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IIASA Working Paper

WP-89-102

December 1989

WORKING PAPER

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FOREWORD

Within IIASA's Environment Program, the Biosphere Dynamics Project seeks to clarify the policy implications of long-term, large-scale interactions between the world's economy and its environment. The project conducts its work through a variety of basic research efforts and applied case studies. One such case study, the Forest Study, has been underway since March 1986 and focuses on the forest-decline problem in Europe. Objectives of the Forest Study are:

a) to gain an objective view of the future development of the European forest resources;

b) to illustrate the future development of forest decline attributed to air pollution and the effects of this decline on the forest sector, international trade and society in general;

c) to build a number of alternative and consistent scenarios about the future decline and its effects; and

d) to identify meaningful policy options, including institutional, technological and research/monitoring responses, that should be pursued to deal with these effects.

In the framework of the Forest Study a whole series of working papers on the conditions of the Polish forest sector have been published. This paper is one in the Polish series under the auspices of the Forest Study. Because of increased decline, the silviculture methods have to be adapted to the new conditions. The objective of this study is to illustrate the required changes of the silvicultural management at increased decline caused by air pollutants.

B.R. Döös
Leader
Environment Program

ABSTRACT

Data presented by the Headquarters of the State Forests in Poland indicate that about 645,000 ha were threatened by industrial emissions in the mid-1980s. The authors have carried out a complementary study and have come to the conclusion that about 2.8 million ha were threatened in 1988. Due to the future emissions the area under threat is estimated to increase to about 4.2 million ha in the year 2000. This rapid development of decline requires a changed silvicultural management.

Guidelines for the changed management of the following order of stands threatened by air pollutants are discussed:

(a) stands characterized as being "in the regeneration class";

(b) clear-cut stands;

(c) second-order clear-cut stands;

(d) seedlings and thickets;

(e) stands of medium age classes; and

(f) stands with a share of deciduous species exceeding 20%.

CONTENTS

SILVICULTURE METHODS IN POLISH FORESTS AFFECTED BY INDUSTRIAL POLLUTANTS

Jan Greszta and Marian Mączyński

1. INTRODUCTION

The urgent problem of decline of pine and spruce forests and the impairment of the commercial function of stands in Poland necessitate the development of specific methods in managing forests where various levels of damage occur as a result of toxic substances. Above all, the current magnitude and range of damaging effects must be objectively estimated, the distance from the different sources of emission being taken into consideration. This paper aims to present a foundation of planning stand-improvement measures and a basis of timber production in the next 30 years, i.e. to the year 2020. In Poland today, all forests are within the range of more or less severe air pollution.

Contrary to all appearances, the determination of ranges of pollution in the country is fairly complicated. This is especially remarkable in delimiting zone I (the zone with the smallest degree of damage caused by industrial emissions), i.e. the borderlines of the largest range, since analytical data do not always agree with the response of plant communities. This chiefly concerns the so-called "invisible damage" which weakens forest stands without a simultaneous appearance of visible signs. It would be safer to delimit a larger zone in agreement with analytical data. However, the classification of a forest area to a corresponding zone of pollution must be associated with a number of additional actions and, hence, with a decrease in the economic efficiency of the stand (e.g. reconstruction of stands, shortened cutting cycle, replacement of fast growing species by slowly growing ones). Therefore, this has to be profoundly justified. In examining the effect of industrial pollution on forests, several factors which have no equivalent in other studies of this type have to be taken into consideration. These factors are:

(a) The negative effect of pollution is a relative concept on account of great differences in the threshold sensitivity of particular species to different compounds (elements) and also of the synergistic (joint) action of numerous compounds on plants. Therefore, in speaking about a negative effect on a stand, one should specify what species is/are examined. In the present case, the degrees of damage were determined on the basis of criteria established for pine and spruce stands, i.e. for stands which constitute about 80% of all Poland's forest land and a similar percentage of all timber produced.

(b) Contrary to other elaborations on spatial aspects (i.e. cartographic presentations), the concept of a zone is characterized by a fairly great instability of borderlines with regard both to dusts and gases.

The aim of the present work is to determine the impact of pollutant emissions on forests, the extent of damage, and methods of forest management on areas threatened by pollutants. The production cycle of a stand may take 100 years, and therefore it is not possible to plan the reconstruction of stands and the methods of securing it (i.e. silviculture measures) if prognoses for a period of at least half of the planned cutting cycle are not taken into consideration.

Most forests in Poland have been subject to the routine of the clear-cutting system with associated changes in their species composition. Therefore the determination of forest types which would correspond with tasks imposed on stands requires profound analyses of ecological conditions and valuation of forests with respect to their compatibility with the habitat and their occurrence in different zones affected by industrial pollution. This might be used in elaborating general lines of management for both the near and distant future.

2. GENERAL DESCRIPTION OF POLISH FORESTS

The forest land in Poland covers 27.6% of the country area. According to the Chief Census Bureau, the total forest land amounts to 8,666,545 ha of which 7,077,300 ha are state forests (6,735,100 ha managed by the Ministry of Agriculture, Forestry and Food Economy, 82,200 ha covered by national parks, and 262,000 ha managed by other ministries) and 1,551,100 ha are private and municipal forests (Smykała 1980; Łonkiewicz et al. 1987).

The forests managed by the nationalized enterprise "State Forests" grow on the following habitats:

(a) Coniferous forest sites – 67.7% of forest land; in this area, fresh coniferous forest sites account for 35.5%, on poor or sandy soils with Scots pine as the dominant species;

(b) Mixed forest sites – 29.4% of forest land on fertile soils; the stands are composed chiefly of oak, beech, fir and spruce; and

(c) Alder swamp – 2.9% of forest land on fertile wet soils; the stands are composed chiefly of alder and ash.

Considering altitude, lowland sites cover 89.4%, upland sites 2.9%, and mountain forests 7.7% of Poland's forest land.

In private and municipal forests, coniferous sites cover 65.8% of the forest land, with fresh coniferous forest sites as the dominant type (40.5%), mixed forest type covers 27.2%, and alder swamp forest covers 7.0%. The share of lowland and upland habitats in the area of private and municipal forests reaches 88.4%, and in mountain sites 11.6%.

In general, coniferous mixed forest sites constitute about 70% of all habitats, mountain forest sites cover 8.7%, and the habitats under mixed and deciduous forests only 21.7%. Pine is the dominant species (Table 1). Polish forests are mostly young (Tables 2 and 3). Currently the mean age is 52 years. In state forests the mean stand volume per ha is 178 m^3 with an annual increment of 6 m^2/ha/yr; in private forests the respective values are 101 m^3 and 4 m^3/ha/yr.

In recent years the growing impact of industrial pollutant emissions on forest productivity has been observed. The emissions are a serious threat to forest development and in some regions a state of ecological disaster already occurs (the Sudeten Mountains).

Table 1. Species composition of Polish forest (in percentage of area).

Species	State Forests	Private and Municipal Forests
Pine, larch	71.6	66.6
Spruce	7.1	5.7
Fir, Douglas fir	2.4	4.7
Oak, ash, maple, sycamore, elm	5.5	3.3
Red beech	4.0	2.4
Birch, hornbeam, acacia	5.0	7.7
Alder	3.8	8.7
Asp, poplar, willow	0.6	0.9
Total	100.0	100.0

Table 2. Distribution of Polish forests by age class. Forests less than 1 ha are not included.

Age Class	State Forest		Private Forests
	ha	%	%
Total Area (ha)	6,395,915		1,362,588
I*	1,145,698	17.9	17.6
II	1,512,151	23.6	35.9
III	1,430,830	22.4	21.8
IV	1,082,964	16.9	9.7
V	702,011	11.0	3.4
VI	223,211	1.8	–
VII	112,595	3.5	–
Regeneration Classes			
a	133,505	2.1	–
b	51,755	0.8	–
c	306	–	1.6

Table 3. Summary of age classes of Polish Forests, in percentage within ownership classes.

Age Class	State Forests	Private Forests
to 40 years of age	41.5	63.5
40–80 years of age	39.3	31.5
above 80 years of age	19.2	5.0

3. MATERIAL AND METHODS

3.1. Degree of Damage to Forests

A new map of forest decline in Poland (Figure 1) has been prepared. It is based on Greszta's (1975) results and recent studies carried out by selected teams of scientists (Czyż et al. 1965; Trampler et al. 1987). These latter works were used as complementary data and presented in the form of small-sized figures beside the basic map (Figure 1). On the basis of these studies, it is estimated that 35% of Polish forests, i.e. 2,853,741 ha, are affected by industrial emissions. Of this area, 62% (1,769,314 ha) is located in zone I with the smallest degree of damage, 30% (856,120 ha) in zone II with a medium degree of damage, and 8% (228,300 ha) in zone III where the greatest injuries are observed.

Data from the Headquarters of State Forests quote minimum values, claiming that 7.8% of forest land, i.e. 645,927 ha of state, municipal and private forests are threatened by industrial emissions (areas below 1 ha are omitted). On the other hand, according to Trampler et al. (1987) the percentage of forests in damage zones I–III reaches 83.7% in the three pollution regions denoted A, B and C in Figure 1 (see also Table 4). The expected losses in stand productivity will increase to 28.9%, i.e. 11.4 million m^3 of timber.

The data of the Headquarters of State Forests are lower than those of Trampler et al. (1987) (Table 4) who took into consideration also the effect of biotic factors, this being sometimes irrelevant to the action of industrial pollutant emissions.

Table 4. Results of a preliminary inventory of forest damage in Poland.

