Int. Agrophysics, 1998, 12, 361-371

ENVIRONMENTAL IMPACT OF EMISSIONS FROM THE NITROGEN FERTILIZER PLANT IN PUŁAWY

L. Puszkar[1], *T. Puszkar*[2]

[1]Institute of Soil Science and Plant Cultivation, Puławy, Czartoryskich 8, 22-100 Puławy, Poland
[2]Department of Nature Conservation, University of Maria Curie-Skłodowska, Akademicka 19, 20-033 Lublin, Poland

Accepted September 1, 1998

A b s t r a c t. The impact of the nitrogen fertilizer plant in Puławy involved profound, destructive alterations to the broad-sense natural environment which comprised not only the soil, water and air but also plants and animals. Initially, at the end of 1960's and at the beginning of 1970's the changes were very acute only to become of chronic character later on.

The results of the studies were used as bio-indicators to measure both the extent of damage to the environment and to assess the validity of the methods developed to reclaim the degraded environment.

Tested and calibrated as a synthetic bio-indicator of air pollution in the Puławy area, lichens were used as a tool to evaluate the extent of air contamination with different kinds of emission. Those measurements can also be used in monitoring large areas, a very important practical consideration with respect to assessing environment pollution status.

K e y w o r d s: nitrogen works Puławy emissions, environmental impact

INTRODUCTION

The area affected by the nitrogen fertilizer plant in Puławy is one of the best studied with respect to impact of industrial emissions, their kind, time and mode of action. Within a very short time after the plant was put in operation, as early as in 1967 adverse changes were recorded in the surrounding forest environment, and the affected area kept increasing in size (Figs 1and 2). A zone of "biological death" arose very quickly to be described in many publications [e.g., 1,14,20,23-27,31,39-41,51,52, 54]. Comprehensive investigations were started into both the effect of the damage to environment and on the search of their underlying causes in the agricultural and forest environment [20,39-41]. The physiological response of plants to various pollutants resulting in die back, malformations, changes in chemical composition was the prime object of interest. The survey included tree species such as, e.g., pine, birch, oak [8,12,15,16,20,42] different crop plants such as cereals, root crops, vegetables, medicinal plants, ornamentals [40,41,54], wild vegetation including changes to units of vegetation [6,7,20,23,24,42] and changes to the fauna [9-11,22,31-34,38,43,44]. Possibility of using changes to the flora and the fauna as bio-indicators of the processes taking place in the environment was also investigated [9-11, 19,20,23-25,27,31-36].

The study was set against the background of changes in the atmospheric pollution by taking physical measurements [2,39-41] of microclimate [39-41,52], changes in the chemical composition of water [5,51] and changes occurring in the soil [3,17,20.39,41,51]. In addition, agricultural and forest research was conducted into the possibilities of checking the damage to the environment in the Puławy area [20,39-41]. Another focus of research was on the manner in which crops grown in the "biological death zone" can be utilized [40,41] and the issues related to health risks to humans

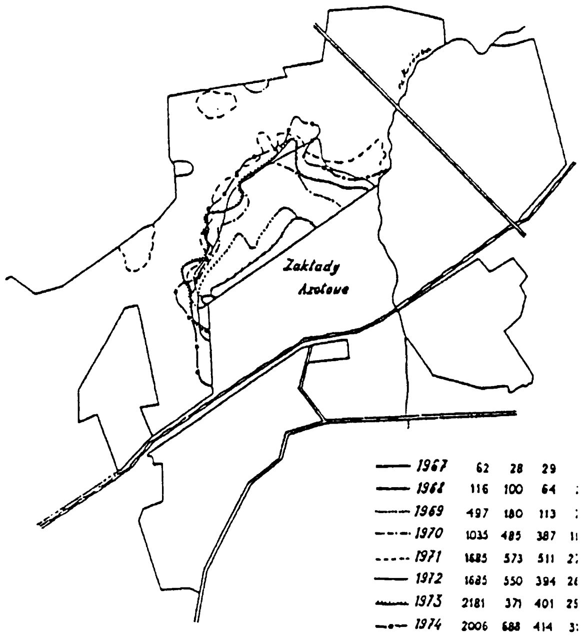

Fig. 1. Range of the biological death zone in the emission-affected area of the fertilizer nitrogen plant in Puławy over the years 1967-1974.

