Air Pollution and Climate Change Effects on Health of the Ukrainian Forests: Monitoring and Evaluation[1]

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Abstract

Forests in the Ukraine are affected by environmental pollution, intensive forestry practice, and recreational uses. These factors make them sensitive to impacts of climate change. Since 1989 Ukraine has participated in the International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests). A network of monitoring plots has been established in 14 administrative regions and in the Crimea. From 1989 to 1995 the primary estimation criteria by the ICP Level 1 Program — defoliation and discoloration of forest stands — have been observed on 215 plots. Data obtained by the ICP-Forests protocol show that the recent decrease in air pollution was not followed by reduced forest defoliation. Thus, the estimation parameters established for that monitoring program are inadequate to determine accurate cause-effect relationships between forest health and external impacts. Defoliation and discoloration extended and expanded with the support of the USDA Forest Service's Forest Health Monitoring Program (FHM). More intensive and more informative monitoring has been implemented, complementing activities on the primary extensive monitoring network. Climate change impact may indicate pest damage, air pollution, fungi, or weather anomalies. These causes are difficult to identify at the extensive monitoring level. In summer 1995, climate change impact on the Ukrainian forests was estimated using the FHM protocols for forest vulnerability and adaptations assessment. Potential forests, main tree species distribution, and forest communities biodiversity was made estimated by using a geographical information system (GIS).

Introduction

Ukrainian forests cover 10 million hectares and about 14.3 percent of the total country. Forest distribution pattern, growth, and health are connected with temperate, continental climate conditions, except for a narrow strip of subtropical coastal forest in the southern Crimea. Ukrainian forests are composed of about 54 percent coniferous trees and 46 percent deciduous trees. The average annual growth increment is about 4 cubic meters per hectar. Managed plantations are about half of the forested lands. *Pinus sylvestris* L. (about 35 percent of forest stands), *Picea abies* Dietr. (16 percent), and *Abies alba* Mill. (3 percent) are the main forest- forming coniferous species. *Quercus* spp. (22 percent), *Fagus sylvatica* L. (13 percent), and *Carpinus betularius* L. (2 percent) are dominant hardwood species. Softwood genuses are *Betula* spp., *Populus* spp., *Alnus* spp., and *Tilia* spp. (9 percent).

Ukrainian forests are considered valuable environment-forming factors. Among the countries of the former Soviet Union, Ukrainian forests have been strongly affected by anthropogenic sources such as the high levels of air pollution. Overall industrial emission of pollutants was about 17 million tons per year. The main sources are ferrous metallurgical plants and the coal industry. Industrial emissions consist of 21.4 percent particulate pollution, 30.2 percent SO_2, 8.0 percent NO and NO_2, 33.5 percent CO_2, and 6.9 percent hydrocarbons. It is estimated that motor vehicles add about 40 percent to the overall air pollution: more than 51 percent CO_2, 46 percent hydrocarbons, and 22 percent NO_2 of the total volume of emissions are caused by motor vehicles.

This paper discusses the spatial distribution and degree of anthropogenic damage to Ukrainian forests as determined by using the monitoring protocol of the ICP-Forests and the FHM programs.

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Air Pollution

To evaluate the intensity of air pollution, we used generalized data on industrial pollutant emissions from a network of plots (grid size 16x16 kilometers) in 18 administrative regions and big industrial cities in the Crimea Republic from 1985 to 1993 *(fig. 1)*. Since 1985 until 1993, the total amount of pollutant emissions from industrial sources decreased by 52.8 percent. Air pollution levels are expected to continue decreasing with the industry recession.

To determine geographical zones that are homogenous in relation to air pollution, we used the cluster analysis method (Duran and Odell 1974). By using Chebyshev's metrics, data on the total amount of pollutant emissions, their sources, and dynamics were plotted on a dendrogram reflecting the degree of similarity between the territorial units *(fig. 2)*. The dendrogram shows that all the administrative regions can be divided into two classes that differ by total intensity and composition of emission. Further K-means clustering (Duran and Odell 1974) was based on the preliminary hypothesis of only two classes in the sample. The analysis shows that the first class includes the Donetskaya region and parts of Luganskaya, Zaporozhskaya, and Dnepropetrovskaya region (territorial units 3, 5, 7, 8, and 11). The second class includes the remainder units. The first class shows a higher density level of pollution as indicated by emissions within that area and the impact of stationary sources *(figs. 3, 4)*. This resulting classification scheme is used to study relationships between changes in forest health and atmospheric pollution.