Degree of environmental pollution	Areas		Extent of Damage Zones %						
	Total Land '000 ha	Forested Land '000 ha	0	Ia	Ib	IIa	IIb	III	Total
A	19,717.0	5,555.0	20.0	36.2	24.3	14.1	5.4	0.0	100
B	10,506.0	2,751.9	10.8	15.8	34.2	20.8	16.7	1.7	100
C	1,186.0	342.8	0.0	0.0	36.4	27.3	27.2	9.1	100
Total	312,083.0	8,644.7	16.3	28.3	27.9	16.7	9.9	0.9	100

Sulphur dioxide is regarded as the decisive factor of damage to forests in Poland on account of its common occurrence at high concentrations. At the regional level, the impact of nitrogen oxides (NO_x), HF, Cl, and other elements is also taken into consideration. It is planned that two nuclear power plants will be constructed by the year 2000. Thus, a 50% increase in energy will be obtained on the basis of current energy raw materials (hard and brown coal). Up to now there are no adequate methods of coal desulfurization. Hence, even the National Economic Plan does not provide for the limitation of emissions using SO_2-reducing installations to 1995. It is stipulated that an improvement should occur after that year, consisting of prohibition of increases in emissions. A gradual reduction of SO_2 emission is not planned before the year 2000. Therefore, considering the patterns presented in Figures 2 and 3, the area of forests under the impact of industrial emissions will increase. The dynamics of increases in the endangerment of forests must be regarded as very high irrespective of which prognosis is taken into consideration: that of

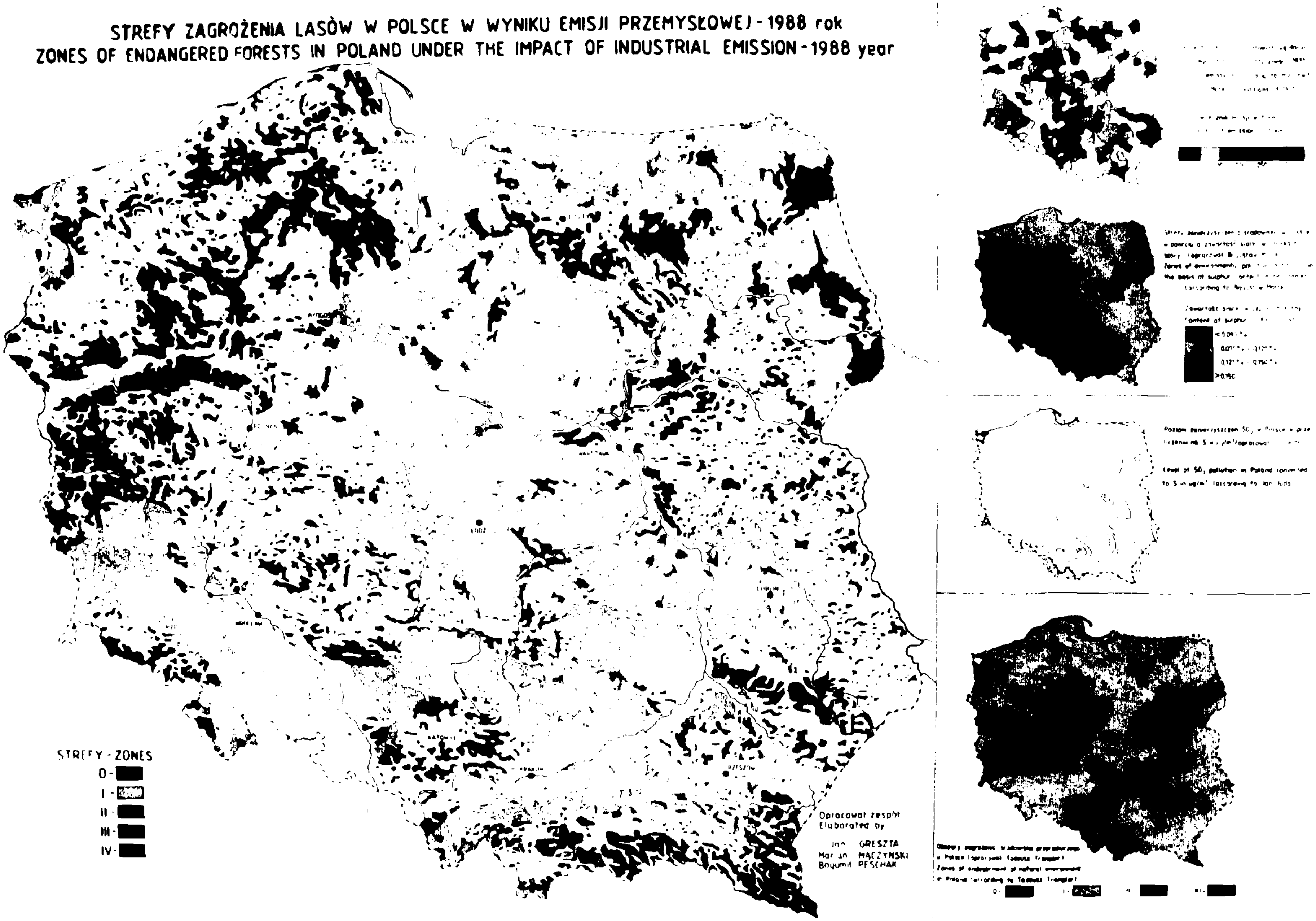


Figure 1. Zones of endangered forests in Poland under the impact of industrial emissions in 1988.

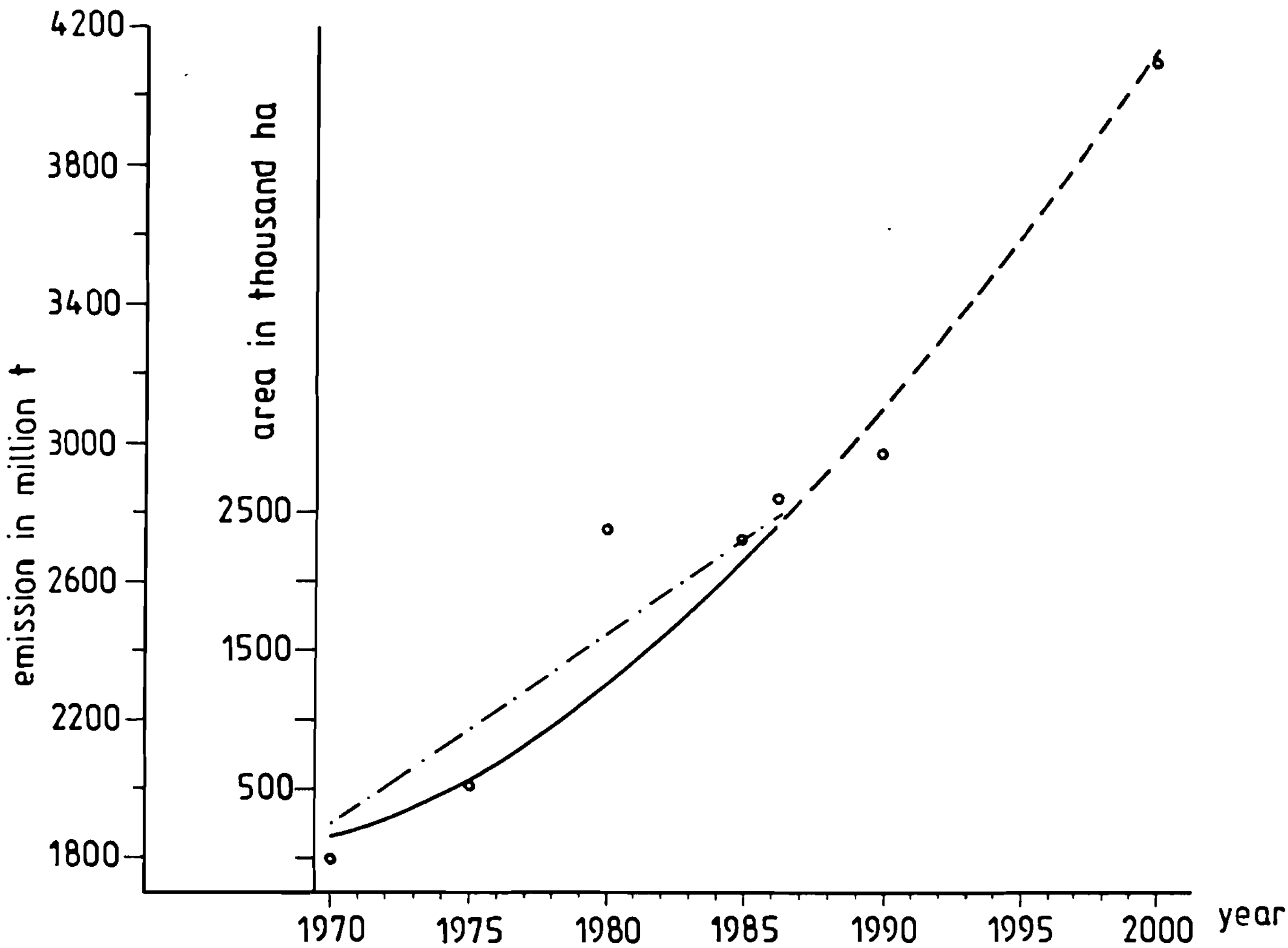


Figure 2. Increase in SO_2 concentration in million tons in the particular years and the corresponding curve of increase of forest land under the impact of industrial emission.

