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ECOLOGICAL HORIZON

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INTRODUCTION

Environmental pollution nowadays is considered to bring about ecological changes of significantly large scales. Earlier, local problems related to environmental pollution in the vicinity of cities and industrial enterprises were in the focus of investigations. Now the situation has significantly changed: environmentalists, along with wide public and governmental agencies discuss regional scale problems such as the effect of long-range pollution transport on fresh-water ecosystems in Scandinavia, or the state of forests in the European Region.

Some of the arisen questions have already been analysed and the answers are fairly clear, e.g. the negative role of acid rains in degradation of fresh-water bodies in Scandinavia. In other cases, e.g. diagnostics of the causes of forests weakening in Central and Western Europe is not in a position to indicate the major factor. Modern applied ecology does not possess adequate methods as yet, it can provide only some conclusions of general qualitative nature [11].

However, the intensity and scale of the observed phenomenon, stated at the meeting of the representatives of 30 countries in Munich in june 1984 and the Third Session of the Executive Body for the Convention on Long-range Transboundary Air Pollution in July 1985, stipulate the need to formulate and start implementation of requisite ecological research, to undertake practical measures in this sphere.

In the nearest future it is necessary to develop a reliable technique to assess the effect of an aggregate of anthropogenic global and regional factors, environment acidification included, on the state of continental ecosystems. It is necessary to separate the effect of each factor from the integral effect, to reliably distinguish man-induced changes against the background of natural variations in the state ecosystems. Having solved these problems, one might make substantiated recommendations in the sphere of monitoring the effects, pollution standardization, and rational limitation of pollutant discharge.

These are, in our opinion, outlines of perspective directions of research in the sphere of applied ecology today. Below, we are trying to describe more specifically the essence of these directions and their major goals, probable methodological approaches, outcomes to certain practical questions of ecological standardization.

OXIDES OF SULPHUR AND NITROGEN

Hundreds and thousands of pollutants are emitted into the environment due to anthropogenic activities. However, only few of them are capable of continuously affecting ecosystems on a considerable spatial scale of the order of 1,000 km, depending on the emission amounts, persistence, toxicity, ability to propogate, and so forth. Oxides of sulphur and nitrogen, being constituents of atmospheric pollution, are the primary priority pollutants to be studied with respect to their effect on vegetation. It should be stressed that these pollutants are the major primary factors, since spreading and circulating in natural geophysical environments they effect plants both directly and indirectly by inducing secondary (derivative) adverse factors, which are discussed below.

The direct impact of sulphur and nitrogen oxides is due to their penetration into green assimilative organs of plants. Sulphur dioxide is a strong assimilation poison. An approximate list of various SO_2 atmospheric concentration effects on higher plants is given in [13].

Changes induced by SO_2 concentration < 30 $\mu g/m^3$ are beyond instrumental detection, though they are liable to be assessed with the help of mathematical models. SO_2 concentrations from 30 $\mu g/m^3$ reduce the content and rate of galactolipide synthesis in phototsynthesising cells; 250-280 $\mu g/m^3$ bring about ultrastructural changes in chloroplasts registered by electron microscopy; 500-1000 $\mu g/m^3$ reduce oxygen emanation and chlorophyll content, inactivate chlorophyllase, desorganize tilacoids and membrane systems; 1000-1400 $\mu g/m^3$ cause continuous degradation of organelles, affect protein and lipide synthesis, considerably reduce CO_2 assimilation. Further increase in SO_2 concentration causes acute damage to plants: chlorosis, necrosis, death.

These changes are accompanied by changes in morphology: affected plant proportions, affected processes of production. The latter directly effect such ecologically and economically important characteristics of the state of vegetation as woodstand growth and agrocenoses yields. The most sensitive tree species are pine and spruce.

Evidently, the most SO_2 sensitive plants are epiphytic lichens. Concentrations up to 100 $\mu g/m^3$ do not cause death of higher plant species but kill many epiphytic lichens. The most sensitive groups of epiphytic lichens are genera Usnea, Labaria, Sticta, Ramalina, Cladonia; the effect of as low a concentration as 30 $\mu g/m^3$ reduces intensity of their photosynthesis [6]. The review of the effect of sulphur dioxide and of a number of other pollutants in lichens can be found in [3,4].

It should be noted that the amount of reliable experimental data on the effects of SO_2 concentrations within the range of 0-100 $\mu g/m^3$ is rather insufficient. The data of field observations show considerable noise due to the effect of other factors and of natural time-space variability of biological objects. Though, it is this range of concentrations that is characteristic of the European region as a whole. Within Western Europe areas with characteristic average concentrations 10 $\mu g/m^3$, 10-25 $\mu g/m^3$ and 25 $\mu g/m^3$ make up 69%, 30% and 1%, respectively, as estimated in [2]. The situation may have changed now, though insignificantly.