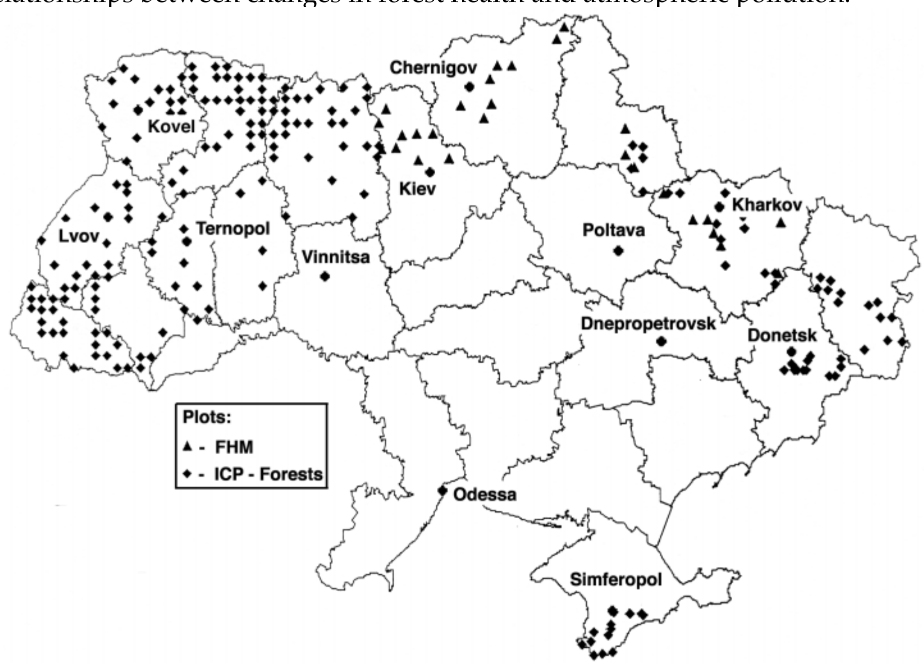

Figure 1 — International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests) and Forest Health Monitoring (FHM) plots.

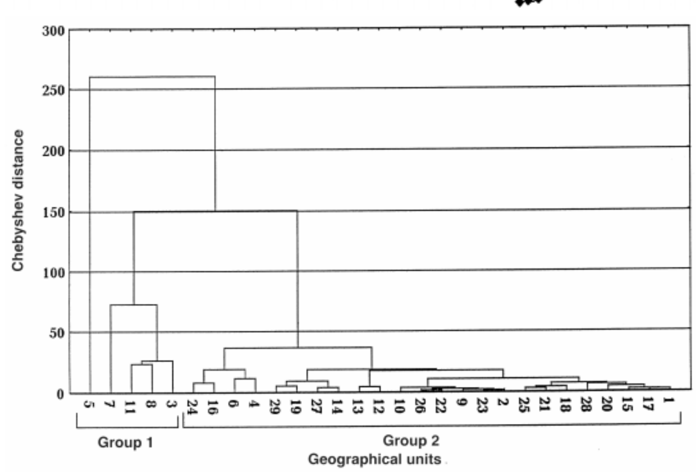

Figure 2 — Differences between geographical units by pollution.