—— — — emission of SO_2 into atmospheric air

— · — · — forest land affected by industrial deposits

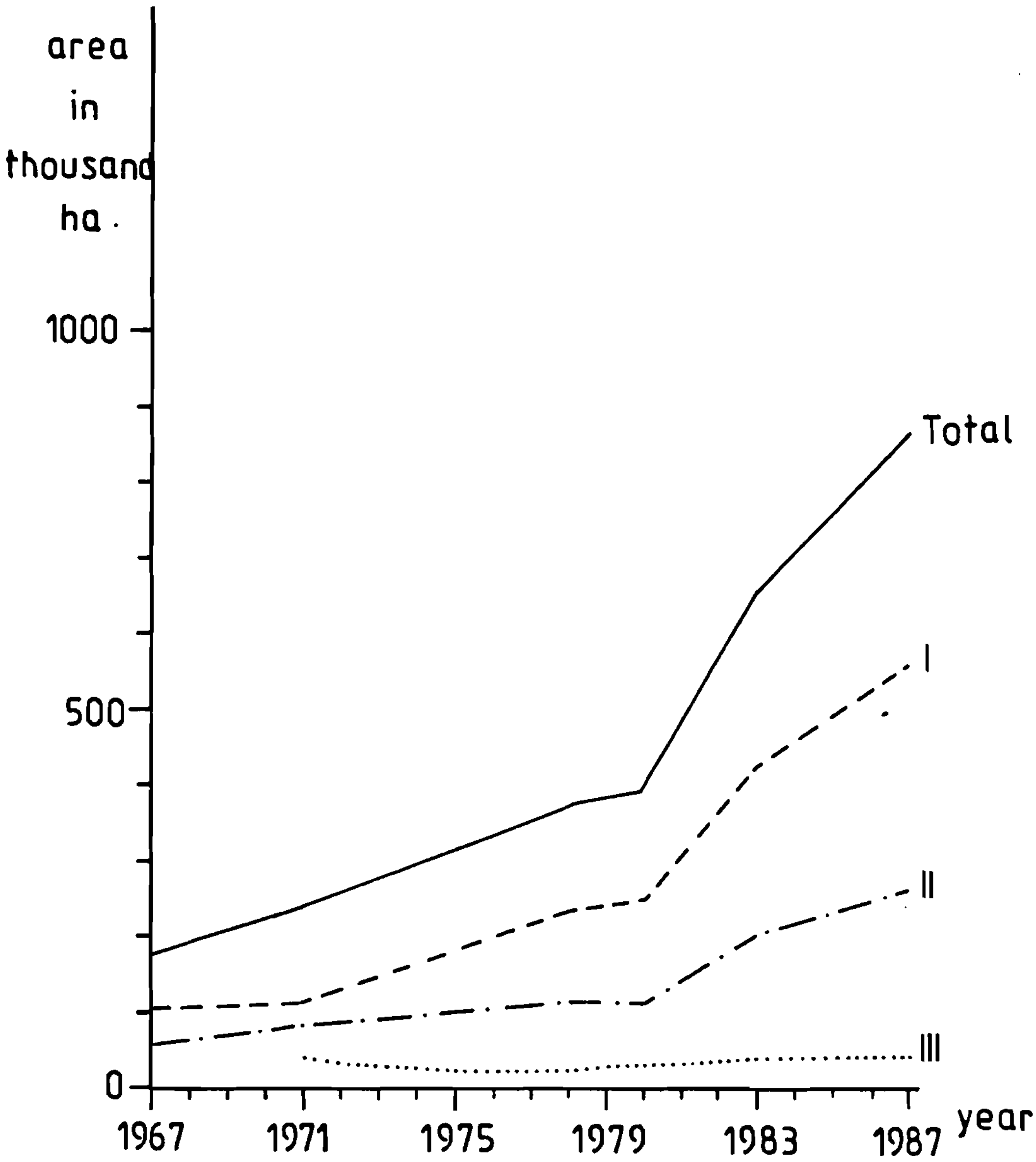


Figure 3. Forest land affected by industrial emissions in thousand ha (according to data of the Headquarters of State Forests).

————	total area	— — —	area of zone I
— . — . —	area of zone II	....	area of zone III

minimum danger (Figure 3) based on official data, or that elaborated by the present authors.

Changes in forest habitat and extent of losses in forest resources (i.e. tree growth) were determined on the basis of results obtained on experimental plots in the Krakow-Silesian Industrial Region, Legnica-Glogow Copper Basin, and in forests of the Staszow and Mielec region (Greszta 1975; Greszta 1979; Greszta et al. 1967). The obtained values were applied to stands in the entire territory of Poland. A total of about 100 experimental plots was used.

The delimitation of zones/degrees of forest damage was carried out on the basis of analyses of:

(a) number of needle generations on a shoot;
(b) number of needles on a one-year shoot; and
(c) increment in shoot length.

Moreover, complementary data were taken from order No. 143 MLPD from September 19, 1970, concerning the zones of endangerment of forests and forest economy, the estimation of losses, and the costs of reconstruction of stands. Particular attention was paid to such indices as changes in the color of needles and in the vitality of trees.

The investigation was carried out in two types of forest habitat, i.e. mixed coniferous forest sites and fresh coniferous forest sites. In the case of chronic injuries in mixed coniferous forests, a distinct correlation was found between the magnitude of emission and the number of needles and appearance of the assimilative apparatus of Scots pine. Average increments of shoots were differentiated in trees of coniferous forest sites in the three damage zones (Tables 5 and 6). In zone I, the increment of shoots in the upper part of the crown of Scots pine differs from that in the other two zones of air pollution. In each case a significant difference was found between zones II and III despite the fact that in each case arithmetical means of shoot increment were greater in zone II than in zone III (Tables 5 and 6). A significant difference in the magnitude of differences was found between zone I and zone II. A similar differentiation appeared in the number of needles per shoot. Zone I significantly differs in this respect from the other zones of air pollution. On account of less severe pollution of air under tree crowns, smaller differences appeared among the damage zones in the magnitude of increment and number of needles in the lower part of the crown. Significant differences were found only between zones I and II in the case of shoot increment, while the differences in the number of needles per shoot between these zones were always non-significant (Tables 7 and 8). Shoot increment is a more stable indicator of the degree of pollution than the number of needles per shoot. The difference between zones I and II was always significant in this case, while with regard to the number of needles in the lower part of the crown it was non-significant and in the upper part significant (first generation) or highly significant (second generation).

Similar dependencies were found in the comparison of zones I and III (Tables 9 and 10). On more fertile forest sites of coniferous mixed forests, the effect of air pollution is less pronounced in the growth of woody plants than on poorer sites. In coniferous mixed forests and fresh coniferous mixed forest sites, the difference in shoot increment and in number of needles per shoot was non-significant between zones II and III in each case examined (Table 8). However, arithmetic means of shoot increment and of number of needles per shoot were always greater in zone II than in zone III. Between zones I and II, a distinct differentiation was found only in the increment of shoots in the upper part of the

Table 5. Average annual shoot growth and number of needles per shoot on forest habitats.

Damage Zone	Upper Crown						Lower Crown			
	1-Year Old		2-Year Old		3-Year Old		2-Year Old		3-Year Old	
	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles
III	2.32	50.3	2.72	44.9	3.18	66.1	4.17	62.5	4.9	42.8
II	4.16	59.9	4.33	40.5	4.04	73.2	4.37	60.5	–	–
I	11.76	134.7	10.22	98.9	5.81	85.6	5.25	71.3	5.8	31.1

Table 6. Average annual shoot growth and number of needles per shoot on mixed forest habitats.

Damage Zone	Upper Crown						Lower Crown			
	1-Year Old		2-Year Old		3-Year Old		2-Year Old		3-Year Old	
	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles
III	4.26	71.5	3.80	42.8	4.26	68.3	4.70	57.1	4.16	28.8
II	5.95	95.8	4.98	64.6	5.45	86.1	4.72	59.0	4.31	36.2
I	9.51	127.1	8.44	83.3	5.81	88.9	5.54	80.5	5.46	45.5

Table 7. Statistical significance of differences of average annual shoot growth and number of needles per shoot in forest habitats among the damage zones. One asterisk (*) indicates statistically significant difference of the F statistic at P=0.05; two asterisks at P=0.01.

Difference Between Zones	Upper Crown				Lower Crown			
	1-Year Old		2-Year Old		1 Year Old		2-Year Old	
	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles
	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99
I–II	7.60*	74.7*	5.89*	58.3**	1.77*	12.4	0.88*	10.8
	5.70	69.1	4.56	37.1	1.21	12.5	0.80	15.1
	8.43	104.7	6.91	56.2	1.84	18.9	1.21	22.8
I–III	9.44**	84.4*	10.22**	54.0*	2.63**	19.4**	1.08*	8.8
	5.57	69.1	4.56	37.1	1.21	12.5	0.80	15.1
	8.43	104.7	6.91	56.2	1.84	18.9	1.21	22.8
II–III	1.84	9.7	1.61	4.4	0.86	7.0	0.21	2.0
	5.57	69.1	4.56	37.1	1.21	12.5	0.80	15.1
	8.43	104.7	6.91	56.2	1.84	18.9	1.21	22.8

Table 8. Statistical significance of differences of average annual growth of shoots and the numbers of needles on mixed forest habitats among the zones. One asterisk (*) indicates statistically significant difference of the F statistic at P=0.05 two asterisks at P=0.01.

Difference Between Zones	Upper Crown				Lower Crown					
	1-Year Old		2-Year Old		1 Year Old		2-Year Old		3-Year Old	
	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles	Annual Shoot Growth (cm)	Number of Needles
	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99
I–II	3.56*	31.3*	3.46**	18.7	0.36	2.8	0.82*	21.4*	1.15	9.3
	2.71	28.5	2.01	43.7	1.25	21.0	0.75	1.51	2.17	18.9
	4.10	43.2	3.04	66.2	1.90	31.8	1.14	22.9	3.29	28.6
I–III	5.25**	55.6**	4.64**	40.5	1.55*	20.6	0.84*	23.4**	1.30	16.6
	2.71	28.5	2.01	43.7	1.25	21.0	0.75	15.1	2.17	18.9
	4.71	43.2	3.04	66.2	1.90	31.8	1.14	22.9	3.29	28.6
II–III	1.69	24.3	1.18	21.8	1.19	17.8	0.02	2.0	0.15	7.3
	2.71	28.5	2.01	43.7	1.25	21.0	0.75	15.1	2.17	18.9
	4.10	43.2	3.04	66.2	1.90	31.8	1.14	22.9	3.29	28.6

Table 9. Statistical significance of differences of average shoot growth and number of needles between upper and lower crowns on coniferous forest habitats in the damage zones. One asterisk (*) indicates statistically significant difference of the F statistic at P=0.05; two asterisks at P=0.01.

Damage Zones	1-Year Old		2-Year Old	
	Growth of Shoot (cm)	Number of Needles	Growth of Shoot (cm)	Number of Needles
	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99
I	5.95 8.44 15.49	49.1 96.7 177.4	4.97 6.59 12.10	27.5 58.2 106.9
II	0.12 3.85 4.82	13.2 46.2 84.7	0.04 2.06 1.79	19.9* 14.2 29.8
III	0.86* 0.82 1.50	15.9* 12.0 18.6	1.45* 9.98 0.50	17.6* 16.2 26.9

Table 10. Statistical significance of differences of average annual shoot growth and number of needles between upper and lower crowns on coniferous mixed forest habitats in the damage zones.