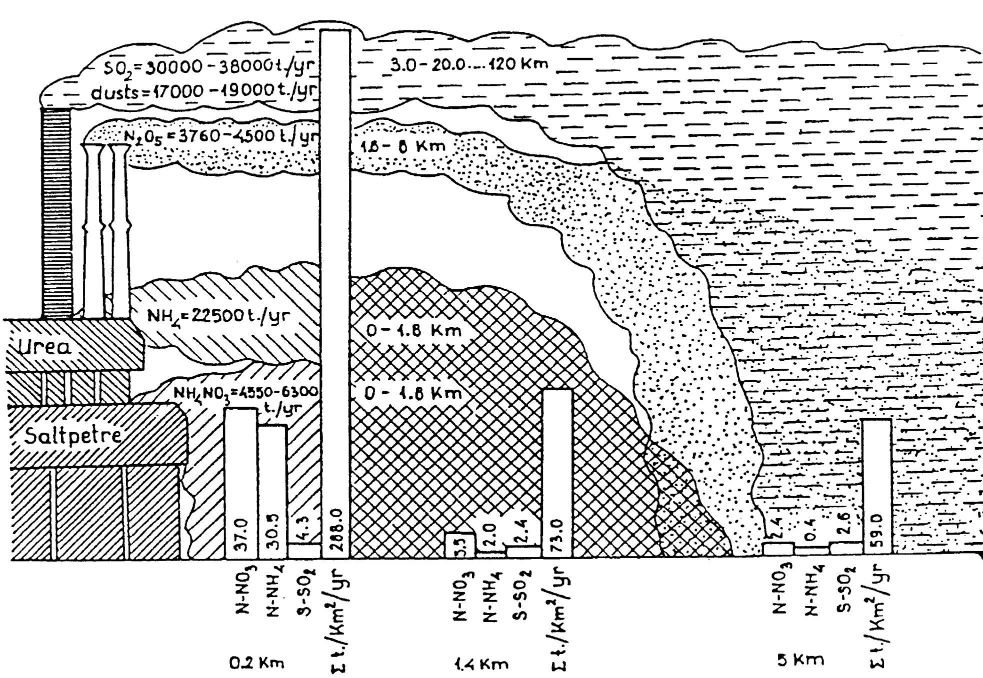

Fig. 2. Range and rate of emission from the Nitrogen Plants in Puławy in 1967-1974.

[47,48,50]. As a result of those many-sided investigations a comprehensive image was obtained of the destructive impact that the nitrogen fertilizer plant at Puławy has on the natural environment [20,40,41].

THE COMPLEX SYSTEM OF ENVIRONMENT DEGRADATION

The nitrogen fertilizer plant in Puławy was located in a deforested area occupied by weak habitats of dry (54%) and fresh (27%) forest on sandy dunes low in nutrients, chiefly in nitrogen and suffering periodical acute water deficits.

The production of urea was started in the autumn of 1966 and the first damage to pine stands occurred as early as the spring of 1967 [8,12,13,41]. Since that time the area with damage to the pine stand has been spreading outwards [12-14,20,21,45].

Excessive concentration of nitrogen compounds affects the trees in two ways: directly by causing necrosis, death of the assimilation apparatus and precocious shedding of needles. In the most severely affected area only one-year old needles were present. As a result, i.e. because of the reduced life span of needles, the surviving needles were excessively long. The growth of the trees became checked and their crowns became deformed. Branches and twigs dried up resulting in dried tree-tops, especially during winter as the shoots, water-soaked and not lignified enough, were killed by frost [12,13,15,16,21].

Indirect impact was primarily related to a sudden enrichment of the soil and water with excess nitrogen resulting in an intensive transformation of the soil environment. Before the construction of the factory was started the soils in the area had been generally poor and characterized by periodical shortages of water and of some biogenes, especially of nitrogen. Having grown under the shortage of nitrogen the pine trees started to take up the nutrient from the soil more intensively leading to the increased nitrogen contents of needles and of bark [12,13,21]. Under the over-abundant surplus of nitrogen other nutrients also were taken up more vigorously which shortly led to deficits of phosphorus, potassium, magnesium, calcium and a number of micro-nutrients [1,2, 17,20,39-41].

Thus the primary cause which was the excessive fallout of pollutants enhanced by original water relations being disturbed through the construction work was further aggravated by changes in the soil and water environment.

Dying of pine needles and shoots resulted in more sunlight penetrating to the bottom of the forest which combined with a transitory increase in soil fertility enabled profuse development of the undergrowth, particularly that of birch and oak, as well as of bushes. Those plants benefited from the increased supply of nitrogen, which while being toxic to the pine-tree, was necessary for their good growth. The makeup of the undergrowth started to shift towards species characteristic of forest clearing habitats and those associated with human habitations, most of them thriving on nitrogen-rich soils [6,8,20,23,24,39-42,46]. Those species, along with trees and bushes, contributed to a fast depletion of nutrients and to an increased water deficit. The changes in the soil environment brought about changes in the composition of plant communities. It became manifest as changes of the specific makeup, changes in frequency and domination of species and in the output of plant communities (Fig. 3).