The effects of nitrogen oxides on plants is supposed to manifest in a similar way, though relevant studies are lacking . The development of such studies is urgent. Another reason to comprehensively study nitrogen oxide emissions and distribution is stipulated by their indirects effects on plants, the true scales of which are yet hardly assessed. What we imply, is the occurence of anthropogenic ozone. Fairly complete information on this problem, discussed briefly below, is given in [7].

Ozone is known to form in the atmoshere in the course of photochemical and thermal reactions:

$NO_2 + h\gamma \rightarrow NO + O$:

$O: + O_2 + M^{\cdot} \dashrightarrow O_3 + M^{\cdot}$

$M^{\cdot}$ is a molecule absorbing the reaction energy. The kinetics of these reactions is complex and depends on light spectrum composition, radiation degree, presence of metals, hydrocarbons, and particulates in the atmosphere.

Thus, man-made emission of nitrogen oxides induces formation of anthropogenic ozone. The atmospheric content of O_3 over background continental areas is thought to be 0.01-0.02 ppm; regional background for Western Europe - 0.02-0.04 ppm; characteristic impact levels (cities and their surroundings) - 0.1 ppm.

Ozone imposes high phytotoxic effects. Ozone is believed to bring about 90% of the total crop loss in the USA out of the impact of the whole of all atmospheric pollutants. Indentification of the precise mechanism of ozone phytotoxic effects is still ambiguous. In particular, ozone and its radicals, formed as a result of its penetration into green assimilative organs of plants, affect polyunsaturated fatty acids and thiolic groups. Ozone also affects photosynthesis processes in chloroplasts when, as supposed, penetrating into chloroplasts and/or inducing radical formation in them.

Trial data (see Table 1) show significant damage from regional levels of ozone, characteristic of Western Europe.

Table 1

O_3 Effects on plant productivity (from [7], adapted)

Species	O_3 concentration	Dose	Effect, control percentage	Measured parameter
Trifolium incarnatum	0.03	8 hr x 6 weeks	92.3	fresh plant mass
Zea mays Golden Midget variety	0.05	6 hr x 74 days	93.8	number of grains
Rhaphanus sativus Cherry Bell variety	0.05	8 hr x 5 times a week x 5 weeks	68.9	fresh plant mass
Glycine max Dare variety	0.05	6 hr x 43 days	75.4	the same
Pinus taeda Wild foxtail pine	0.05	6 hr x 28 days	86	the same
Fraxinus pencylvanica Black ash	0.05	the same	86	the same

The effect of over 0.1 ppm may be as great as 50% of the control biomass decrease, this demonstrates high toxicity of ozone. It should be noted that common diagnostics [8] of plant damage with O_3 by visual (morphological) features begins to show significant results when concentrations are close to 0.1 ppm.

We believe that available world ecotoxicological "dose-effect" information with regard to ozone effect on terrestrial plants would enable one, after proper processing, to assess with the help of mathematical models a prediction of the effect of ozone on vegetation in Europe. It would require geophysical assessment of the field of anthropogenic ozone over Europe, and a prediction of its changes as a function of anthropogenic factors, in particular, nitrogen oxide emissions.

The presence of a number of constituents in the atmosperic sub-cloud layer, sulphur and nitrogen oxides and sulphates included, results in a certain natural acidity of precipitation (pH 5.6). The growth of the concentration of these constituents due to human activities, industrial and transport emissions, increases precipitation acidification, in some cases up to pH 4.5. Thus formed acid rains present a very significant factor of man-induced effect on terrestrial ecosystems [6].

On a local scale near cities and industrial enterprises acid rains can show up direct effects, in particular, acute plant damage, while on a regional scale it is more difficult to reveal the effect of acid rains on vegetation [14].

An experiment within Norway, Project SNSF, was performed to detect the effect of acidification on the growth of coniferous trees (pine and spruce) under non-impact conditions using field methods. Statistic analysis of the annual rings of Norway spruce and Scotch pine at 6150 trial sites did not reveal any association with soil acidification. The model estimated decrease in growth made up 0.5%, while the experiment resolution stipulated by the disguise effect of other factors, anthropogenic factors included, happened to be over 1% [12]. It should also be noted that acid precipitation can stimulate growth on alkaline soils with nitrogen and sulphur deficiency [6].