Damage Zones	1-Year Old		2-Year Old	
	Growth of Shoot (cm)	Number of Needles	Growth of Shoot (cm)	Number of Needles
	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99	Femp F0.95 F0.99
I	3.70* 3.07 5.64	38.2* 31.3 57.5	2.90* 2.71 4.98	2.8 38.0 69.7
II	0.50 2.34 4.30	9.7 38.4 70.6	0.26 0.30 0.55	5.6 11.0 20.2
III	0.00 – –	3.2 7.3 13.4	0.90** 0.27 0.50	14.2 14.7 26.9

crown. No analogical regularity could be observed in the number of needles per shoot. The impact of air pollution on the increment in shoot length is manifested to a much less degree. Differences between the zones in the increment of shoots and the number of needles per shoot are much smaller here than in the apical part of the crown. As in coniferous mixed forest sites, the shoot increment, responding negatively to air pollution, was a more stable index than the number of needles per shoot. This is distinctly manifested in examining significant differences between zones I and III (Tables 5 and 6). The mean number of needles may depend on such factors as the method of sampling, storage of needles, date of taking samples, and transport. Such factors have no bearing on the computation of increment in shoot length. In fresh coniferous mixed forests, arithmetic means show that in zone III the average shoot increment and the mean number of needles per shoot are larger in the lower part of the crown and the differences are significant in each case. In zone I the mean increment and the mean number of needles are always larger in the upper than in the lower part of the crown; however, statistical computations show that in each case the difference is insignificant. In more fertile sites of mixed forests these dependencies are slightly different. In zones II and III, differences in the shoot increment and number of needles per shoot between the upper and lower part of the crown are hardly discernible and with one exception, insignificant. In zone I, where the least air pollution was found, the increment of shoots and the number of needles per shoot were larger in the upper part of the crown than in the lower. The differences were statistically significant with the exception of one case.

On the basis of measurements, considerable percent differences were found in the number of needles. In zone III in fresh coniferous forests, the Scots pine shows a 62% reduction in the number of first-year needles and a 54% reduction in the second (last) generation as compared with zone I. In mixed forest sites the respective values are 42% and 48%. Pines growing in zone II show a 50% reduction of needles in coniferous forest sites and a 23% reduction in mixed forests. This phenomenon is less regular in the lower part of the crown and the differences between the particular zones are insignificant (zone III about 17%, zone II about 14%).

The above comparisons show that in more fertile sites, differences in the number of needles on trees growing in particular zones are less pronounced. In our macroscopic approach, the areas where the number of generations of needles dropped below two were not differentiated. Irrespective of the zone, two generations of needles are found in the upper part of the crown and three in the lower part; however, in some plots lying small distances from sources of pollution, the number of needle generations was limited to one. This chiefly concerns the zone of acute damage. Stands lying in the comparative zone I usually had three generations of needles (Greszta 1970).

Another factor influencing the shape of the tree crown is the increment in shoot length. Here the differences between zone I (with the smallest injuries) and the zone of the most severe damage reach 75% in stands on fresh coniferous forest sites and 55% in mixed coniferous forests. Differences between the intermediate zone II and zone I reach about 60%. These values pertain to shoots in the upper crown. In the lower part, the corresponding differences were 25% between zones III and I and 20% between zones I and II, being similar for stands on fresh and mixed coniferous forest sites.

The valuation of losses in increment was based on traits of production capacity of forest sites, the stand being regarded as their function. The comparison of valuation elements in the particular zones was based on mean values from several experimental plots. In each plot, one dominant and one co-dominant tree were cut (Kraft's classes 1 and 2) and sectional measurements were carried out.

On the basis of results of the analysis, (Figures 4 and 5) losses in increment could be determined. It was found that in zone I of industrial air pollution, the impact of emissions brought about a 24% reduction of volume increment irrespective of the fertility of the habitat (Figures 6 and 7). This was equivalent to a 0.8–0.7 decrease in stand quality classification. In zone II, the increment of pine trees was reduced by 48%, this corresponding to changes in stand quality classification by 2.0 to 1.3 units. In zone III, losses in pine increment reached 74% (Figure 7), decreasing the stand quality by 2.5 units.

Trunk analysis showed that the culmination of increment in stand volume did not occur at the same time on different plots. The stands on sites of mixed forest in zone I usually showed culmination of volume increment at age 50–55 years. In this case, relatively small deviations from theoretical data appear. As the concentrations of emissions increase, the culmination of increment is shifted from 50 to 65 years, this being characteristic for poorer habitats.

The differentiation of average volume at a given age and of average annual volume increment between the zones is very distinct. In the two types of habitats examined, the greatest increase in volume and in average volume increment is observed in zone I, while the smallest increases in these values appears in zone III (Figure 8).

The pattern of increment curves in coniferous forest sites in zone I is similar to that in mixed forest sites in zone III. The results obtained suggest that this is the extreme zone where stands still survive. Apart from losses in increment the age of the stand is decreased; in zones I and II, a decrease of 10–15 years and in zone III of about 30 years was found. This accounts for changes in the production cycle of the given management class and affects its economic results since valuable assortments, e.g. large timber, are lost (Figure 9).

Losses in timber production are a function of losses in increment and of losses resulting from excessive self-thinning of trees (Figures 10, 11, 12). Stands growing in polluted regions are not only characterized by poor growth but are rapidly thinned on account of high tree mortality rates (Table 11).

Table 11. Stand-density indices for the Krakow-Silesian industrial region of Poland.

Forest Type	Stand-Density Index		
	Zone I	Zone II	Zone II
Coniferous Mixed	0.67	0.58	0.64
Fresh Coniferous	0.75	0.71	0.64

The Table 11 values were applied to the entire area of Poland. This generalization is possible if emissions affect stands throughout their lifetime, i.e. from planting to final cutting. If the source of emission started much later, the computed losses should be reduced by the coefficient of the time of the negative influence of the pollutants. In the case of Poland, the resulting error is fairly small since 50% of the forest area is occupied by stands less than 50 years of age and a great part of their growth has occurred under the impact of industrial emissions.

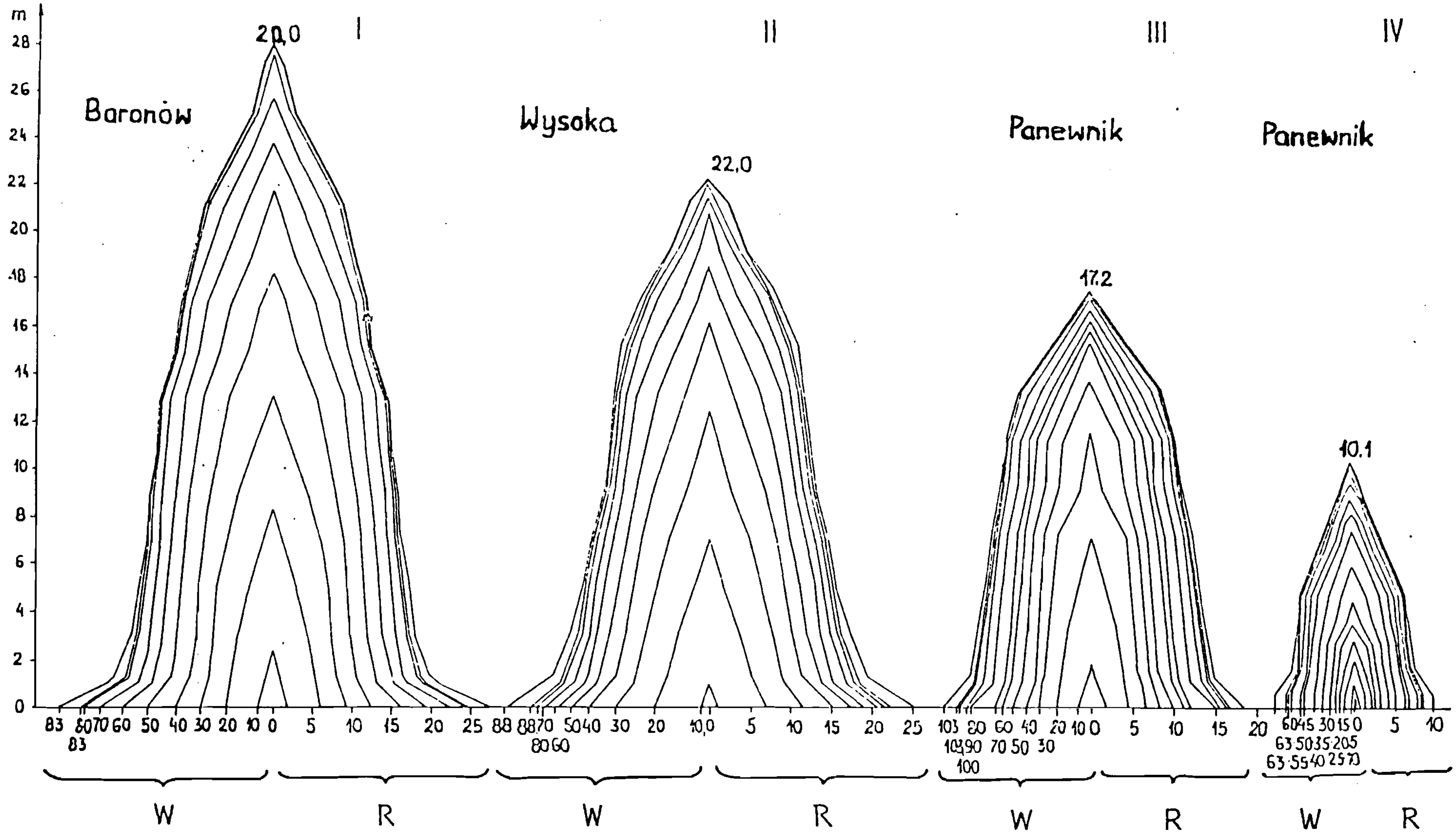


Figure 4. Analysis of tree trunks in the particular zones (I–IV) of industrial air pollution. The height of trees in meters was marked on the y-axis, and on the abscissa on the left of each graph, the age of trees in years (W) was given, and the radius of the diagonal cross-section of trunks in cm (R) on the right.

