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Papers review

BIOLOGICAL AND CHEMICAL INDICATION OF ROADSIDE ECOTONE ZONES

Agata Poszyler-Adamska, Andrzej Czerniak

Dept of Forest Engineering, August Cieszkowski Agricultural University of Poznań, Mazowiecka 41, 60-623 Poznań, Poland. E-mail: agata_poszyler@tlen.pl

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Abstract. A public motor road net crossing forest complexes influences the natural environment to a very high degree. Soils in roadside forest ecotone zones constitute a certain filter buffering chemical contamination generated by motor traffic. The aim of the paper is to present the methods of identification of transport contaminants influencing the roadside stand condition. The results of monitoring roadside ecotone zones indicate the necessity of applying such technical appliances as oil-derivative separators, filtering screens or geomembranes close to motor roads to limit the migration of chemical compounds and preserve the homeostasis of precious natural forest complexes.

Keywords: motor traffic, forest, roadside ecotone zones, trace contamination, monitoring.

1. Introduction

East European countries are presently facing an urgent need of modernizing their transportation routes, as well as constructing new ones, owing to an abrupt intensification of traffic. Poland offers 20 000 km of state roads. The national programme of the construction of new roads and motorways in Poland assumes constructing 1 700 km of motorways by 2 010, and 1 500 km of express roads. Additionally, modernization of the majority of the presently utilized road surfaces is planned due to their technical condition as well as the necessity of increasing of the presently permissible axle load from 10 to 11,5 tonnes/axle.

Two stages of damages can be observed in forests neighbouring with public roads: initial damages directly resulting from the process of road construction and later-occurring damages ascribed to the long-period impact of traffic and anthropopressure factors. Initial damages result from deforestation practices, physiographical changes and ecological impact of road works producing and emitting noise, vibration and dust. The later-occurring damages resulting from transport route exploitation are: changes of water relations, deformation of forest habitats, fragmentarization of forest complexes, limitation of forest fauna migration as well as depreciation of both touristic and recreational values. Forest complexes species biodiversity is both negatively and positively influenced by transportation routes [1].

A public motor road net crossing forest complexes influences the natural environment to a very high degree. Forest ecotone zones roadside soils constitute a certain filter buffering chemical contaminants generated by traffic (carbon and nitrogen oxides, lead compounds, heavy metals, hydrocarbons, dioxins). Industrial refuse, deposited in road foundations, can also constitute the source of chemical contamination [2–5].

2. Investigation object and methodology

The condition of a permanent existence of a forest ecosystem is a balance of the main processes of metabolism. Each significant change in the chemical balance evokes disturbances of homeostasis, quantitative and qualitative succession of the successive components of both the plant and animal world, and as a result degradation of the natural environment. An increase of concentration of some chemical elements in an ecotone zone may have a negative influence on the biological activity of soils as well as the health state of the plant cover. The aim of the paper is to present the methods of identification of transport contaminants influencing the roadside stand condition. The range of the interdisciplinary monitoring of the forest ecotone zone is presented on the example of a research project in realization meant for the forest complex neighbouring on the state road Nr 11 (traffic category KR4).

Bioindication of roadside ecotone zones carried out with an application of stands, dendrometric or defoliation methods is significantly impeded. It results from a varied species structure, heterogenous biosocial structure and non-typical habit of roadside tree crowns. The environmental quality of ecotone zones under the influence of transport routes can be defined by carrying out chemical and microbiological investigation as well as bioindicational analyses of the assimilatory organs of the plant cover.

Range of conducted chemoindicational monitoring of roadside ecotone zones:

- defining the soil-moisture conditions on the basis of soil and geotechnical investigation;
- contamination of roadside soils with heavy metals, chlorides and sulphates;
- evaluation of vertical and horizontal migration of heavy metals by magnometric methods;
- evaluation of roadside soil microbiological activity on the basis of the activity of dehydrogenases, phosphatases, urease and protease;
- defining the radioactivity of potassium K-40, radon Ra-226, thorium Th-228 as well as the activity of caesium Cs-137 isotope in the soil;
- analysis of the migration of oil-derivative substances;
- evaluation of forming of ecotone zone soil reaction;
- evaluation of the indicators of surface and groundwater quality;
- degree of cummulation of heavy metals in assimilatory organs of arborescent bioindicators of *Pinus sylvestris* L. and *Betula pendula* Roth.;
- speciation analysis accompanied by sequential extraction enabling quantitative description of heavy metal occurrence forms in humus horizons;
- evaluation of soil and plant bioindicators of contamination with dioxins (polichlorinated dibenzodioxin PCDDs and dibenzofurane PCDFs);
- bioindication of roadside ecotone zones on the basis of selected physical characteristics of *Pinus sylvestris* L.;
- evaluation of the health state of stands growing in areas neighbouring with a transport route;
- evaluation of plant succession on the basis of phytosociological investigation and inventory of the ecotone zone plant cover.

3. Results and discussion

The content of heavy metals, chlorides and sulphates was analysed within an area of a few transects selected at a various distance from the road crown edge. Soil samples for chemical tests were collected at a various depth. The results were compared with those of the background, and the soil quality standards [6]. The concentrations of the analysed heavy metals were higher than those permissible for protected areas, whereas they met the indicators set for forest and transportation grounds (Fig 1). An increase of heavy metal content in the soil increased phytoaccumulation.

Some indicators of surface and groundwater quality were exceeded, whereas no increased radioactivity was observed for potassium K-40, radon Ra-226, thorium Th-228 as well as for caesium Cs-137 isotope.

The results of radioactive elements in soil samples, which where collected from ecotone zone, were:

Potassium K-40 – 261,28 ± 18,74 Bq/kg,
Radon Ra-226 – 8,35 ± 1,42 Bq/kg,
Thorium Th-228 – 8,08 ± 1,37 Bq/kg,
f1 = (0,16 ± 0,02) < 1,2;
f2 = (8,35 ± 1,42) < 240 Bq/kg.

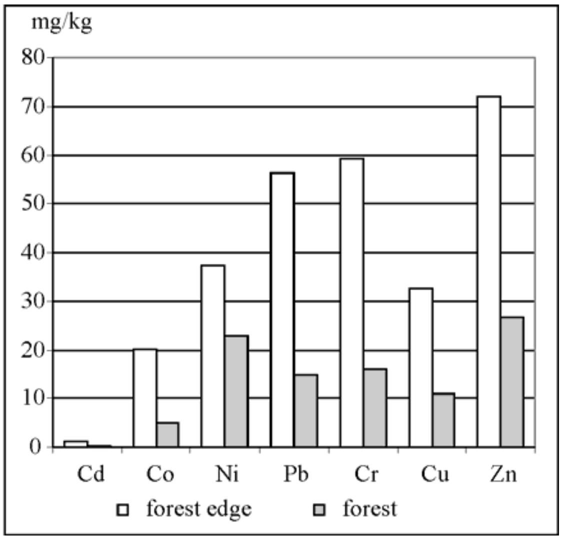

Fig 1. Contents of heavy metals in humus layer

The activity of caesium Cs-137 isotope measured by magnetometric methods was 26,73 ± 2,07 Bq/kg.

The results of radioactive elements in soil samples, which were collected from ecotone zone, were:

Potassium K-40 – 283,72 ± 19,96 Bq/kg,
Radon Ra-226 – 9,04 ± 1,45 Bq/kg,
Thorium Th-228 – 6,14 ± 1,21 Bq/kg,
f1 = (0,16 ± 0,02) < 1,2;
f2 = (9,04 ± 1,45) < 240 Bq/kg.

The activity of caesium Cs-137 isotope measured by magnetometric methods was 20,89 ± 1,76 Bq/kg.

Heavy metal migration was analysed applying the magnometric method, alternative to the costly geochemical methods [7]. The analysis of ferrimagnets content consists in field evaluating of their surface or vertical distribution in the soil (Figs 2, 3).