Superimposed on changes in the soil and in the flora were those in the fauna. Due to a fast rate at which the weakened tree stands died back, animal species classified as pests (especially secondary pests attacking weakened tree stands) did not manage to benefit from the momentary surplus of food in their natural succession cycles because the trees were dying too fast [20,38]. Likewise, other animal species living on plants receded as the forest vegetation died back and were not capable of colonizing large patches of transient vegetation, ruderal or native to habitations and forest clearings. Also the predatory fauna which plays an important balance-maintaining role in the ecosystems died or moved elsewhere very rapidly due to the rapid changes in the species they preyed upon [19,20,22,31-36].

An increased shedding of needles, water deficit which grew from periodic to continuous, the changes in the nutrient content of water and soil, and a continued heavy fallout of pollutants slowed down the process of breaking down the forest litter both by soil fauna [9-11,31,33,34] and by microbes [39, 41]. The soil fauna was the first to give way [9-11,31,33,34] to be followed by soil microbes transforming from active to resting stage thereby reducing the microbiological activity of the soil and resulting in a progressive build up of non-decomposed organic matter contributed mainly by dead trees [3,39-41].

Changes in the morphology of tree crowns, increased access of light to the surface, changes in the undergrowth followed by drying and dying of trees together with an increasing water deficit also resulted in significant microclimate changes, especially in an increased difference between the minimum and maximum temperatures, changes in air humidity and the extension of the drought period [52]. Seasonwise, there was a distict shortening of the spring season, lengthening of the summer drought period, and shortening of the autumn plant growth. Autumn plant growth tended to shift toward winter as the water deficit further aggravated by the surplus of nitrogen compounds in the soil was relieved by late-season rains. The unprepared plants were devastated by first autumn freezes and the ensuing losses, especially in broadleaved stands, were substantial [52].

In the study of the area affected by the nitrogen fertilizer plant further account has to be taken of the interactions between pollutants which aggravated the contamination situation by generating new toxic substances. It became apparent from the study of lichens as indicators of air pollution and especially by their chemical composition resulting from absorbing air-borne compounds [25,27,29,30]. The study revealed that the environment in the Puławy area is damaged not only by nitrogenous compounds, but also by sulphur emission, both directly and by altering the acidity of the environment [27,51].

FLORA- AND FAUNA-BASED INDICATORS OF THE DEVASTATION OF THE ENVIRONMENT IN THE PUŁAWY AREA

The process of forest dieback brought on by industrial emissions came about in a few stages. The first to give way to pollution was the pine tree through the loss of part of its assimilation apparatus. Physically exposed to emissions after the pine trees were felled birch trees were the next to be affected followed by oak trees. Initially, branches and small twigs died during winter and new twigs and leaves were put out from auxiliary buds on the trunk resulting in bizarre-looking, broom-shaped trees. The patches of vegetation which had appeared in the tree-less desert-like areas also retreated leaving behind an exposed ground littered with non-decompossed plant debris. Investigations of the soil, forest trees, crops and animals yielded evidence of the zoned character of the effect of air-borne industrial pollution on the environment in the Puławy area. The zones spread outwards from the fertilizer plant as the devastation of the environment progressed. Starting from zone 0 and moving on to zone 3 the description of forest decay along with processes and phenomena characteristic of each zone can be made by the use of plant and animal bio-indicators.

Flora bio-indicators

By using bio-indicators which are based on the responses of individuals and species and on the changes of plant communities we obtain the assessment of both the direct impact of the emission and of its indirect effect through changes in the soil, water and air. Thus it is a synthetic indicator of changes of a number of environment parameters.

While making the assessment of the extent of damage to the environment by the use of indicator plants physiological changes were of prime consideration. Based on this, suggestions were put forward to determine pollution zones by evaluating needle age and the rate of needle dieback [12,14,15,20,42,46]. This method is currently used to evaluate the impact of industrial emissions on forests. Based on those evaluations, in 1980 a map of damage to forest tree stands was produced, on which 4 zones of atmospheric pollution in the Puławy area were shown (Fig. 3).

0 - no injury zone

I - low hazard zone

two to three needle age groups, slight light yellow discoloration of needle tips, 25% of trees show damage symptoms

II - medium hazard zone

one, or occasionally two needle age groups, light yellow discoloration gradually passing into dark brown progressing from the base to the tip, 25 to 75% of the trees show damage symptoms, frequent deformations and thinning of tree crowns, drying up of twigs and single branches.

III - high hazard zone

one-year old needles only, extremely long with brown lesions, pine-tree crowns severely thinned and disfigured, entire stands dying back quickly, more than 70% of trees show damage.

In addition, note was taken of the fact that the pollutant content of the bark or other parts can also be good indicators of pollution [13,21].

In order to assess the range of the emissions from the nitrogen fertilizer plant, forest plant communities as well as the newly established communities of plants associated with human habitations and forest clearings can also be screened for pollution-related changes. Those changes involved the specific makeup, domination, and primary productivity [16,20,23, 24,39-42]. Floristic bio-indicators were also used to assess the validity of the several approaches used to reclaim the devastated area [20,23,24,39,41].