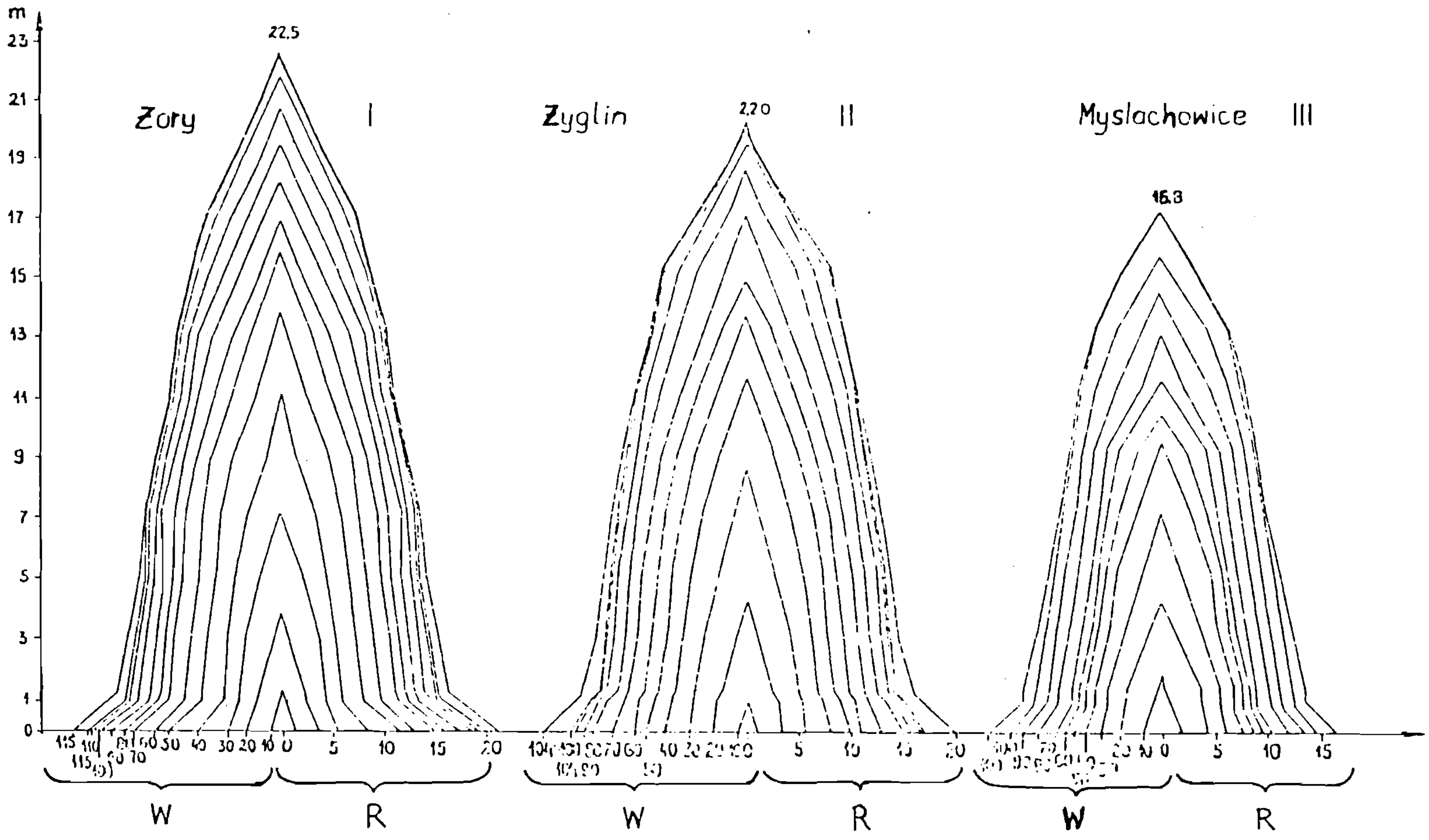


Figure 5. Analysis of trunks in zones I, II and III. The height of trees in meters was marked on the y-axis, and on the abscissa the age of trees in years (W) was given on the left side of each graph, and the radius of the diagonal cross-section of trunks in cm (R) on the right.

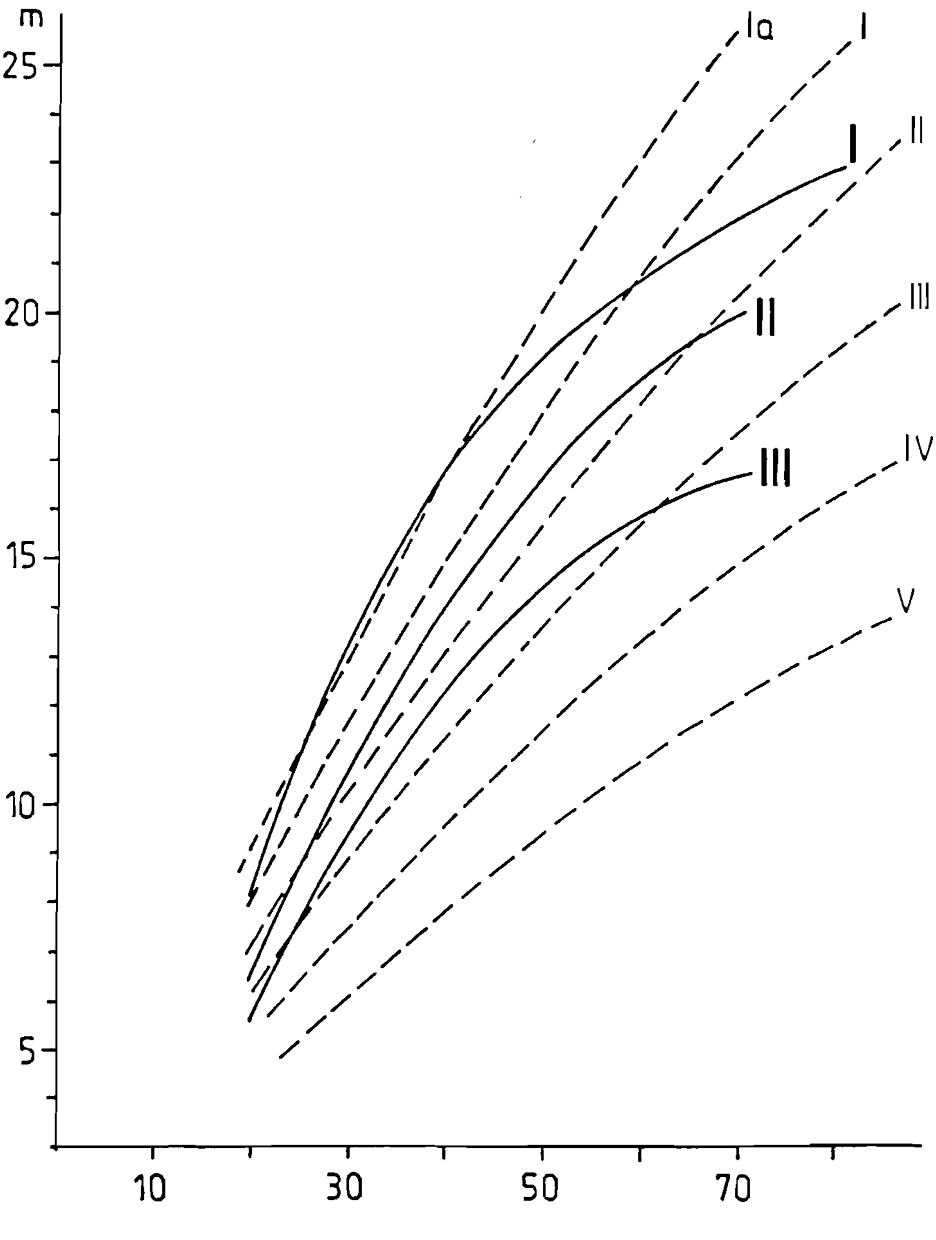


Figure 6. Average height of trees under study (continuous line) in relation to the tabular size of tree stand heights (broken line) for various site classes on partly mixed coniferous forest habitats in zones I, II, and III. The height of the trees was marked on the y-axis, and the age of trees in years was marked on the abscissa.

