trees, varying in height from 26 to 37.5 m and in diameter (DBH) from 30 to 45 cm (Table 6). The tree volume of stands varied from 68 to 209 m^3 in particular stands (Table 6). Brenna and Pieniny NP stands were included in quality

class I; Tatra NP, Magura NP, and Bieszczady NP stands to class II; and Babia Góra NP stand to class III (Table 6).

Comparison of forest stands – years 1998 and 2005

The forest stand in Babia Góra NP was destroyed by strong windfall. The number of trees on investigated plots distinctly decreased (126 trees in 1998, 64 in 2005) (Table 6), the cover of tree layer changed (50–70% in 1998, 10–40% in 2005) (Table 2, 3). The number of vascular plants and bryophytes decreased also (42 species in 1998, 28 in 2005) (Table 2, 3). Forest stand in Tatra NP underwent insignificant changes due to windfall. The number of species and the floristical composition of the stand are still very similar in 2005 to 1998 (Table 2, 3). In Brenna stand the oldest trees (> 115 years) were cut. The number of trees in plots decreased (69 trees in 1998, 41 trees in 2005) (Table 6). The cover of tree layer distinctly decreased (70% in 1998, 10–40% in 2005). The number of species in herb layer in Brenna stand increased (38 species in 1998, 55 species in 2005) (Table 2, 3). Ruderal plants, and grasses occur due to changes in light conditions. Only small changes in the forest stands in Pieniny NP, Magura NP, and Bieszczady NP were noticed in 2005 in comparison to 1998 (Table 2, 3).

Discussion

Geographical, ecological, floristical, and dendrological characteristics of the Carpathian forests, as described in the present paper on the basis of data from 6 permanent plots distributed along the Polish part of the Carpathian Mountains, are consistent with data given for these mountains by other authors (among others, Jaworski, Karczmarski 1991; Jaworski et al., 1991; Szwagrzyk et al., 1995; Fabijanowski, Jaworski, 1995).

According to Badea et al. (2002) the most damaged forests (data obtained in 1998) occur in the Western Carpathians, while the least in the Southern Carpathians. Many factors can be responsible for damage to the Carpathian forests. The most important factor is undoubtedly human activity, both direct (type of forest management) and indirect (industrial development accompanied by gaseous and dust emissions). The Carpathian forests for some decades have been under the influence of air pollutants transported by westerly winds from urban-industrial centers in Austria, Germany, Czech Republic, Poland, Slovakia, and Hungary (Bytnerowicz et al. 2002b). During the last ten to twenty years the emissions of SO_2 and NO_2 have been much reduced in entire Europe. Concentrations of these gases in the Carpathians are presently below the toxic level for vegetation (Bytnerowicz et al., 2002a, b). Therefore these pollutants presently do not directly endanger the Carpathian forests. However, the recent decrease in atmospheric SO_2 and NO_2 concentrations is accompanied by an increase of O_3 concentrations. In the Carpathians concentrations of tropospheric O_3 frequently reach a toxic level for forest trees (Bytnerowicz et al., 2002a, b). The O_3 concentrations change considerably along the Carpathian arch. The highest O_3 concentrations are generally found in the Western Carpathians, while the lowest in the Southern Carpathians

(Bytnerowicz et al., 2002a, b). A decreasing proportion of the damaged stands along the Carpathian arch from the West to the East and South corresponds therefore with the level of O_3 noted in these areas. The concentrations of O_3 differ also between seasons. The high concentrations of O_3 occur usually in May (Bytnerowicz et al. 2002a, b). In spring O_3 can pose a particular threat to sensitive young leaves and needles of trees. The herb layer plants are more sensitive to O_3 than trees, so damage caused by O_3 to these plants may be higher (Bull, 1996; Bytnerowicz et al., 2002b). This supposition has been confirmed by the results of studies by Manning et al. (2002), carried out in many locations in the Carpathians. They have found conspicuous, typical damage by O_3 in more than a dozen herb layer species and in some species of open areas (meadows, road sides). It may be expected that ambient concentrations of O_3 may further increase in the Carpathians, particularly in the warmer and stronger insolated Southern Carpathians. Therefore, managers and policy makers should be prepared for increased threats to the Carpathian forests caused by photochemical smog, and specifically its phytotoxic component, O_3.