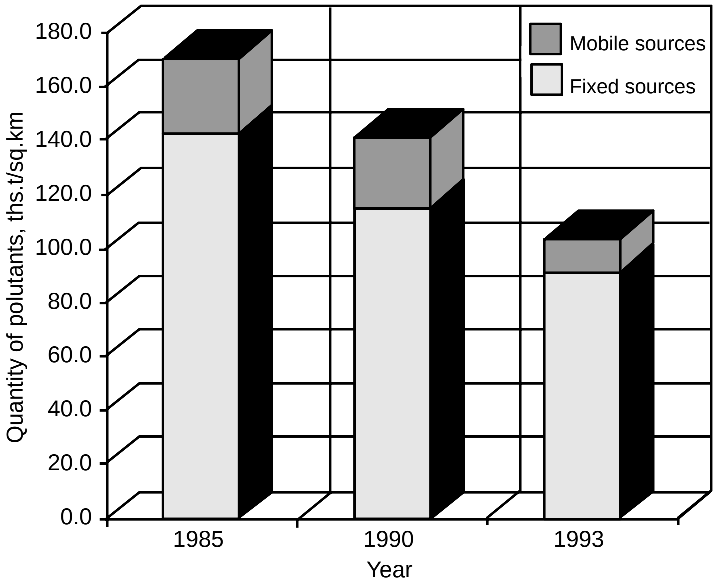

Figure 3 — Emissions by regions with intensive air pollution (Group 1).

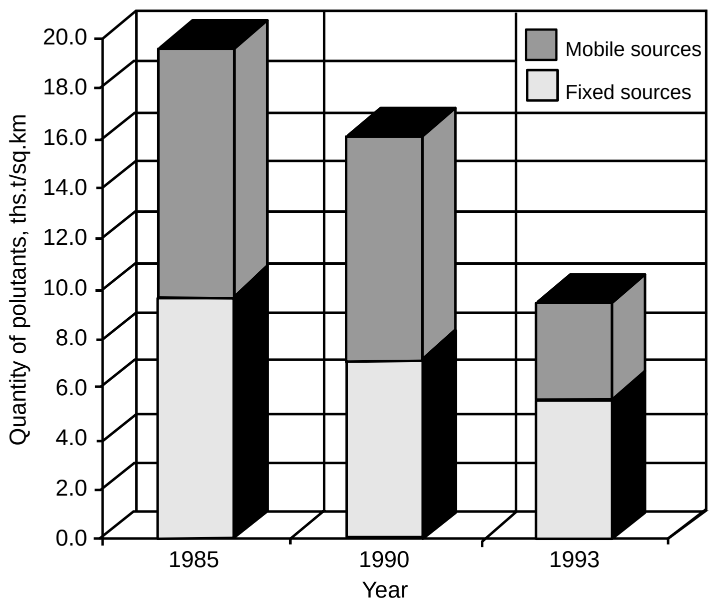

Figure 4 — Emissions by regions with low air pollution (Group 2).

Assessment of Dynamics and Distribution of Forest Damage in the Ukraine

In the Ukraine network, 215 forest monitoring plots have been established *(fig. 1)*, but some plots were not observed annually. There were 53 plots in 1989 (552 coniferous and 736 deciduous trees) and 134 in 1995 (1,467 coniferous and 1,743 deciduous trees). The monitoring is designed to identify zones of forest decline and to study cause-effect relationships between changes in forest health and atmospheric pollution.

Degree of crown defoliation in the stands is a common indicator of monitoring that characterizes the forest condition. For a comparative analysis all data of observations are divisible by the following classes according to degree of crown defoliation: not defoliated, 0-10 percent; slightly defoliated, 11-25 percent; moderately defoliated, 26-60 percent; severely defoliated, more than 61 percent. In accordance with ICP Forests assessment criteria, defoliation less than 25 percent is not considered an indicator of worsening forest condition, since such values may be within the range of natural fluctuation of tree phytomass *(tables 1-4)*.

***Table 1** — Defoliation of all species by classes (1995).*

Total plots	Total trees	Percent of defoliation Class 0 0-10	Class 1 11-25	Class 2 26-60	Class 3 61-99	Class 4 100	Classes 2-4	Classes 1-4
134	3,210	23.6	46.8	28.1	1.5	0.0	29.6	59.3

***Table 2** — Defoliation of all species by 10 percent classes (1995).*

Species	Total	Tree quantity (pct) in 10 percent defoliation classes									
	trees	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
All	3,210	23.6	1.9	3.6	13.0	3.7	1.8	1.0	0.6	0.5	0.3
Conifers	1,467	28.1	0.3	5.6	9.3	3.4	1.4	0.9	0.5	0.5	0.0
Broadleaves	1,743	19.8	3.3	1.9	16.1	3.9	2.2	1.0	0.7	0.5	0.6