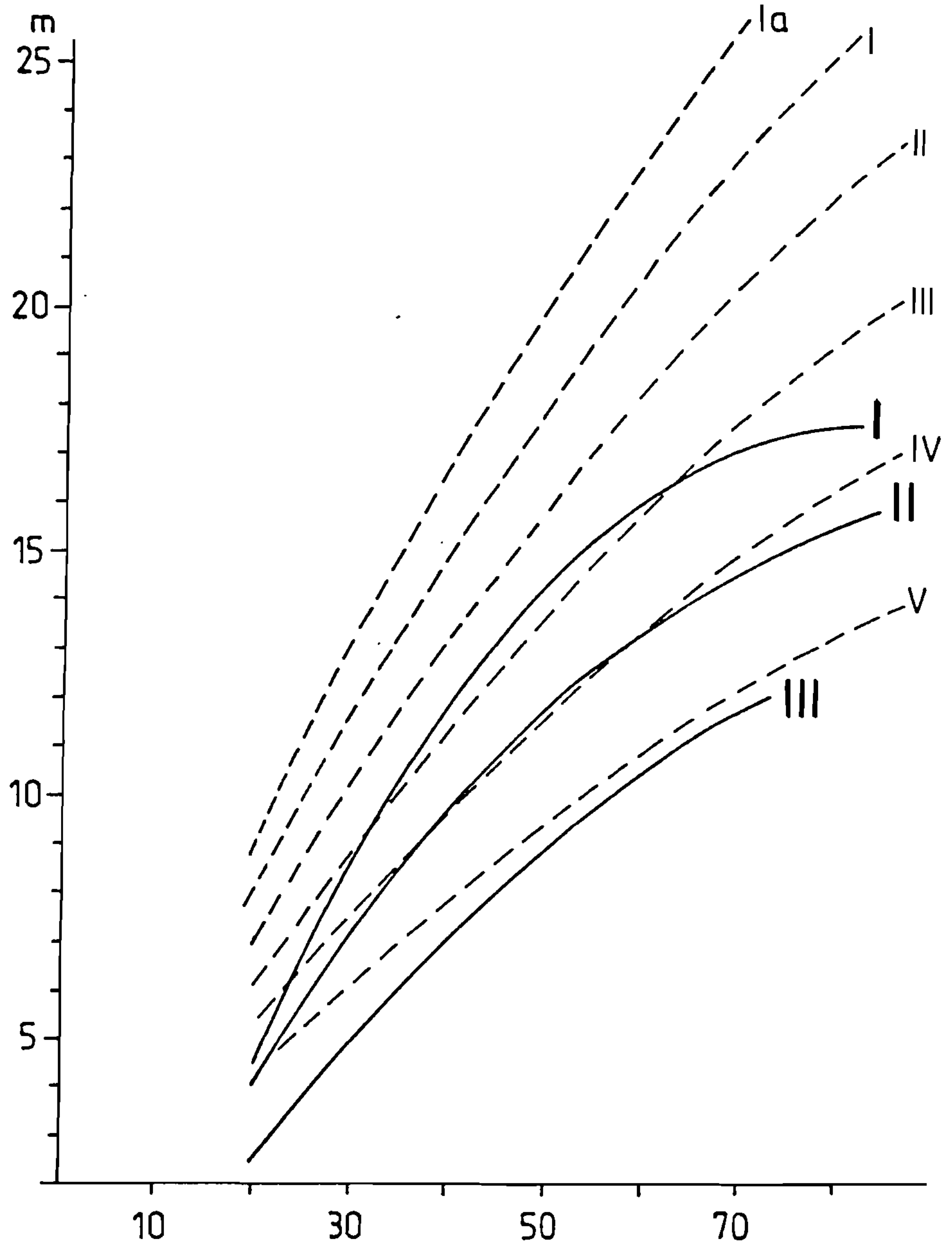


Figure 7. Average height of trees under study (continuous line) in relation to the tabular size of tree stand heights (broken line) for various site classes on fresh coniferous forest habitats in zones I, II, and III. The height of the trees was marked on the y-axis, and the age of trees in years was marked on the abscissa.

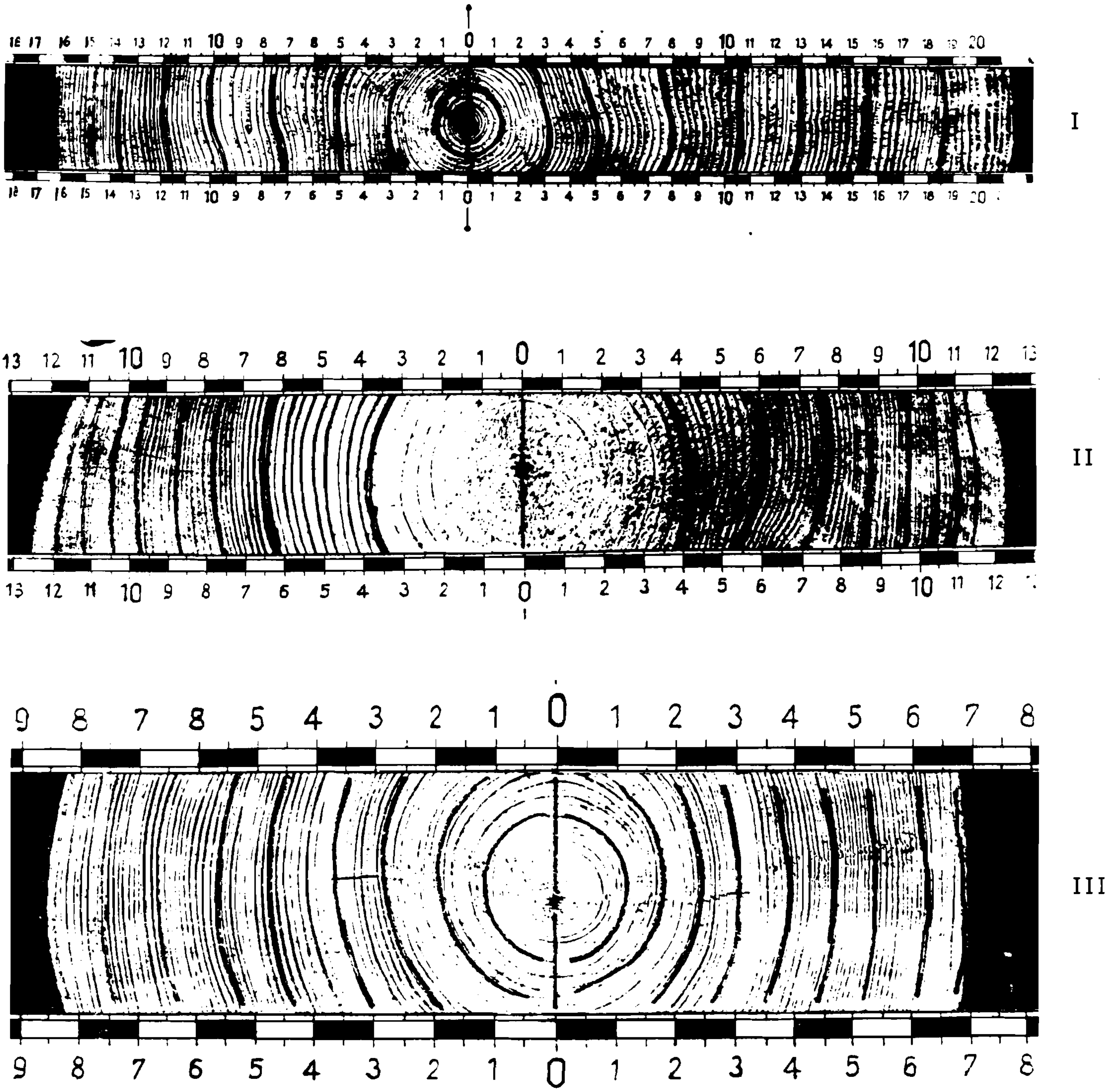
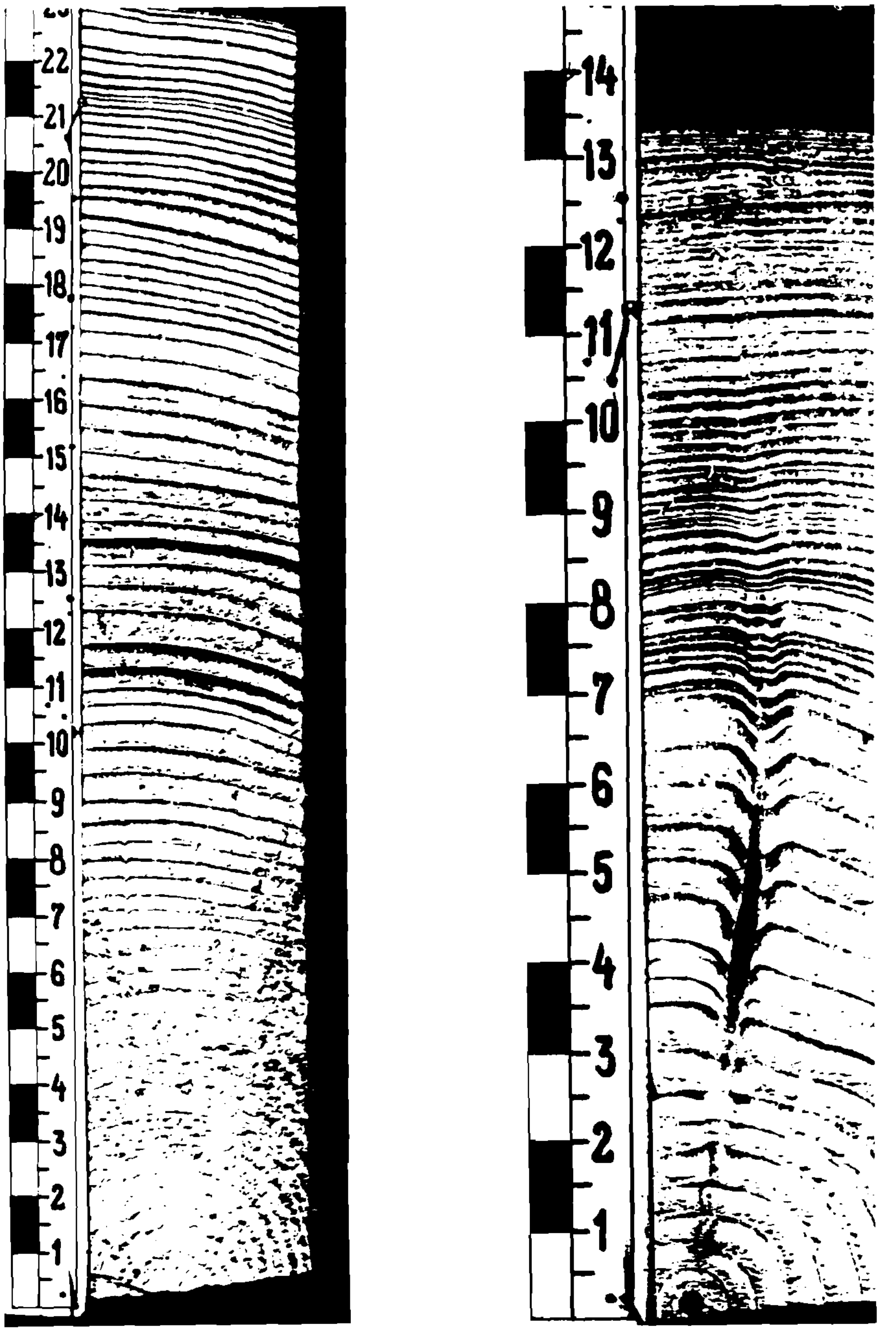


Figure 8. Slowing down in annual growth of timber owing to industrial emission in the particular zones of industrial air pollution.