Conclusion

Forests growing in the Western Carpathians as a result of long-term effects on air pollution, as well as introducing in many areas trees which have alien origin, are more susceptible to impact of the natural factors like windthrow or gradation of pests (e. g. bark beetles). The characteristics of the Carpathian forests, based on data from 6 vegetation sites scattered over the Polish part of the Carpathian Mountains and on two observation years (1998 and 2005) show, that in the sites, where such events do not take place, differences in floristic composition were not essential. On the other hand, floristic composition in permanent plots subjected to these factors was slowly changed. Data collected during these studies confirm, however, the richness and floristic diversity of these forests.

Translated by the authors

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References

Anonymous, 1996: National parks in Poland (in Polish). Sport i Turystyka. MUZA S. A., Warszawa, 287 pp.
Badea, O., Tanase, M., Georgeta, J., Amisoara, L., Peiov, A., Hana, U., Bucha, T., Wawrzoniak, J., Shparyk, Y., 2002: Forest health status in the Carpathian Mountains, Europe: 1997–1999. In Szaro, R. C., Bytnerowicz, A.,

Oszlanyi, J. (eds), Effects of Air Pollution on Forest Health and Biodiversity in Forests of the Carpathian Mountains. NATO Science Series, I. Life and Behavioural Sciences. Vol. *345,* IOS Press, Amsterdam, p. 69–75.

Barker, J.R., Henderson, S., Noss, R.F., Tingley, D.T., 1991: Biodiversity and human impacts. In Nierenberg, W.A. (ed.), Encyclopedia of earth system science. Academic Press, Inc., San Diego.

Borecki, T., Lubczyński, L., Miścicki, S., Nowakowska, J., Wójcik, R., 1995: State of tree stands in national parks (in Polish). Biblioteka Monitoringu Środowiska, Warszawa, 75 pp.

Bull, K., 1996: Workshop summary. In Karenlampi, L., Skarby, L. (eds), Critical levels for ozone in Europe: testing and finalizing the concepts (UN-ECE Workshop Report, University of Kuopio, Finland, p. 7–8.

Bytnerowicz, A., Godzik, B., Frączek, W., Grodzińska, K., Krywult, M., Badea, O., Barančok, P., Blum, O., Černy, M., Godzik, S., Maňkovská, B., Manning, W., Moravčik, P., Musselman, R., Oszlányi, J., Postelnicu, D., Szdżuj, J., Varšavová, M., Zota, M., 2002a: Ozone, sulphur dioxide and nitrogen dioxide air pollution in forests of the Carpathian Mountains. In Szaro R. C., Bytnerowicz, A., Oszlányi, J. (eds), Effects of Air Pollution on Forest Health and Biodiversity in Forests of the Carpathian Mountains. NATO Science Series, I. Life and Behavioural Sciences. Vol. *345*, IOS Press, Amsterdam, p. 138–160.

Bytnerowicz, A., Godzik, B., Frączek, W., Grodzińska, K., Krywult, M., Badea, O., Barančok, P., Blum, O., Černy, M., Godzik, S., Maňkovská, B., Manning, W., Moravčik, P., Musselman, R., Oszlányi, J., Postelnicu, D., Szdżuj, J., Varšavová, M., Zota, M., 2002b: Distribution of ozone and other pollutants in forests of the Carpathian Mountains in central Europe. Environ. Pollut., *116*: 3–25.

Bytnerowicz, A., Godzik, B., Grodzińska, K., Frączek, W., Musselman, R.C., Manning, W.J., Badea, O., Popescu, F., Fleischer, P., 2004: Ambient ozone in forests of the Central and Eastern European mountains. Environ. Pollut., *130*: 5–16.

Czuraj, M., 1991. Tables of volume of trunks and entire trees (in Polish). PWRiL, Warszawa, 362 pp.

Dynowska, I., Maciejewski, M. (eds), 1991: Upper Vistula basin (in Polish). PWN, Warszawa-Kraków, T. I, p. 341, T. II, p. 282.

Fabijanowski, J., Jaworski, A., 1995: Silviculture (in Polish). In Warszyńska, J. (ed.), Karpaty Polskie – Przyroda, Człowiek i jego działalność. Uniwersytet Jagielloński, Kraków, p. 253–263.