***Table 3** — Defoliation of conifers by age group and species.*

		Conifers											
		age to 59 years					age equal or more than 60 years						
Defolia-tion class	Defolia-tion (pct)	*Pinus sylvestris*	*Juniperus communis*	*Abies alba*	*Picea abies*	Total	*Pinus sylvestris*	*Juniperus comm-unisabies*	*Picea abies*	*Abies alba*	Other	Total	Overall
0	0-10	14.3	100	33.3	12.2	50.5	21.4	100	95.5	28.8	100	24.2	28.1
1	11-25	71.4	0.0	50.0	61.1	36.1	51.6	0.0	4.5	27.3	0.0	48.1	46.2
2	26-60	10.7	0.0	16.7	25.6	12.5	25.3	0.0	0.0	43.9	0.0	25.8	23.9
3	61-99	3.6	0.0	0.0	1.1	0.9	1.7	0.0	0.0	0.0	0.0	1.9	1.8
4	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100	100	100	100	100	100	100	100	100	100	100	100

The results showed an increase in tree defoliation during the observational period from 1990 to 1995 *(figs. 5-7)*. Fraction of trees that defoliated to 25 percent increased in 1990 to 1995 from 4 to 27 percent. Average yearly defoliation of the forest stands increased from 9.5 to 22.6 percent. Maximum defoliation as high as 44 percent was found in the Luganskaya region in 1995; the minimum was about 5 percent in the Ternopol'skaya region in 1990. Average defoliation for the whole monitoring period was highest in the Donetskaya (36 percent) and the Luganskaya (28 percent) regions probably because of air pollutants emitted in the Kharkovskaya and Rovenskaya industrial areas (*fig. 8*). The lowest defoliation levels for the whole period were in the Ternopol'skaya (8 percent) and in the L'vovskaya (9 percent) regions. The greatest defoliation was seen in 1994.

Comparative analysis of tree species was accomplished by assessing differences in defoliation levels by years. Neuman-Keuls post-hoc test (Murphy and others 1988) was used to obtain the matrix of the differences reliability. Further analysis related only species with reliable differences from other ones (P-level less than 0.05). Then species' sets were divided into classes so that within a class there is no species with reliable differences in defoliation levels.

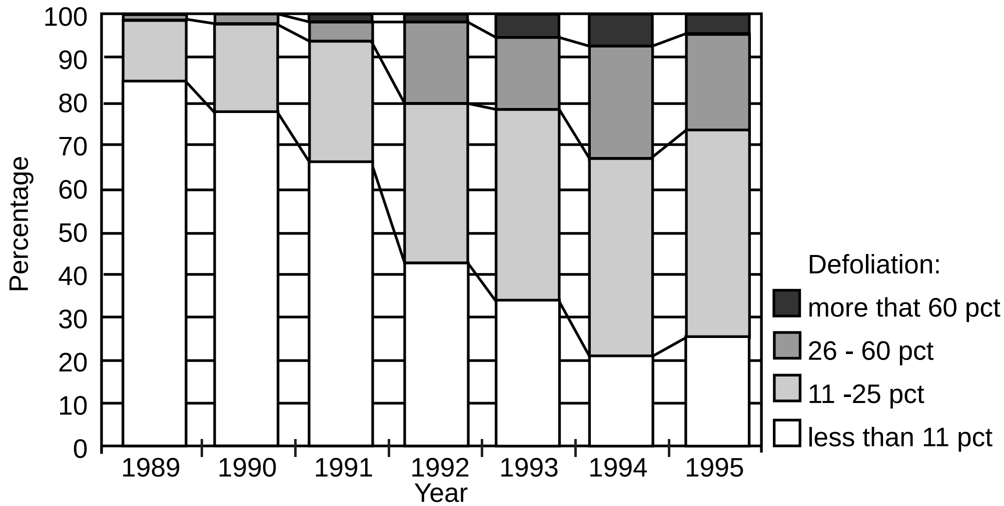

Figure 5 — Defoliation of conifers from 1989-1995.