A B

Figure 9. Increment in width of annual rings. A. Normal. B. Inhibited after a 20-year period.

Figure 10. Pine-wood stands in zone I of industrial air pollution.

Figure 11. Pine-wood stands in zone II of industrial air pollution.

Figure 12. Pine-wood stands in zone III of industrial air pollution.

The results of trunk analysis which showed a decrease in tree height and cross-section area, and took into consideration the index of stand density, made it possible to demonstrate the magnitude of losses in pine stands in the damage zones. The losses were determined by comparing the actual volume with the expected one derived from tables of forest resources (Szymkiewicz 1971). Contrary to some data suggesting stronger damage to stands in poorer habitats, the percent inhibition of production is very similar in the two types of habitat. The differences, in the range 3–7%, probably result from a slight habitat differentiation of the particular stands.

Simultaneously, qualitative losses originate and are expressed by changes in timber assortments in the direction of progressively less valuable ones (Jurkowski et al. 1967). According to foresters from the Olkusz Forest Inspectorate, about 30% of harvested timber is used for pulp or fuel. The quality of pine timber in this Inspectorate worsened during the decade 1965–1975 (Table 12), and the condition is even worse today. Apart from changes in assortments, reconstruction plans have also to take into consideration a remarkable change in species composition. In zone III, deciduous species will constitute 80%, in zone II 60%, and in zone I 40–50%. This should be reflected in plans of timber production for the years 2000 and 2020 (Łonkiewicz et al. 1987; Szczuka 1975). In this period a severe deficit will appear in the supply of construction lumber and assortments produced from stands above age class IV. Thus, the structure of assortments and the species composition of timber supplied to industry will change.

Table 12. Distribution of pine timber across quality classes in the Olkusz Forest Inspectorate.

Quality Class	Percentage of Timber	
	1965	1975
I	10	0
II	20	5–7
III	70	93–95

4. STANDS IN POLISH FORESTS

The present stands have been formed under the influence of long and often improper management. The development of their current species composition was directed by numerous factors which cumulated from the middle of the 19th century. Fairly natural stands compatible with the habitat were removed and replaced by artificially regenerated ones with Scots pine as the dominant species in lowlands and spruce in the mountains. Foresters managing our stands did not resist the trends which prevailed in 19th century Europe and introduced pine and spruce, expecting that their rapid growth would secure quick profits. As with most stands planted in the last century, the native origin of seeds was not taken into consideration. Seeds were marketed by Austrian and German firms and represented a mixture from all European forests. In many cases stands from these seeds grew poorly, showing excessive branching, crooked trunks, and development of poor crowns. Such factors as water relations changed by excessive cutting, unsuccessful attempts at land reclamation, and the introduction of pine of improper provenance on most sites upset the biocenotic balance of our forests. The management of forests by way of clear-cutting as the only harvest method and the associated artificial regeneration led to the development of even-aged stands. Then in turn, the artificial regeneration which chiefly consisted of planting nursery-grown stock of pine and frequently disregarded the character of the habitat, led to the prevalence of pure pine stands. Now, very few stands demonstrate varied age structure and species composition. This state of the Polish forests is to a great degree responsible for the susceptibility of today's stands to all kinds of damage, including injuries brought about by industrial emissions.

On account of the deformation of forests described above, the processes of stand development can fully demonstrate their cycling variation in natural stands only, or in those which approximate the natural condition. In one-aged pure stands, there occur chiefly the processes of natural storied movement and self-thinning of trees. The poor resistance of pine thickets and poles to industrial pollution brings about excessive self-thinning of deadwood, not justified by natural competition.

5. CURRENT METHODS OF FOREST MANAGEMENT

In most Polish forests, management is limited to section clear-cutting with the direction of cutting contrary to prevailing winds, i.e. in the west-east direction. According to "Principles of silviculture in the state forest economy" (Anonymous 1980), the following forms of clear-cutting are applied:

(a) standard clear-cutting areas, 60–80 m in width, with a maximum surface of 6 ha (Ia);
(b) restricted clear-cutting areas of 40–60 m, with a maximum surface of 4 ha (Ib); and
(c) if it is necessary, clear-cutting with belts of over 80 m in width and a surface of over 6 ha.

In deciduous forests the typical shelterwood cutting (IIb) was usually applied, with the width of the logging belt to 150 m and the surface not exceeding 10 ha.

In the mountains the most commonly applied measure was the strip shelterwood cutting (IIa) or the typical shelterwood cutting (IIb). In recent years the methods of group cutting (coppice) and particularly group cutting with selection felling (IIIc) have been promoted, i.e. long-term cutting with groups (coppices) of different size, sheltered or unsheltered, which widen and gradually merge as the natural regeneration developed. With the last type of cutting, the regeneration period takes 40 years or more.

Depending on the actual types of forest sites, the species composition of artificial regenerations be planting should include deciduous trees. The share of these species should reach 20–30% on the poorest sites, 70–80% on more fertile habitats, and 100% on alder swamps. In the zones where the impact of pollution is moderate or strong, the share of deciduous trees should be increased.

6. RECONSTRUCTION OF STANDS

The reconstruction of the species composition and the structure of stands is a complex concept, concerning both the naturally justified reconstruction of multi-species stands on areas currently occupied by degraded communities of transitional character (developed through anthropogenic secondary succession) and the forced change of stands with coniferous species prevailing, on coniferous mixed forest sites, into multi-species stands with the share of pine too low from the ecological point of view. The factor forcing the reconstruction of such forests is the impact of industrial dusts and gases.

Forests should fulfill various tasks and therefore it is necessary to apply various methods of management in different parts of their range. Methods of forest management presented in the scheme presented below take into consideration different functions of stands. The scheme was elaborated for stands of the Niepolomice Primeval Forest (Mączyński 1982) and may to a certain degree illustrate the relations concerning the reconstruction of stands in the whole country (Figure 13).

On account of the damaging action of polluting industries, the species composition of forests should be reconstructed in the next two decades, chiefly in zone III and partially also in zone II.

The following order of reconstruction is recommended:

(a) stands characterized as being "in the regeneration class";
(b) clear-cut stands;
(c) second-order clear-cut stands;
(d) seedlings and thickets;
(e) stands of medium age classes; and
(f) stands with a share of deciduous species exceeding 20%.

According to silviculture principles for damage zones, the "regeneration class" may include every stand of the second age group or older in which the full-valued reproduction of desirable species occurring under the shelter of a negative stand covers 50% of the area at least. The order of stand reconstruction should depend chiefly on the degree of damage, the current vitality, and the changes which may be foreseen in the impact of industrial emissions.

The area of stands in zones III and II to be clear-cut should be planned for the next two decades. The reconstruction of stands requires intensive soil cultivation (chiefly with machines) adapted to local habitat conditions, the relief of the area, soil conditions, water relations, character of the vegetal cover, and the degree of soil toxicity. This is the so-called total reconstruction associated with clear-cutting and artificial regeneration on open areas with a simultaneous change in the species composition. On account of a greater demand for nutrients and a poorer tolerance of soil reaction of deciduous species introduced on poor habitats, it is recommended to lime soils and if possible also to fertilize them with mineral and organic fertilizers. This will also prevent degradation of sites and toxification of soils.

The conversion of species composition on large areas necessitates the preparation of a corresponding supply of nursery stock of deciduous trees in the nearest future. Some species should be planted as many-year transplants; therefore, a suitable area must be prepared for nurseries. Intensification of transplant production and lengthening of the planting season will be possible if most of the transplants are grown in peat and paper pots.

The second-order clear-cut stands should be supplemented by underplanting of deciduous trees in nests and coppices where dead wood was removed or where selection cutting of higher trees was partially carried out (Figure 14). When the canopy reaches the cutting age, coniferous species, chiefly larch and pine (to 20%), should be introduced in inter-coppice spaces in zones of lesser air-pollution damage.