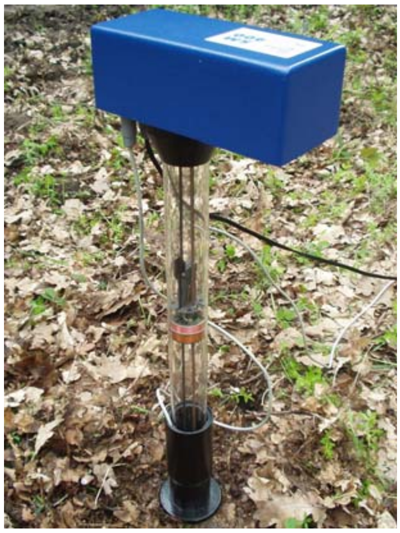

Fig 2. Surface magnetic workability measuring sensor

As a result of the investigation an increased magnetic susceptibility of roadside soils was observed, in comparison to the natural one. In the ecotone zone the susceptibility exceeded the value of 50×10^{-5} units SI and was closely correlated with the heavy metal concentration. A maximum concentration of heavy metals, similarly to the magnetic particles of anthropogenic origin, occurred in the forest litter.

Fig 3. Vertical magnetic workability sensor

The oil-derivative substances generated by traffic migrated chiefly in a vertical direction, and after reaching the underground water level they moved horizontally in the area of the capillary rise. The substances inhibited the development of soil microorganisms harming both trophic and aerobic conditions, and to a smaller degree due to toxic activity.

Soils in a homeostasis state are characterized by a stabilized microbiocenotic composition. Self-regulatory mechanisms, able to maintain the stability and integrity of an ecological system as well as to produce protective barriers against stress factors, stop functioning in contaminated soils. Both the development and activity of soil microorganisms can be defined on the basis of the total amount of microorganisms, amount of selected groups of microbes, intensity of soil respiration, biomass of microorganisms, metabolic quotient of microbes and activity of soil enzymes [8]. The biochemical tests of soil samples proved an inhibitory influence of traffic pollution on the activity of microorganisms expressed by enzymatic activity of dehydrogenases, phosphatases, urease and protease (Fig 4).

Enzymatic activity is also influenced by the soil reaction. The investigation showed a higher acidity of humus horizons in the center of a forest as compared to the transect neighbouring with a road. A lower value of pH at the forest edge is a result of applying chemical substances like sodium chloride (NaCl), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$), to fight the winter slippery of road surfaces.

Spaciation investigation (Fig 5) [9] carried out by the sequential extraction method showed that heavy metals occurred mainly in an aerobic and organic form or permanently immobilized in the crystal lattice of both primary and secondary minerals. Bioaccessible fractions (exchange and carbonate) constituted altogether about 10 % of the total general content, where the participation of the exchange fraction, most easily accessible to living organisms, did not exceed a few percent of the total content.

Dioxins (polichlorinated dibenzoparadioxins – PCDDs) are a group of chloro-organic, aromatic chemical compounds the particles of which show an exceptionally high thermal stability and chemical resistance to oxygenation as well as to processes of biodegradation [10]. They are chemical compounds acting strongly both mutagenly and toxically. With the total sum of emission of 17 congeners equal to 5 749 TEQ/annum the road transport emits 111,1 TEQ/annum, fires – 379,8 TEQ/ annum, and steel metallurgy – 83,4 TEQ/annum. To evaluate the potential toxicity of the investigated soil and plant samples, the 17 most toxic congeners PCDDs/ PCDFs were labelled. The level of a sample toxicity was defined as TEQ (Toxic Equivalency), which is calculated from the result of analyses for mass concentration of all the congeners of PCDDs and PCDFs in which 2, 3, 7, 8 positions in a molecule are substituted by chlorine atoms. The numerical value of TEQ is the total of partial parameters obtained by multiplication of an analytical result of mass concentration of an individual congener by a respective TEF value (Table).

$$TEQ = \sum_{i=1}^{i=17} \left(m_i \times TEF_i \right),$$

where: TEQ – International Toxic Equivalent of tested sample expressed in mass measure units (usually in ng), expressed only for PCDDs/PCDFs; m_i – mass of individual i-congener of PCDD and PCDF [ng]; TEF_i – International Toxicity Equivalency Factor for i-congener of PCDD/PCDF, in relation to toxicity of 2, 3, 7, 8-TCDD.

As a result of the analyses, the total content of congeners PCDDs and PCDFs in the collected soil samples was evaluated at a level of up to 10,0 ng PCDD/F-TEQ/kg. For comparison, it can be mentioned that the content of congeners PCDDs and PCDFs in the forest soil of unpolluted areas does not exceed the value of 5,0 ng PCDD/F-TEQ/kg.