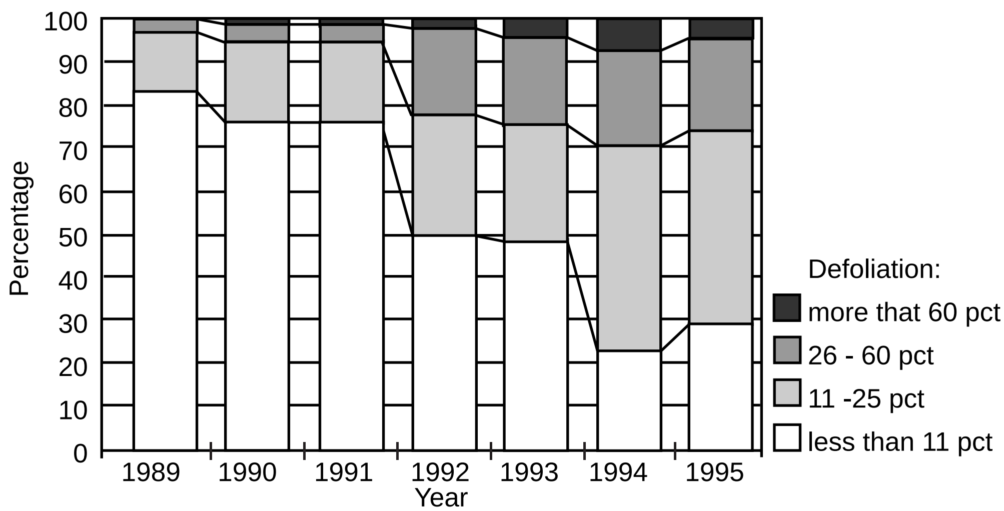

Figure 6 — Defoliation of broadleaves from 1989-1995.

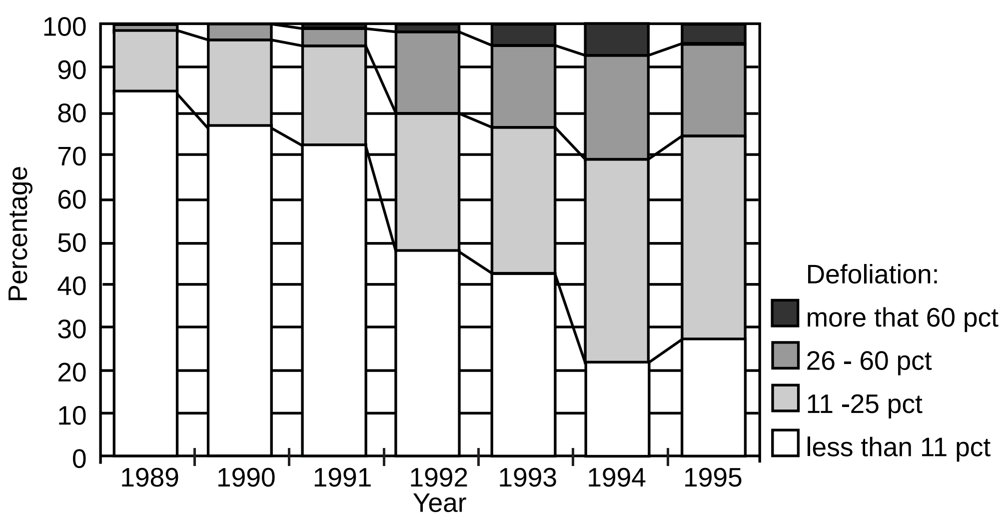

Figure 7 — Defoliation of all species from 1989-1995.