The study furnished evidence that the pollution-devastated area around the nitrogen fertilizer plant can be reclaimed solely by resorting to agricultural means which take account of the specific husbandry applied to the area.

Since changes in the vegetation and the reactions of individual species provide a synthetic indicator that involves the action of many

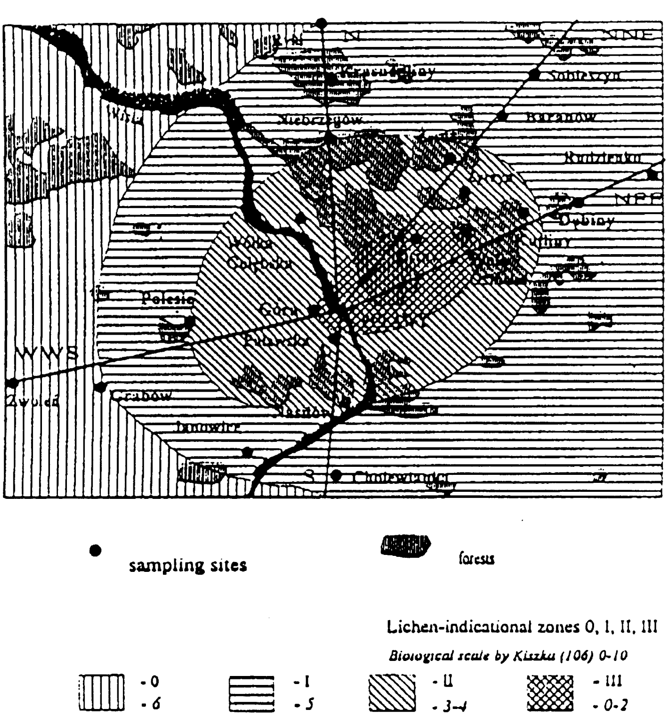

Fig. 3. The range of lichen-indicational zones in the environs of Puławy on the basis of epiphytic lichen distribution.

environmental factors (soil, water, air) and industrial emissions are the basic cause behind those changes, for the Puławy area a method was developed that makes use of lichens as bio-indicators [4,25-27,29,30,39,41, 53]. In that method lichens, local and transplanted, are analysed for pollutant contents, rate at which the alga component of the lichen dies down, i.e., the ratio of living to dead cells - viability index (Tables 1 and 2).

Four zones of air pollution in the Puławy area were distinguished based on synthetic pollution coefficients that take account of lichen morphological responses (percentage of living and dead alga cells, viability index) and of lichen-accumulated amounts of N and S:

Zone 0 - occurred sporadically and involved areas in which lichens showed no visual lesions such as discoloration or necrosis. For the lichens of that zone the percentage of living alga cells was from 75 to 100%. The viability index was over 2.0 and nitrogen and sulphur contents of the thalli were below 1.3% and 400 mg kg^{-1}, respectively.

Zone I - was characterized by the presence of light-grey lichens. The percentage of living alga cells was 50.1 to 75%, the viability index from 1.0 to 2.0, and nitrogen and sulphur contents 1.31 to 1.60 and 401 to 700 mg kg^{-1}.

Zone II - was characterized by heavy damage to lichens, which showed light brown, or brown and pink discolorations, percentage of living alga cells reduced to 25.1 to 50%, viability index from 0.51 to 1.00, nitrogen content from 1.61 to 1.90% and sulphur content from 701 to 1,000 mg kg^{-1}.

In Zone III the exposed lichens turned to brown, often with necrotic spots. The percentage of living alga cells was from 0 to 25%, the viability index was below 0.50% and the nitrogen and sulphur contents were over 1.90% and 1,000 mg kg^{-1}.

T a b l e 1. Changes in the appearance of thalli across the emissions impact zones around the nitrogen fertilizer plant in Puławy over the years 1982 - 1989

Zone	Distance from emitter (km)	Morphological changes of thalli
0	>30	no visual damage to thalli
I	30-21	light ashy discoloration
II	20-16	beige or beige-pink discoloration
III	15-0	brown discoloration with rolled upwards gutter-like margins

Fauna bio-indicators

Extensive research on the fauna occurring in the area around the nitrogen fertilizer plant in Puławy was launched by the Research Institute of Forestry [20], by the Institute of Soil Science and Plant Cultivation [39-41] and by other research establishments [22,43,44] almost as soon as the factory was put in operation (Table 3). They focused on phenomena which could be linked to particular extent of damage to the environment and also could provide the basis for an attempted assessment of the impact of industrial emissions on the different classes of fauna in the factory-affected area. The responses of the fauna in the pollution zones were as follows:

Zone 0 - alterations to the forest environment were still not found and the incidence of pests was comparable to that in the whole area under the Puławy Forest Administration.