Fleischer, P., Godzik, B., Bičárová, S., Bytnerowicz, A., 2005: Ozone effects of air pollution and climate change on forests of the Tatra Mountains, Central Europe. In Omasa, K., Nouchi, I., De Kok, L.J. (eds), Plant Responses to Air Pollution and Global Change. Springer-Verlag Tokyo, p. 111–121.

Fleischer, P., Godzik, B., Bičárová, S., 2006: Tropospheric ozone in the Tatra Mountains, risk for forest and man (in Slovak). In Krzan, Z. (ed.), Przyroda Tatrzańskiego Parku Narodowego a Człowiek, Tom III, Człowiek i Środowisko. Tatrzański Park Narodowy, Polskie Towarzystwo Przyjaciół Nauk o Ziemi – Oddział Krakowski, Zakopane, p. 65–72.

Godzik, S., Sienkiewicz, J., 1990: Air pollution and forest health in Central Europe: Poland, Czechoslovakia and German Democratic Republic. In Grodziński, W., Cowling, E.B., Breymeyer, A.I. (eds), Ecological Risks - Perspectives from Poland and the United States. National Academy Press, Washington D.C., p. 155–170.

Godzik, B., Grodzińska, K., 2002: Long-term effects of tropospheric ozone on selected forest ecosystems in the Carpathian Mountains. In National Conference "Long Term Ecological Research in Poland" in the framework of International Long Term Ecological Research Network (ILTER). State Committee for Scientific Research, Poland, p. 14–19.

Godzik, B., Fleischer, P., Grodzińska, K., Bytnerowicz, A., Matsumoto, Y., 2003: Long-term effects of air pollution on spruce forest in the Tatra Mts – ozone and vegetation studies. Ekológia (Bratislava) *22*, Suppl. 1: 95–109.

Godzik, B., Grodzińska, K., 2003: Ozone concentrations of the forested areas in the Carpathian Mountains. Annual Report, Polish Academy of Sciences, p. 33–35.

Godzik, B., 2006: Tropospheric ozone measurements in the Tatra Mountains and its effects on plants. In Arapis, G., Goncharova, N., Baveye, P. (eds), Ecotoxicology, Ecological Risk Assessment and Multiple Stressors. NATO Security through Science Series – C: Environmental Security, Series IV: Earth and Environmental Series – Vol. *6*. Springer, Netherlands, p. 325–336.

Grodzińska, K., Mirek, Z., Szarek, G., 1995: Environmental damage and restoration attempts in Poland - an overview. In Urbańska, K., Grodzińska, K. (eds), Restoration ecology in Europe. Geobotanical Institute SFIT, Zürich, p. 113–130.

Grodzińska, K., Godzik, B., Badea, O., Barančok, P., Istona, J., Moravčik, P., Niemtur, S., Oszlányi, J., Parpan, V., Varšavová, M., Bytnerowicz, A., Szaro, R. C., 2002: Vegetation of selected forest stands in the Carpathian

Mountains. In Szaro, R. C., Bytnerowicz, A., Oszlányi, J. (eds), Effects of Air Pollution on Forest Health and Biodiversity in Forests of the Carpathian Mountains. NATO Science Series, Series I: Life and Behavioural Sciences. Vol. *345,* IOS Press, Amsterdam, p. 96–117.

Grodzińska, K., Godzik, B., Frączek, W., Badea, O., Oszlányi, J., Postelnicu, D., Shparyk, Y., 2004: Vegetation of the selected forest stands and land use in the Carpathian Mountains. Environ. Pollut., *130*: 17–32.

Grodzińska, K., Szarek-Łukaszewska, G., 1997: Polish mountain forests: past, present and future. Environ. Pollut., *98*: 369–374.

Guderian, R., Klumpp, G., Klumpp, A., 1989: Effects of SO_2, O_3 and NO_x singly and in combination on forest species. In Oztürk, M.A. (ed.), Plants and pollutants in developed and developing countries. Ege Univ., Izmir, Turkey, p. 231–268.

Jaworski, A., Karczmarski, J., 1991: Structure and dynamics of virgin type stands in the Pieniny national park (exemplified by four experimental plots) (in Polish). Zesz. Nauk. AR, Leśnictwo, *20*: 45–83.