Table 4 *— Defoliation of broadleaves by age group and species.*

Defoliation class	Defoliation percent	Broadleaves												Overall
		Age to 59 years					Age equal or more then 60 years							
		Quercus robur	*Fagus sylvatica*	*Caprinus betularius*	Other	Total	*Quercus robur*	*Quercus petrea*	*Caprinus betularius*	*Fagussylv atica*	*Caprinus betularius*	Other	Total	
0	0-10	20.3	4.2	24.4	44.4	18.1	9.1	12.6	20.9	34.7	20.0	30.2	20.0	19.8
1	11-25	29.0	50.0	24.4	44.4	34.5	49.5	50.3	59.7	33.8	64.0	46.2	48.6	47.2
2	26-60	40.6	43.7	51.2	11.2	42.7	39.5	35.2	19.4	31.5	16.0	23.6	30.5	31.7
3	61-99	10.1	2.1	0.0	0.0	4.7	1.9	1.9	0.0	0.0	0.0	0.0	0.9	1.3
4	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

The data collected were used to group species by defoliation change rate by using cluster analysis of average defoliation values:

- Group 1—*Betula verrucosa, Ulmus spp., Quercus robur, Alnus incana, Pinus sylvestris;*
- Group 2—*Fagus sylvatica, Quercus petrea, Acer tataricus, Acer pseudoplatanus, Tilia cordata, Juniperus communis, Abies alba, Fraxinus exelsior;*
- Group 3—*Betula pubescens, Fagus orientalis, Carpinus orientalis, Carpinus betularius, Acer platanoides, Alnus glutinosa, Populus tremula, Pinus pallasiana, Padus racemosa;*
- Group 4—*Quercus pubescens, Picea abies, Juniperus oxycedrus.*

Group 1 had a relatively uniform defoliation growth rate *(fig. 9)*. Its average defoliation rate was greater than for any of the other groups (except for group 4 in 1993). Group 3 had the same pattern. However, the average defoliation rates for group 3 was reliably lower than the rest. The defoliation rate of group 2 steadily increased from 1989 to 1994, then noticeably decreased in 1995. Group 3 was different from others due to the high defoliation peak in 1993. We expect the cause of the peak was the particular climate conditions in 1993 and decreased defoliation in 1994 and 1995. The measured pattern of defoliation changes in the Ukraine forests showed that their photosynthetic function continues to decline. Defoliation of group 1—consisting of main forest forming species, *Quercus robur* and *Pinus sylvestris*—tended to steadily increase. Its correlation coefficient for linear trend D=3.7279xT+2.4141 was 0.8989. To isolate causes of defoliation change patterns will require longer time-series observations and more adequate and complete data sets of measurements.

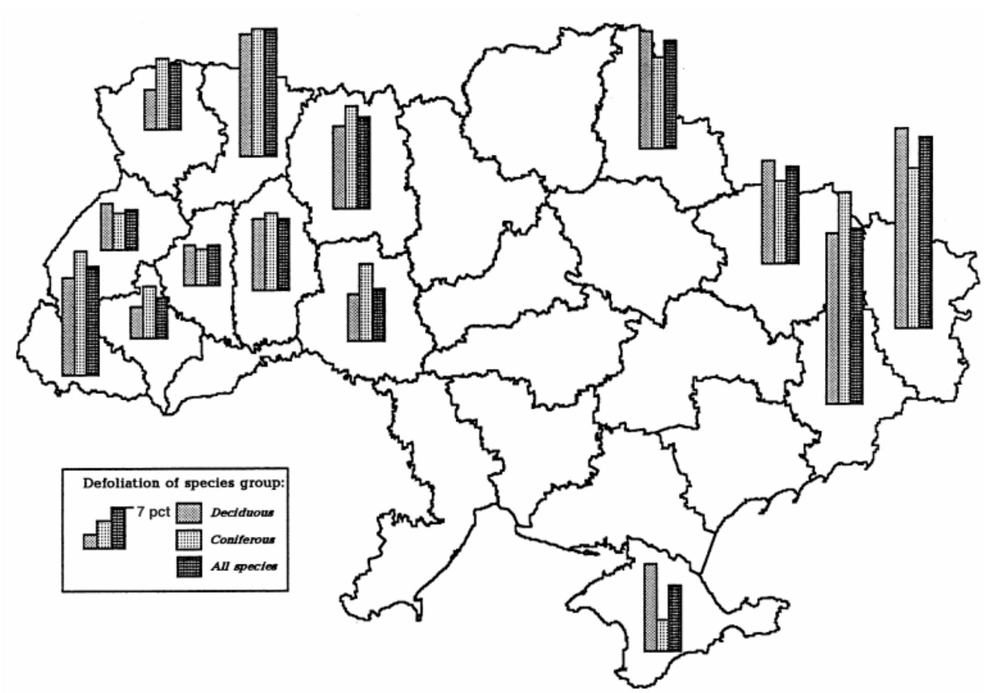

Figure 8 — The mean defoliation by regions in the Ukraine from 1989-1995.