Zone I - damage and alterations were small. The first to occur were changes in the patterns of animal populations [19,20]. The

T a b l e 2. Pooled data on cell percentage and on viability index of lichens exposed to pollution in the Puławy area (after Puszkar [27])

Zone	Distance from emitter (km)	% cells living	% cells dead	Viability index	Nitrogen content (%)	Sulphur content (mg kg^{-1})
0	>30	75.1 -100.0	0.0 - 25.0	>2.0	<1.3	<400
I	30-21	50.0 - 75.0	25.1 - 50.0	1.01-2.00	1.31-1.60	401-700
II	20-16	21.5 - 50.0	50.1 - 75.0	0.51-1.00	1.61-1.90	701-1000
III	15-0	0.0 - 25.0	75.1 -100.0	<0.50	>1.90	>1000

T a b l e 3. Correlation between the animal groups and the ecological factors Puławy 1974

Animal	Emission			Plants (%)			Climatic factors					Soil factors				Soil fertilizing		
	$S\text{-}SO_4$	$N\text{-}NO_3$	$N\text{-}NH_4$	covered	forest plants	field plants	light	soil moisture	evapo-ration	temp. max	temp. min	soil temp.	pH	% of humus	thicknes s of A horizon	$N\text{-}NO_2$	$N\text{-}NO_3$	$N\text{-}NO_4$
Soil forms Euedaphon hemiedaphon	-0.069	-0.186	0.038	0.407	0.331	0.180	0.016	0.126	0.109	-0.100	-0.116	-0.121	0.185	-0.040	-0.069	-0.202	-0.166	-0.138
Epedaphon	-0.226	-0.303	-0.165	0.114	0.263	-0.129	-0.063	0.144	-0.247	-0.329	-0.263	-0.169	-0.134	0.036	0.022	0.041	-0.045	-0.045
Atmobionts	-0.033	0.141	0.373	0.095	0.062	-0.020	0.198	0.103	0.248	0.304	0.147	0.176	0.006	-0.140	-0.196	-0.175	-0.206	-0.181
Σ	-0.204	-0.204	-0.030	0.234	0.328	-0.054	0.012	0.118	-0.084	-0.186	-0.182	-0.113	-0.041	-0.022	-0.079	-0.096	-0.155	-0.136
Lumbricidae	0.348	0.322	0.186	0.934	0.036	0.537	0.413	0.242	0.287	0.086	-0.218	0.173	0.101	-0.323	-0.181	0.119	0.314	0.420
Myriapoda+ *Isopoda*	-0.302	-0.459	-0.377	0.034	0.434	-0.305	-0.488	-0.304	-0.419	-0.596	0.018	-0.303	-0.225	0.108	0.170	-0.129	-0.196	-0.165
Insect larvae	-0.088	-0.027	-0.011	0.327	0.240	0.163	0.058	0.153	0.171	-0.037	-0.112	-0.126	0.195	-0.039	-0.075	-0.184	-0.161	-0.117
Carabidae	-0.296	-0.058	-0.036	0.105	0.198	-0.035	-0.277	-0.168	-0.017	-0.210	0.078	0.062	-0.174	0.028	0.260	-0.232	-0.276	-0.261
Formicidae	-0.237	-0.299	-0.249	0.101	0.291	-0.164	-0.047	0.185	-0.291	-0.323	-0.245	-0.198	-0.094	0.023	-0.086	0.031	-0.043	-0.035
Aranca	-0.012	-0.267	-0.181	0.063	0.179	-0.112	0.115	0.302	-0.286	-0.297	-0.458	-0.272	-0.083	0.055	-0.084	0.279	0.200	0.188

frequency curves for individual members of soil and surface fauna became progressively flattened as the emission pressure increased. The shifts were towards large number of species represented by very few individuals and a decreased number of species characterized by high populations. The frequency of trapping events and the populations in soil samples were reduced, especially in case of hitherto populous species. Another important phenomenon was the change of dominant species belonging to different systematic groups [9,11, 19,20,39,41]. At that stage of environment degradation a frequently observed phenomenon was a short-lived rebound in total numbers of whole groups under investigation which was very often mistaken for the response to reduced emission pressure whereas actually the rebound was related to changes in domination patterns i.e., to the recession of the dominants and the sub-dominants of the former structure, the vacant ecological niches being temporarily occupied by increased numbers of former recedents and influents as they moved up to higher ranks.

In that zone there occurs what Pawłowski [49] and Rajski [37] described as the "closed community stage" of the order of succession. In that stage the transformations are quantitative and affect mainly the dominance systems, the specific compositions being unchanged or changed but slightly. In that system homeostatic mechanisms still continue to function by activating and mobilizing substitute chains. Attempts to aid such an ecosystem by resorting to either agriculture or forestry-based measures is still a viable option provided that the underlying cause, in this case further emissions, is stopped thereby stopping further buildup of pollutants in the soil.