Jaworski, A., Skrzyszewski, J., Świątkowski, W., Karczmarski, J., 1991:Structure of lower montane zone virgin type stands in selected areas of the Bieszczady Mts. (in Polish). Zesz. Nauk. AR, Leśnictwo, *20*: 17–43.

Manning W.J., Godzik B., Musselman R. 2002. Potential bioindicator plant species for ambient ozone in forested mountain areas of central Europe. Environ. Pollut., *119*: 283–290.

Maňkovská, B., Černy, M., Moravčik, P., Godzik, B., Grodzińska, K., Badea, O., Barančok, P., Oszlányi, J., Varšavová, M., Fleischer, P., Blum, O., Parpan, V., Bytnerowicz, A., Szaro, R. C., 2002: Chemical and morphological changes in Carpathian Mountains trees caused by air pollution. In Szaro, R. C., Bytnerowicz, A., Oszlányi, J.(eds), Effects of Air Pollution on Forest Health and Biodiversity in Forests of the Carpathian Mountains. NATO Science Series, Series I: Life and Behavioural Sciences. Vol. *345*. IOS Press, Amsterdam, p. 173–184.

Maňkovská, B., Godzik, B., Badea, O., Shparyk, Y., Moravčik, P., 2004: Chemical and morphological characteristics of key tree species of the Carpathian Mountains. Environ. Pollut., *130*: 41–54.

Matuszkiewicz, J. M., 2002: Forest communities of Poland (in Polish). Wydawnictwo Naukowe PWN, Warszawa 2002, 358 pp.

Mirek, Z., Piękoś-Mirkowa, H., 1992: Plant cover of the Western Carpathians (S Poland). In Zarzycki, K., Landolt, E., Wójcicki, J.J. (eds), Contributions to the knowledge of flora and vegetation of Poland. Veröff. Geobot. Inst. ETH, *107*: 116–150.

Mirek, Z., Piękoś-Mirkowa, H., Zając, A., Zając, M., 1995: Vascular plants of Poland – A checklist. PAN, W. Szafer Institute of Botany, Kraków, 303 pp.

Mirek Z., Piękoś-Mirkowa, H., Zając, A., Zając, M., 2002: Flowering plants and Pteridophytes of Poland. A checklist. Szafer Institute of Botany, PASci. Kraków, 442 pp.

Niemtur, S., Maňkovská, B., Godzik, B., Grodzińska, K., 2002: Changes in Carpathian forest soils caused by air pollution and other factors. In Szaro, R.C., Bytnerowicz, A., Oszlányi, J. (eds), Effects of Air Pollution on Forest Health and Biodiversity in Forests of the Carpathian Mountains. NATO Science Series, Series I: Life and Behavioural Sciences. Vol. *345*. IOS Press, Amsterdam, p. 225–235.

Ochyra, R., Szmajda, P., 1978: An annotated list of Polish mosses. Fragm. Flor. Geobot. *24*: 93–145.

Ochyra, R., Żarnowiec, J., Bednarek- Ochyra, H., 2003: Census Catalogue of Polish Mosses. Institute of Botany, PASci., Kraków, 372 pp.

Oszlányi, J., 1997: Forest health and environmental pollution in Slovakia. Environ. Pollut., *98*: 389–392.

Starkel, R. (ed.), 1991: Geography of Poland – nature environment (in Polish). PWN, Warszawa, 669 pp.

Szafer, W., Zarzycki, K. (eds), 1972: Flora of Poland (in Polish). T. 1. PWN, Warszawa, 614 pp.

Szaro, R. C., Johnston , D.W. (eds), 1996: Biodiversity in managed landscapes. Oxford University Press, New York, 780 pp.

Szwagrzyk, J., Szewczyk, J., Bodziarczyk, J., 1995: Structure of forest stand in the Żarnówka reserve of the Babia Góra National Park. Folia Forestalia Polonica ser. A, Forestry, *37*: 111–123.

Vološčuk, I., 1999: The national and biosphere reserves in Carpathians – the last nature paradises. ACANAP, Tatranská Lomnica, Slovak Republic, 244 pp.

Warszyńska, J. (ed.), 1995: Polish Carpathians. Nature, man and his activity (in Polish). Uniwersytet Jagielloński, Kraków, 367 pp.