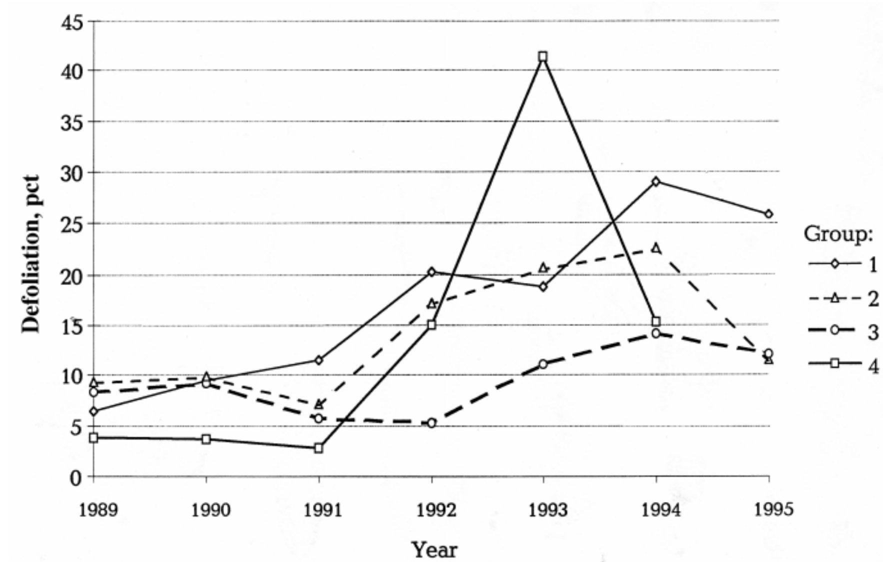

Figure 9 — Defoliation of species groups from 1989-1995.

The expected decrease of general defoliation has not occurred in spite of the considerable decrease of air pollutant emissions since 1992 in the Ukraine. The possible causes of this phenomenon include:

- Affect of accumulation of pollutants in soil from previous years;
- Global climate changes;
- General increase of anthropogenic factors on forest ecosystems (lumbercamp, pesticides and herbicides, recreation, drainage, and irrigation, etc.);
- Advection of pollutants to Ukrainian forests from upwind industrial countries.

In 1989, 82.9 percent of coniferous trees were not defoliated, 15.9 percent were slightly defoliated, and 1.4 percent were moderately defoliated. In 1995 the percent of non-defoliated trees fell (24.7 percent), and the percent of slightly and moderately defoliated trees increased (48.7 and 24.6 percent, respectively). In 1989, 84 percent of deciduous trees were not defoliated, 12.9 percent slightly, 3 percent moderately, and 0.1 percent were severely defoliated. In 1995 the portion of non-defoliated trees was the least (19.8 percent), and the portion of slightly, moderately, and severely defoliated trees increased (49.3, 30, and 0.9 percent, respectively).

Among the coniferous trees, *Pinus* and *Picea* (*Juniperus* in Crimea) had the highest defoliation, while *Quercus, Fagus, Caprinus,* and *Betula* were the most defoliated among the deciduous trees. However, the observed defoliation and discoloration may be induced by pests, diseases, air pollution, or weather anomalies. In order to isolate a real cause-effect relationship between forest conditions and external impacts, we used complex methods of analysis.