Zone II - medium heavy damage and alterations. Research revealed that within groups dissimilar with respect to their trophicity, e.g., ground beetles [19,20] changes in mutual ratios of zoophages and phytophages occurred [9,11,20,34]. The domination of entire animal groups rather than individual species became changed and replaced by other groups without any significant reduction to the whole trophic level. For instance, within the surface predatory fauna ants and then ground beetles declined and spider populations, mostly webless, were on the increase. Changes in dominance groups and the shortening of the list of species initiated a marked decline of the whole animal populations in that zone.

In the order of succession, or rather recession, we deal with the stage of "open community" in this case involving a succession of alterations brought on by emission pressure and environment changes destabilizing the functioning ecosystem. Transformations in the animal world fall into "qualitative changes". The changes are mostly those of the specific makeup which is subject to substantial alterations associated with the reduction in the number of species and with the switch from stenotypic to euritypic species. It is still possible to stop that retrograde succession, or rather "industriogenic" recession. However, it will involve setting up artificial ecosystems with selected resistant species that can be maintained successfully only at large expense and on condition that further buildup of pollutants in the soil is stopped.

Zone III - described as "biological death zone" can be characterized as an area where the animal world becomes extinct which is particularly true of phytophagous invertebrates living on open surfaces [20,38]. It is also an area from which specialized predators became eliminated. Only part of soil-surface predatory fauna, capable of actively adapting the environment, such as ants [22] and irregular eaters such as spiders remained in selected spots. Both groups fed on the so-called atmobionts, i.e., air-borne organisms periodically blown there with the wind [20,34,43,44]. As the vegetation died back cryptobiotic phytophagous species died alongside. The decline of soil and predatory soil-surface fauna was abrupt and individual species were scattered in specific environments such as bark piles, tree stumps, along abandoned roads and houses, in land depressions etc.

In zone III the issue of ecological systems has become irrelevant since those areas can only be reclaimed from scratch. In the Puławy area it was done through giving up any attempts at maintaining forest vegetation and planting agricultural crops in the deforested area instead. Here crops are treated mainly as a sanitizing recourse with some restricted possibility of utilizing the resulting biomass, e.g., for compost production [39,41]. The re-colonization by animal species depended on the crop to which it the reclaimed land was sown but they were mainly phytophagous species, very often crop pests which, as a rule, multiplied outside the emission impact area.

CONCLUSIONS

The impact of the nitrogen fertilizer plant in Puławy involved profound, destructive alterations to the broad-sense natural environment which comprised not only the soil, water and air but also plants and animals. Initially, at the end of 1960's and at the beginning of 1970's the changes were very acute only to become of chronic character later on.

The impact of the nitrogen fertilizer plant in Puławy on the environment in the Puławy area, and its underlying causes and effects, were investigated by a number of research units including the Forestry Research Institute and the Institute of Soil Science and Plant Cultivation, Polish Academy of Sciences etc.

Conducted over many years, the research involving agronomic, forestry-related, and biological aspects of the problem have contributed to the development of methods for agricultural reclamation of devastated areas. The methods provided not only for the management of the areas by merely sowing them to grass but also involved sanitizing through the removal of plant biomass and its utilization in the form of compost. As was shown by the study conducted by the Forestry Research Institute re-introduction of forest can only be made to a limited degree, outside the area of high emission pressure.

The agricultural approach to the reclamation of devastated areas received further support from floristic and fauna studies which used qualitative and quantitative changes within animal and plant communities as bio-indicators. The communities were analyzed for specific composition, frequency and domination patterns, changes in the order of succession of plant and animal communities and the output of original plant communities.

The above data were used as bio-indicators to measure both the extent of damage to the environment and to assess the validity of the methods developed to reclaim the degraded environment.

Tested and calibrated as a synthetic bioindicator of air pollution in the Puławy area, lichens were used as a tool to evaluate the extent of air contamination with different kinds of emission. It was shown that, along with nitrogen-bearing emissions, the Puławy area is exposed to dust emissions, a source of heavy metals and very toxic sulphur emission. Those measurements can also be used in monitoring large areas, a very important practical consideration with respect to assessing environment pollution status.