Getting onto soil, acid rains with $pH < 5.6$ effect cation exchange processes: Ca^{2}, MG^{2+}, K^{+}, Na^{+} are replaced with H^{+}. Their flush (wash down) to under-ground water depletes soil. On the other hand, introduction of sulphates and nitrates with acid precipitation first stimulates plant growth, but then induces deficiencies of K, Mo, P which changes soil compostions. Soil acidification results in the occurrence of toxic heavy metals in the soil solution. Aluminium, transforming in acidified soils (pH 5.0) into soluble form, stimulates washout of calcium, organic matter sedimentation, bounding of plant accessible phosphorus, adversely effects the growth of root cells and plant state of the whole. These processes are discussed in detail in [10].

Because of the variety of the effects of acid rains getting onto soils and ambiguity of the integral effect, model laboratory experiments under controlled conditions have been performed.

The scheme of a special experiment - "soil algae-test", the essence of which is in soil extraction with a solution of certain acidity (acid rain simulation), further growth of unicellular fresh-water algae in the extract and registration of their rate of increase is described in [9]. Unicellular algae have been taken instead of higher plants because of the desire to make the experiment faster and expediency of measuring the culture density using automatic facilities. The specimen ot typical for the USSR acidic soil-podzol soil, exemplified in the cited paper, is characteristic of almost half of the USSR territory.

Bacteria-free unialgal culture of Chlorella C010, offered by the Plant Physiology Institute of the USSR Academy of Sciences, was tested in the experiment. Soil extraction was performed by distilled water acidated with sulfuric acid. The applied solutions were: acid solution (pH = 2.0 % 4.5), subacid (pH = 5.0 % 6.0), and neutral (pH = 6.5). Extraction duration - 15, 30 or 60 minutes. Statistical analysis of the results has revealed the effect on a high level of reliability - up to 95% and higher. Note, that the revealed effect - change in the rate of the test culture growth - is an integrated effect, the response to all the changes in the soil extract properties occurring with the change in the extractor acidity and extraction duration.

It should be stressed again that emanation of heavy metals, of Al in particular, induced by soil acidification is of certain significance for the occuring total effect on plants. Their atmospheric fluxes onto the soil on the regional and global scales, judging by the assessments available, might be neglected, since in the foreseen future these fluxes will not bring about significant changes in the total content of heavy metals in soils. In particular it referes to aluminium, the reserves of which in soils are huge.

PESTICIDES

The world pesticide production has exceeded 5 mln t/yr, and goes on expanding. These substances are known to propagate over great distances circulating in the environment, poorly decompose, and considerably damage biota of natural ecosystems and, in some cases, human health. At the same time, the scales of their application in forestry and agriculture are still expanding. In the USA, for axample, pesticide production in 1946-1976 increaased from 90,000 t to 900,000 t.

Inspite of this, crop losses from destructive insects and mites have not reduced, but even slightly increased [15].

Year	1904	1910-1935	1942-1951	1951-1960	1974
Crop losses (%)	9.8	10.5	7.1	12.9	13.0

Thus, despite expansion of chemical control, the yield destroyed by pests is not decreasing. Note that this fact is usually disguised behind apparent efficiency of pesticide application from the point of view of local criteria of a purely economic nature.

According to preliminary assessments [15], this phenomenon might be explained by the fact that the applied pesticides (first of all - insecticides) are often more toxic for natural pest killers than to pests themselves. Applied at a certain area insecticides spread in the atmosphere over wide territories, where they inhibit entomophagans - natural regulators of phytophagans. This results in an increase in the population numbers of the forthcoming generations of phytophagans and, hence, further expansion of the chemical control. Thus, chemical pest control is "self-reproducing", and man has to bear the expenses to cause pest mortality when entomophagans could do it "free of charge".

This problem is not urgent for Europe, but is becoming and more vital for vast regions in Asia, Africa, Latin America. Therefore we consider pesticides one of the foremost priority problems for scientific analysis and development of substantiated strategies of their application, though the major impact of pesticides on vegetation is not a direct toxic effect, but indirect destabilization of the trophic chain "primary producer - consumer - secondary consumer". This scientific problem is under development now in the USSR [5].

ECOLOGICAL STANDARDIZATION

Thus, the effect of other widely spread phytotoxic pollutants [8] - peroxiacetylnitrates, fluorides, ammonia, boron, chlorine, hydrogen chloride, ethylene, propylene, hydrochloric acid - on the regional and global scales is, to our mind, less significant than those mentioned above: oxides of sulphur and nitrogen, atmospheric ozone, heavy metals in soils. Insecticides are of particular importance (see above).