GIS Mapping

Sustainable forest management requires the development of methods for forest health and productivity forecasting. Assessment of the forests' vulnerability to global climate change is one of the generally recognized problems that needs such forecasting. The research team from the Ukrainian Forestry Research Institute has gained experience related to forests' vulnerability assessment to global climate change as a participant in the USDA Forest Service's Forest Health Monitoring Program (FHM). The computer geographic information system (GIS) mapping of potential vegetation land cover was the primary approach to assessing the impact of climate change on forests. Vegetation cover prognosis was based on Holdrige (1967) life zones and on Ukrainian forest land classifications (Holdrige 1967, Vorobjov 1960). Climate change scenarios GFDL, GISS, UKMO, and CCCM (IPCC 1990) from general circulation models were used for projection with the classification models, and maps of potential forest distribution were used to assess the general pattern of climate change impacts. Large scale changes in biological productivity of forest stands were estimated with climate-related productivity indexes (Anuchin 1977). As an initial approach to describe future forest composition, the ranges of climatic species were modelled to determine dominant tree species. Incorporation of forest ecosystem models (gap-type models) provided more detailed forecasts for the most vulnerable forest sites. However, gap-models are inadequate to assess conditions in the Ukraine, and serious problems within the use of gap-models developed in other regions. Ukrainian silviculture uses particular assessment indices for plant response to climate change that are different from the gap-models requirements.

The methodological void in the assessment approach is between the large-scale level of climate conditions and the "locally specific" gap-models that are difficult to spatially extrapolate. Thus, methods for mid-scale impacts assessment were proposed by using the Ukrainian school of forest typology (Alekseyev 1929, Lavrinenko 1954, Pogrebniak 1968, Vorobjov 1960), which synthesizes forest-typological maps from mid-scale maps of soils, hydrology, and relief (1:100,000 - 1:1,000,000).

There are numerous forest-typological classification schemes developed by the Ukrainian school (Ostapenko 1978). They mainly differ by forest land classification criteria used to determine soil humidity and trophic conditions. The latest research involves the improvement of quantitative indices for the criteria and extension of climatic and edaphic grid models onto representation of trophically poor, more warm, and more dry sites. To make mid-scale maps of forest growth conditions (e.g.,forest land maps, forest edaphic maps), forest typology schemes require synthesis of two maps: forest trophic conditions and soil moisture availability. Forest trophic conditions may be derived from available soil maps: tables of correspondence can be established between soil types and trophic indexes compiled from empirical data. However, a preferable for trophic index evaluation method is to estimate the content of phosphorus and potassium in the root inhabited layer of soil. The territorial units of the resulting mid-scale edaphic maps describe edaphic conditions with some degree of generalization, depending on the scale and accuracy of source maps. However, the forest-typological meaning of such an edatope is subject to study. Actually, adjustments of forest estimation methods to the "mid-scale" edatope are required. This methodology is applicable to the broad scale assessment of global climate change and damage caused by air pollution.

Discussion

This assessment of the relative changes of tree foliage suggests a progressive deterioration of crown condition from 1989 to 1994 followed by a slight improvement in 1995. The highest level of defoliation was found among the main conifers, *Pinus* spp. and *Picea* spp., and among the main broadleaves *Quercus* spp., *Fagus* spp., *Carpinus* spp., and *Betula* spp. Forests of the southeast region were the most affected, and the most damaged forests are located in the regions with higher pollution density. However, air pollution is not the only influence on forest health because climate conditions of this region are also not favorable to forest growth.

The set of estimation parameters used for the initial forest monitoring program are not adequate for the determination of real cause-effect relationships between forest conditions and external impacts in the Ukraine. These impacts are air pollution, pests, fungi diseases, unfavorable weather conditions, and intensification of anthropogenic pressure on forest ecosystems. Study of the global climate change influence on forests shows the attributive data composition that is necessary to resolve this problem.

To obtain adequate forest ecosystem data, we must develop a multilevel monitoring system that includes extensive and intensive items. Since 1995 an extensive monitoring system designed according to the ICP-Forests approach was extended with the support of USDA Forest Service's Forest Health Monitoring Program (FHM). This observation program can provide data collection methods that may be used for gap-model development and forestry statistics interpretation. In summer 1995 the Ukraine implemented these methods with the support of the FHM program. A data base has been established to gather data on 32 plots. In addition, more intensive programs to observe Ukrainian forest ecosystems have also been prepared.

To effectively use these methods, they must include forest typology classification of forest growth conditions. This will ensure proper interpretation of the monitoring results and adequate assessment of forest condition dynamics affected by various external factors, including global climate change.

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