REFERENCES

1. **Adamczyk-Winiarska Z.:** The influence of pollutants emitted by the Nitrogen Works at Puławy on soil chemical properties (in Polish). IUNG Puławy, R, 154, 1-91, 1980.
2. **Adamczyk-Winiarska Z., Górski T., Siuta J.:** Studies on air pollution in the Puławy area (in Polish). Zesz. Bad. Rej. Uprzem., PAN, 34, 91-113, 1969.
3. **Adamczyk-Winiarska Z., Król M.:** Chemical and biological changes in soils near Puławy (in Polish). Zesz. Bad. Rej. Uprzem., 51, 81-82, 1972.
4. **Bystrek J., Pomian U.:** The use of lichenes as indices of atmosphere pollution on the example of forests neighbouring with Nitrogen Works at Puławy (in Polish). Folia Soc. Sci. Lubl., G, 23, 1-2, 3-11, 1981.
5. **Chojnacki A.:** Chemical composition of rainfall waters in Poland. Part III - 1966 (in Polish). Pam. Puł., 29, 171-186, 1966.
6. **Fijałkowski D.:** Changes in plant cover near Nitrogen Works at Puławy (in Polish). Folia. Soc. Scient. Lublinensis. B, 14, 33-42, 1972.
7. **Fijałkowski D., Sokołowski A., Puszkar L.:** Rare synantropic plants near Nitrogen Works at Puławy (in Polish). Annales UMCS, C, XXXII, 6, 97-105, 1977.
8. **Gadzikowski R.:** The influence of Nitrogen Works at Puławy on forests in years 1967-1970 (in Polish). Sylwan, 6, 1-11, 1971.
9. **Górny M.:** Zoocenosis soil studies in pine forests near Nitrogen Works at Puławy (in Polish). Zjazd PTG. Katowice-Kraków, 216-218, 1972.
10. **Górny M.:** Bioindication in soils of degraded biotops (in Polish). Wiad. Ekol., XII, 3, 224-229, 1976a.

11. **Górny M.**: Einige pedo-okologische Probleme der Wirkung von industriellen Immisionen auf Waldstandarte. Pedobiologia, 16, 27-35, 1976b.
12. **Jakubczak Z., Chojnacki A., Pieta J.**: The range of amtosphere pollution by Nitrogen Works at Puławy basing on nitrogen amount in pine needles (in Polish). Stud. Puł., B, 248-256, 1968 a.
13. **Jakubczak Z., Koter T., Siuta J.**: Effect of industrial emission on forest plants near Puławy. Post. Nauk Roln., 5, 113, 75-78, 1968b.
14. **Jakubczak Z., Pięta J.**: Effect of industrial emmisions on summer plants near Puławy (in Polish). Zesz. Bad. Rej. Uprzem., PAN, 34, 1-76, 1972.
15. **Kawecka A.**: Changes of leaves of the Scots pine (*Pinus silvestris* L.) due to the pollution of the air with nitrogen compounds (in Polish). Ekol. Pol., 21, 7, 1970.
16. **Kawecka A.**: Changes of leaves of the Scots pine (*Pinus silvestris* L.) due to the pollution of the air with nitrogen compounds. Ekol. Pol., 21, 7, 105-120, 1973.
17. **Kowalkowski A.**: Effect of nitrogen emission on chemical composition of forest podzolic soils near Puławy (in Polish). XIX Ogólnopolski Zjazd Nauk. PTG, Puławy, 207-215, 1972.
18. **Kowalkowski A.**: Effect of atmosphere pollution on forest soils. Las Pol., 10, 8-9, 1977.
19. **Leśniak A.**: Altenations in structures of communites epigeic Carabides Co., as a bioindicator of pollution in forest habitats. 3rd Int. Conf. Bioindicatores Deteriorisations Regionis, September 12-16, 1977, Lidice n. Prague, 1977.
20. **Obmiński Z.** (Ed.): Principles of forest management within the area of industrial air pollution near Puławy. Study Reports 1972-1974 (in Polish). IBL, Warszawa, 1972, 1973, 1974.
21. **Ostrowska A.**: Nitrogen accumulation in pine needles, bark and wood within the impact area of the Nitrogen Works at Puławy (in Polish). Rocz. Glebozn., 31, 117-131, 1980.
22. **Pętal J., Jakubczyk H., Chmielewski T., Tatur A.**: Responds of ants to environment pollution. Progress in Soil Zoology, Prague, 363-373, 1975.
23. **Puszkar L.**: Geobotanical relations in reclaimed deforested area of Nitrogen Works at Puławy (in Polish). IUNG Puławy, R, 145, 1-47, 1979a.
24. **Puszkar L.**: The effect of land reclamation on synantropic plants in the region in Nitrogen Plants in Puławy. Memor. Zool., 32, 87-100, 1979b.
25. **Puszkar L.**: Response of Lichenes as an index of the range of environment degradation degree near Puławy (in Polish). IUNG, Puławy, R, 264, 1-38, 1989.
26. **Puszkar L.**: Bioindicative evaluation of the range and degree of environment pollution in the area of Puławy (in Polish). Studia Puławskie, B, 2, 157-166, 1990.
27. **Puszkar L.**: Lichenes as index of air pollution in Puławy area (in Polish). Habilitation Thesis, IUNG Puławy, H, 12, 1- 120, 1997.
28. **Puszkar L., Puszkar T.**: An attempt to evaluate the state of field and forests ecosystems by using flora and fauna bioindicators in the impact area of Nitrogen Works at Puławy (in Polish). In: Modern trends in ecology - behaviour ecology (Eds Puszkar T., Puszkar L.) Wyd. UMCS, 411-416, 1997.
29. **Puszkar L., Wiącek K.**: Use of Lichenes as bioindicators of environment contamination in the area of Nitrogen Works at Puławy (in Polish). IUNG, Puławy, S, 43, 1-40, 1984.
30. **Puszkar L., Wiącek K.**: Epigeal Lichenes near Puławy as index of air state (in Polish). Stud. Puł., B, 1, 279-306, 1986.
31. **Puszkar T.**: An attempt to use soil fauna as bioindicator of degradation and restitution of nature in area of emission from Nitrogen Works at Puławy (in Polish). Pam. Puł., 66, 229-239, 1976.
32. **Puszkar T.**: Les fourmis (*Formicidae*) de la zone poluee des etablissements de L'Azote de Puławy. Memor. Zool., 29, 129-147, 1978.
33. **Puszkar T.**: Epigeal Fauna as a Bioindicator of Changes in Environment in Areas of High Industral Pressure. Biul. De L'Acad.Pol. des Sciens. S. B. XXVII, 11, 925-931, 1979.
34. **Puszkar T.**: Changes in some elements of zoocenoses in agroecosystems under high pressure of industrial emissions (in Polish). IUNG, Puławy, R, 157, 1-78, 1981.
35. **Puszkar T.**: Ants (Formicidae) in the Agrocenoses Afdfected by Intensive Pressure of Industrial Emissions. Annales UMCS. C, XXXVII, 9, 105-116, 1982.
36. **Puszkar T.**: An attempt to use soil fauna as bioindicator to evaluate the effects of emission from Nitrogen Works at Puławy on surrounding forests (in Polish). In: Waloryzacja ekosystemów leśnych metodami zooindykacyjnymi (Ed. Mazur S.). Fundacja Rozwój SHHW, Warszawa, 112-119, 1996.
37. **Rajski A.**: Ecological succession. Ekol. Pol. 11, 23-50, 1965.
38. **Sierpiński Z.**: Secondary pine pests in stands within area of industrail emissions containing nitrogen (in Polish). Sylwan, 10, 11-18, 1971.
39. **Siuta J. (Ed.)**: Protection and reclamation of arable lands (in Polish). Research Reports. Part I. IUNG, Puławy, R, 39, 1-195, 1972.
40. **Siuta J. (Ed.)**: Air pollution and reclamation of degraded land near Puławy (in Polish). IUNG, Puławy, R, 51, 1-221, 1973.
41. **Siuta J.** (Ed.): Ecological Effects of Industrailisation in Puławy (in Polish). Wyd. IKŚ, Warszawa, 1-264, 1987.
42. **Sokołowski A.W.**: Effect of air pollutants emitted by Nitrogen Works at Puławy on summer plants. Sylwan, 3, 45-56, 1971.
43. **Sokołowski A.**: Natural ants population Formica rufa (*Hym. Formicidae*) in forest contaminated with nitrogen compounds (in Polish). Pozn. Tow. PN. Prace Kom. N. Rol. i L, 44, 117-135, 1978a.