It should be underlined once again that on the regional and global scales both heavy metals and ozone present secondary anthrogenic factors effecting plants. Nitrogen oxide emission and distribution in the atmosphere induce the occurrence of ozone in the atmosphere, while the occurrence of heavy metals in dissolved toxic form is induced by soil or water acidification due to man-induced increase in the content of sulphur and nitrogen oxides in the atmosphere.

Thus, quite a number of adverse factors affect natural phytocenoses and agrocenoses (Fig. 1) causing generally speaking, various effects against a particular ecological natural background. Besides, environmental conditions in natural ecosystems are always variable, as well as time and space characteristics of vegetation. Concentrations of phytotoxic substances $C,\dots,C_n$, in particular, vary with time. Plant response to their impact depends on plant species, type of habitat, and other environmental factors.

These peculiarities of actual ecological processes are to be accounted for in attempts to establish ecological standards. Let us consider a fairly common situation. The value (index) of primary production - this year's phytomass calculated for unit area - is taken as a criterion of the state of ecosystems on a given territory S. The ecosystems state is considred acceptable if the primary production P makes up not less than (100-N) % of this index value in the absence of stress from pollution factors. Analysing special ecotoxicological literature and performing special investigations one can imagine mean seasonal concentration of atmospheric SO_2 (C_{cr}), the effect of which would be reducing plant productivity by N%. But this value will always be to a considerable extent ambiguous. It will vary depending on the type of habitat, species composition of the phytocenosis, climatic factors, other man-made factors. Therefore, it would be correct to operate a distributed value of the critical load for the given territory S. We shall assume it lognormally distributed and indicate its average logarithm using $\ln C_{cr}$, and its dispersion, using DC_{cr}. So, what mean seasonal concentration of atmospheric SO_2 could be recommended as permissible (C_p)? Here one should bear in mind that irrespective of the applied system of emission restriction, the resulting concentration, seasonal values in particular, will be varying. That is, it would be reasonable to operate again with the distributed value with average $\ln C_p$ and dispersion DC_p.

The question of admissibility of relationships between $\ln C_{cr}$, DC_{cr}, DC_p is associated with the concept of a permissible risk of the occurrence of an undesirable ecological effect; in our case, it is the primary production decrease over N%. If P is the admissible risk level, then the admissible relationship is:

$$\frac{\ln C_{cr} - \ln C_p}{\sqrt{D_{C_{cr}} + D_{C_p}}} = \chi \quad ; \; C_p = C_{cr} e^{-\chi \sqrt{D_{C_{cr}} + D_{C_p}}}$$

where χ is defined from

$$\frac{1}{\sqrt{2\pi}} \int_{\chi}^{\infty} e^{-u^2/2} du = p$$

The exponential multiplier in the right-hand side of the equation implies the reserve coefficient which indicates how much lower the permissible pollutant concentration has to be compared to the critical one [1] under given permissible ecological risk p.

Given the information on the joint impact of serveral pollution factors $C_1, \ldots, C_n$ is available, one is in a position, to indentify critical (K) and permissible limits of the total pollution, the ecological risk (level) p being set forth (Fig. 2).

CONCLUSION

At present, the primary priority pollutants from the point of view of their effect on terrestrial ecosystems on the regional and global scales are oxides of sulphur and nitrogen, as well as pesticides.

Acidification of precipitation, induced by emissions of these oxides into the atmosphere, brings about changes in soil composition and occurrence of phytotoxic forms of metals in soil - Al, Cd, and so on. Besides, occurrence of O_3 in the atmosphere due to NO_2 in the course of thermal and photochemical reactions results in significant (phototoxic) effects when O_3 gets into photosynthesising cells.

A particular role in the atmosphere pollution play the insecticides. The current application of insecticides destabilizes the "host-parasite" system on the continental scale as a result of the now accepted strategy of pesticides application due to the fact that they are more toxic for entomophagans than for phytophagans. Note that on a local scale the application of chemical pest control methods seems economically expedient.

As for the scientific problems related to sulphur and nitrogen oxides emission, the following directions in the field of applied ecology are of primary importance:

- development of methods to predict regional and global levels of

SO_2 and NO_2 in the atmosphere if the spatial distribution of emission intensities are known;

- assessment of the major biological effects of SO_2 and NO_2 with due account of their impact on photosynthesizing cells, as well as consequences of precipitation acidification and associated induction of phytotoxic forms of metals in soils affecting root transport; assessment of the effect of NO_2 induced ozone on photosynthesizing cells;
- development of methods to estimate critical and permissible concentration of these pollutants and their complexes in the environment proceeding from the established maximum permissible ecological effect and the risk of its excedence; the difference between critical and permissible impacts (which imply such notions as zone of reserve, reserve coefficient - the portion of the permissible level beyond the critical level) happens to be a function of the maximum permissible risk level.