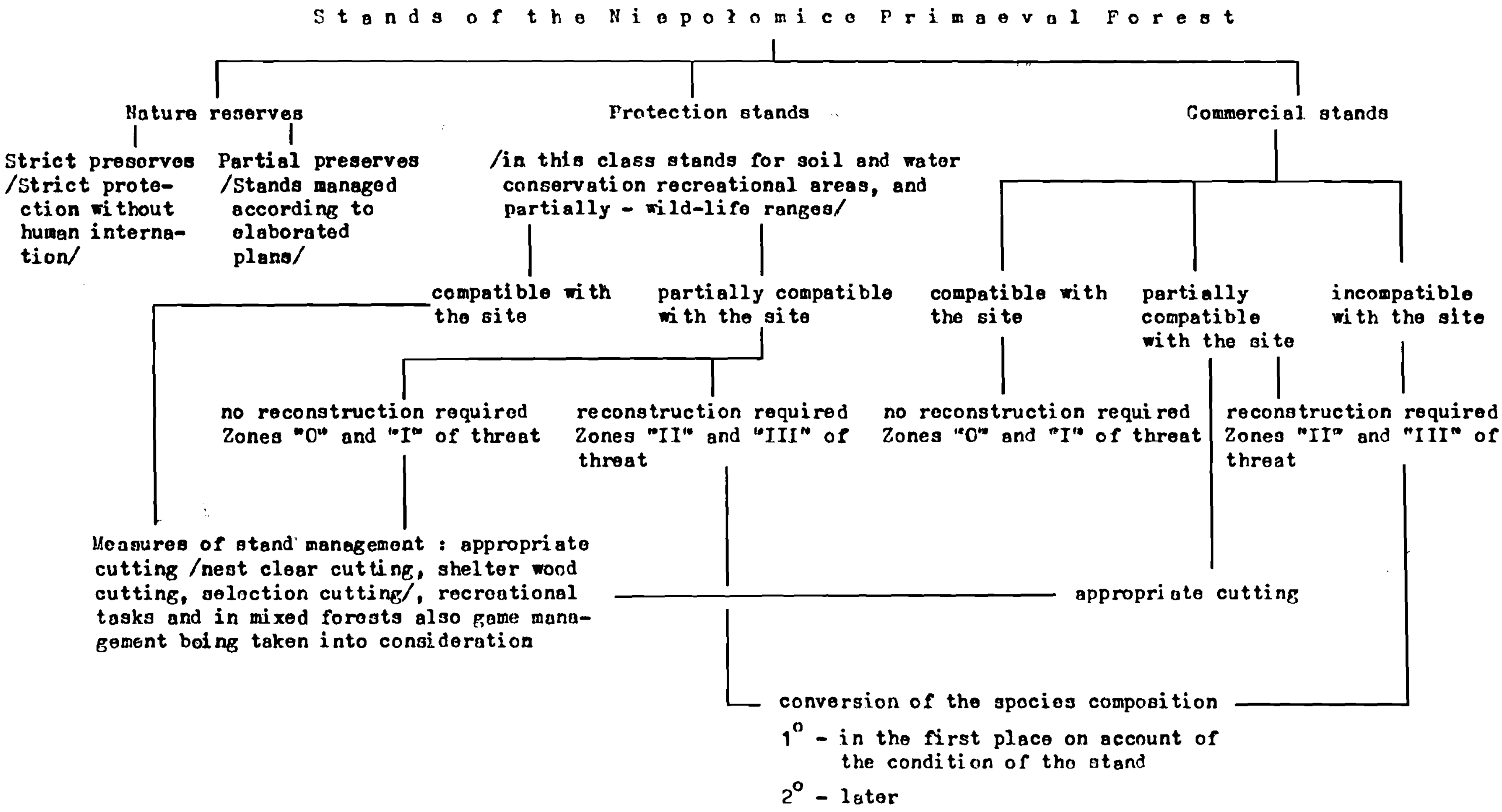


Figure 13. Methods of forest management in Poland.

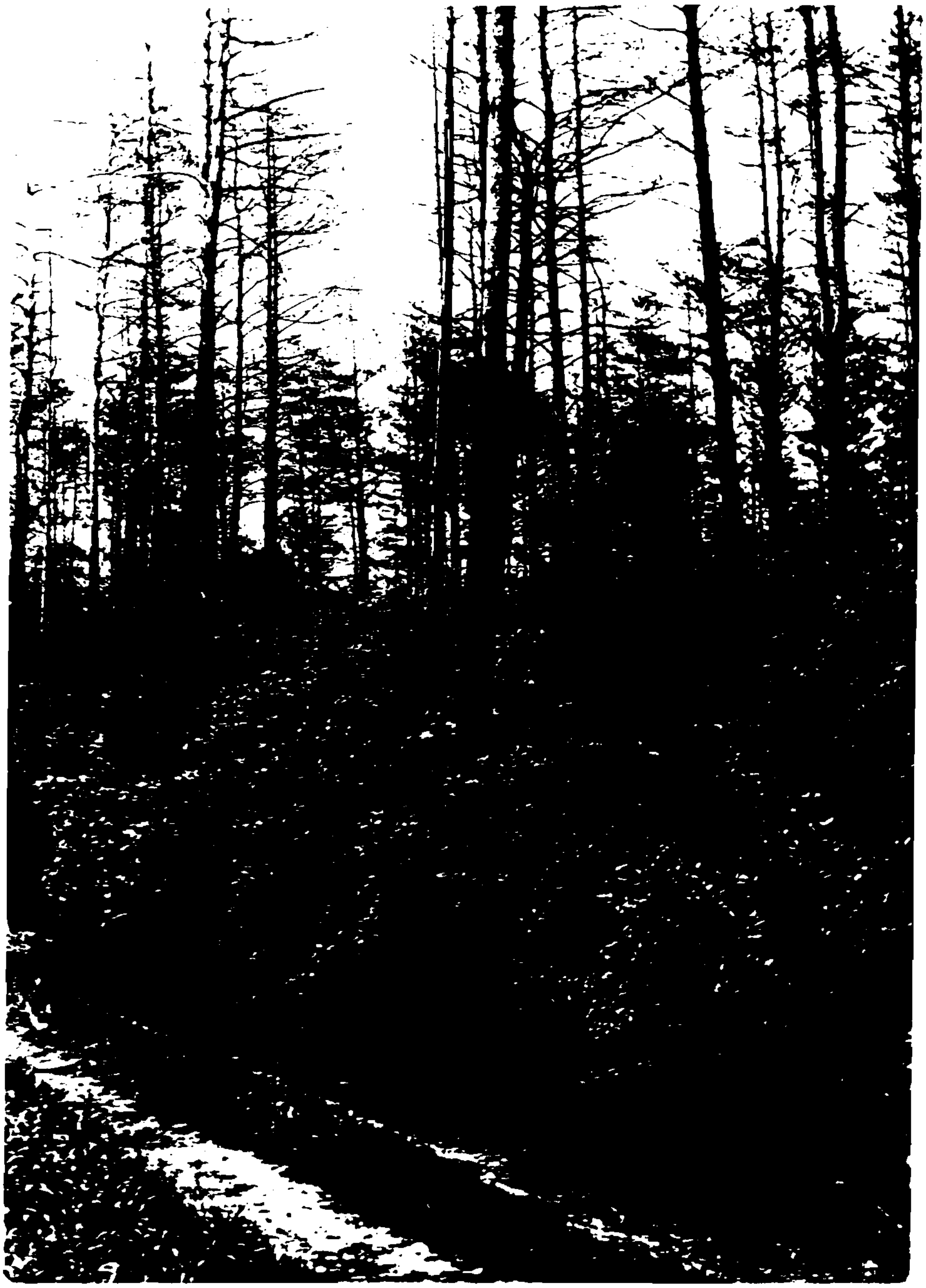


Figure 14. A declining stand underplanted with deciduous species (oak).

Seedlings and thickets with signs of serious damage brought about by industrial pollution, such as bushy form usually without apical shoots, inhibition of height increment, a strong pest infestation, and a stand-density index of 0.7 or lower, should be removed and the area reforested with desirable species.

Stands of medium age classes (the second or higher ones) should be prepared for reconstruction through the introduction of desirable species under the canopy in larger free spaces. In the first order, shade-tolerant species are introduced under the canopy, and then, as more light reaches the forest floor, especially after the removal of the highest trees, regenerations are supplemented with light-loving species. Such measures are not recommended in evenly thinned stands since after some years when the volume and height increase, a proper development of underplanted young trees becomes impossible.

Stands with a 20% admixture of deciduous trees under the canopy of a negative stand may be classified in the regeneration class if the desirable species constitutes 30% at least, beginning from age class II. In such stands the canopy of the stand may be gradually removed, the lower layer being further supplemented with the desirable species.

7. THE MANAGEMENT OF RECONSTRUCTED STANDS

As the above discussion shows, the reconstruction of negative stands may be conducted with all types of cutting, particularly clear-cutting with standard belts (Ia), clear-cutting with restricted belts (Ib and Ic), typical selection cutting (IIb), group cutting (coppice) (IIIa), partial group cutting (IIIb), and selection-coppice cutting (IIIc).

When the clear-cutting method is used, groups and patches of up-growth of natural and artificial origin of desirable deciduous species should be left and protected from damage, if their quality is good. When artificial regeneration is applied by means of planting or seeding, it is necessary to take into consideration the rate of growth of the particular species and the size of their groups. Also, the mixing of specimens of slowly and vigorously growing species should be avoided.

In areas affected by noxious industrial emissions, it is necessary to improve the accessibility of nutrients for the deciduous species introduced on very poor coniferous forest sites. These species, less sensitive to pollution, have greater requirements with regard to fertility. An indispensable condition of good silvicultural results is the improvement of soil sorption and of conditions of nutrition for nursery-grown stock under the canopy, to the period when a suitable density of the undergrowth is reached and the cycling of nutrients through litter decomposition begins. Improvement of the site may be achieved by placing a thick layer of peat mulch under each nursery-grown plant, applying bentonite or dusty waste, and fertilizing with mineral or organic fertilizers (e.g. seeding of lupin).

According to recommendations concerning the modernization of game management, the plantation should include about 10% of trees and bushes which are more attractive for wildlife than are the desirable trees. Among these species are: evonymus, elder, aspen, sallow, alder buckthorn, mountain ash, and hazel. Apart from these species of trees and bushes which are readily consumed by wildlife, food supplies in young stands of thickets and poles may be enriched by leaving negative hornbeam brushwood in transition communities when stand-improvement methods are applied.

Apart from the silviculture measures discussed above, particular attention should be paid to cultivation cutting in younger stands, i.e. the removal or inhibition of growth of trees shown undesirable forms or harmful for the surrounding, and the removal of excessive trees on behalf of the remaining ones. Depending on the stage of growth of the given stand, the following improvement cuttings may be differentiated: early cleaning (CW), late cleaning (CP), thinning (TW), and improvement cutting (TP).

In the case of areas under the impact of heavy industrial pollution, the chief task of cutting is the improvement of the sanitary condition of forests. In a young generation developing in a stand managed by the group (coppice) method of an average period of regeneration, cultivation cuttings are carried out parallel with the progress of the regeneration, i.e. simultaneously with the early and late cleaning and even the thinning, according to the growth of particular patches of regeneration under the canopy. In cultivated forests, the method of selection is obligatory in all kinds of cultivation cutting. The selective way of carrying out early and late cleanings is manifested by the gradual removal of all undesirable components, such as the excessive number of admixtures or trees of improper form, from the species composition of seedlings or thickets. The aim of these measures is to secure the best possible quality and the most vigorous growth of the remaining trees and to obtain the proper species composition and structure of the stand at maturity. The selective direction of thinning is manifested by promoting a suitable number of trees of the best quality and rapid growth, evenly distributed in the stand. This is accomplished by regular cutting of trees interfering in good development of the best trees.

In regions threatened by industrial pollution, there occurs the necessity of an individual approach to particular stands as signs of changes appear, e.g. the excessive self-thinning of deadwood. Therefore, specific silviculture measures should be planned and applied in each stand.

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