44. **Sokolowski A.:** Insects accompanying ants of the group Formica rufa (*Hym. Formicidae*) in forest contaminated with nitrogen compounds (in Polish). Pozn. Tow. PN. Prace Komisji N. Rol. i L., 44, 137-135, 1978b.
45. **Sokołowski A., Kawecka A.:** Problems in terrain management around Nitrogen Works at Puławy (in Polish). Las Pol., 1, 5-6, 1972.
46. **Sokołowski A.W., Kawecka A.:** Effects of industrial air pollution on plants of the Puławy Forest Department (in Polish). Prace IBL, 433, 1973.
47. **Stankiewicz Z.:** Effect of industrial pollution on biological and nutrition value of plants (in Polish). Proc. Symp. NOT, 26-33, 1976.
48. **Stankiewicz Z.:** Biological aspects of oxidated nitrogen compounds excess in environment (in Polish). Medycyna Wiejska. XIII, 2, 1978.
49. **Szafer W.:** Plant Cover of Poland (in Polish). PWN, II, 1959.
50. **Szponar L., Bilczuk L.:** Methamoglobine level in village inhabitants in area polluted by emissions from Nitrogen Works at Puławy (in Polish). Pol. Tyg. Lek., 28, 3-7, 1973.
51. **Terelak H, Terelak T.:** Air pollution with sulphur in Puławy and its effect on nature (in Polish). Stud. Puł., B, 2, 101-106, 1988.
52. **Wołk A.:** Climatic changes in relation to forest degradation degree in area of Nitrogen Works at Puławy (in Polish). Sylwan, 7, 33-46, 1977.
53. **Wójciak H.:** Lichenes occurring in area neighbouring with Nitrogen Works at Puławy (in Polish). Ann. UMCS, C, 39, 29-36, 1984.
54. **Żórawska B.:** Influence of nitrogen ocurring in atmosphere on plants' yielding in Puławy Industrial Region (in Polish). IUNG, Puławy, R, 128, 1-1-49, 1977.