Solution of these research problems might create a basis for formulating questions of inter-state coordination related to maximum permissible levels of occurrence of adverse ecological effects and relevant levels of ecological risk. However, coordination of these problems on a bilateral or multilateral basis comes within the sphere of international economic relations and political activities.

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Fig. 1

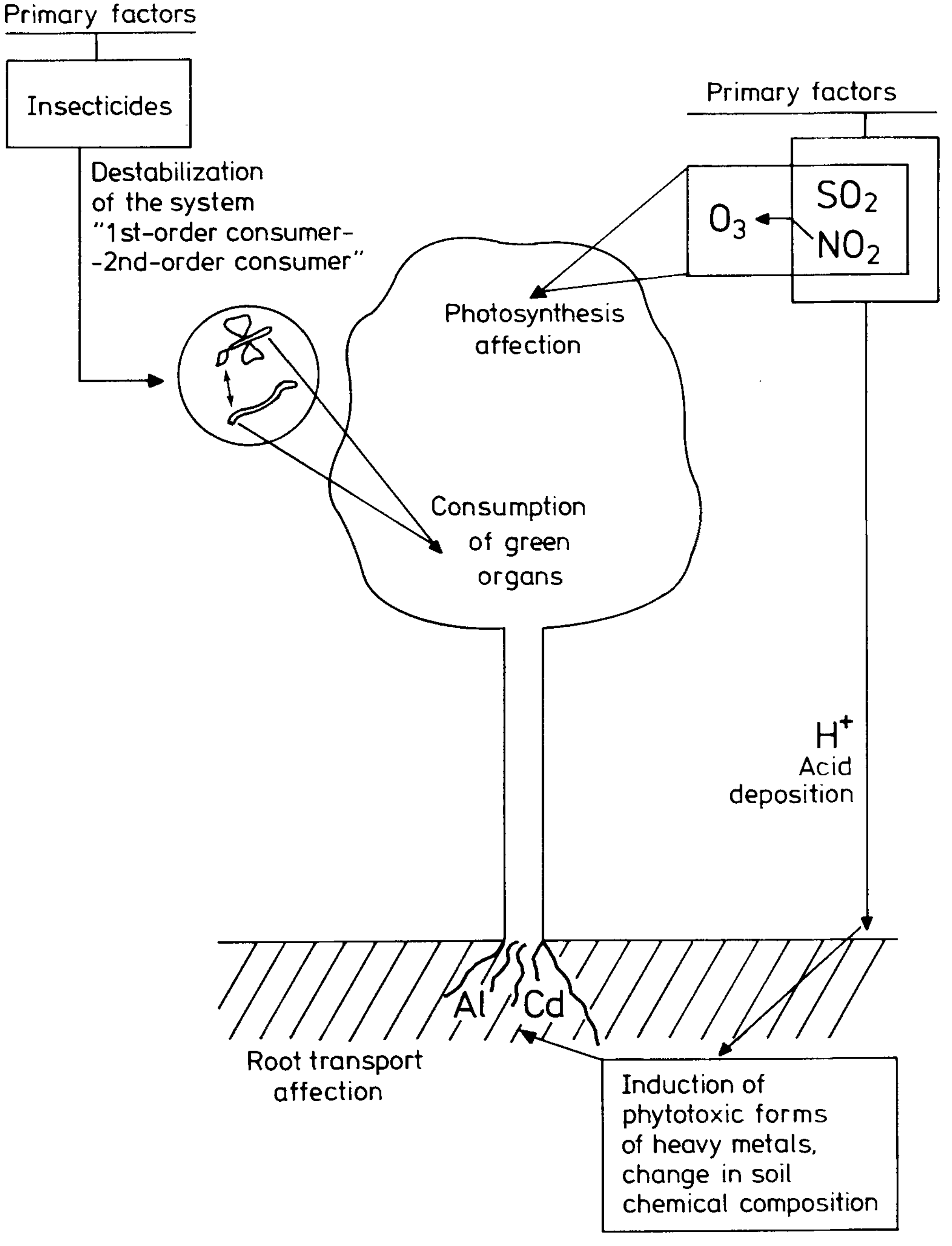
Primary factors
Insecticides
Destabilization
of the system
"1st-order consumer-
-2nd-order consumer"
Primary factors
O3
SO2
NO2
Photosynthesis
affection
Consumption
of green
organs
H+
Acid
deposition
Al
Cd
Root transport
affection
Induction of
phytotoxic forms
of heavy metals,
change in soil
chemical composition

Fig. 2