The reactions of plants to the changes of the chemical composition of the environment found vast applications in chemical monitoring of the natural environment quality.

A sensitive indicator of the condition of the natural environment has turned out to be the assimilatory organs of Pinus sylvestris L. the quality of which is strictly correlated with the health state of a stand. Statistical investigation showed that in extreme cases the chemical contamination generated by traffic could lead to reduction of both needle length and surface as well as to deformation of needles.

Inventory of the plant cover showed a high biodiversity of roadside ecotone zones. A distinct process of plant succession was observed in the neighbourhood of a newly-constructed road section. Parts of the road lane with the plant cover damaged during the construction works were taken over by ruderal species. In course of time the species were superseded, as a result of natural succession, by forest plants typical of the habitat.

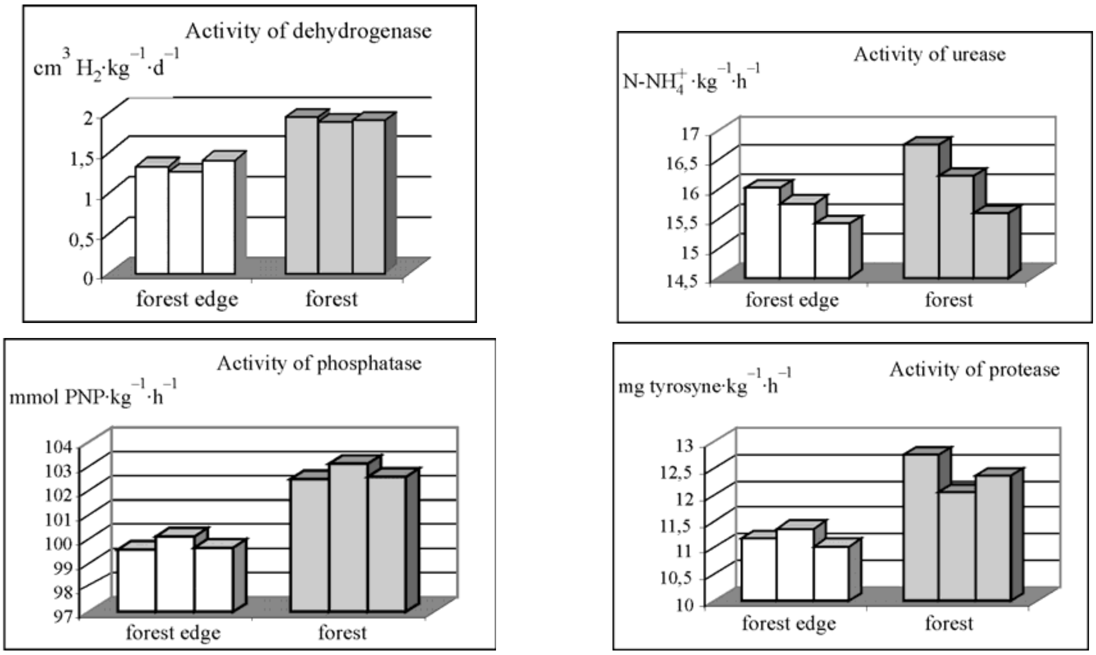

Fig 4. Enzymatic activity of humus horizon in the zone of traffic influence

Conditions of extraction and extraction solvents

Stage 1
10 mL 1M CH_3COONH_4, pH = 7;
shaking time of 1 h, room temperature
→ **Fraction I** Exchangeable form

Stage 2
20 mL 1M CH_3COONa acidified CH_3COOH up to pH = 5; shaking time of 5 h (determined experimentally), room temperature
→ **Fraction II** Carbonate form

Stage 3
20 mL 0,04 M $NH_2OH{\cdot}HCl$ in 25 % (v/v) CH_3COOH;
shaking time of 5 h, temperature of 95 °C
→ **Fraction III** Oxide form

Stage 4
5 mL 0,02M HNO_3 + 5 mL 30 % H_2O_2, pH 2;
shaking time of 2 h, temperature of 85 °C

5 mL 30 % H_2O_2 pH 2;
shaking time of 3 h, temperature of 85 °C

10 mL 3,2M CH_3COONH_4 in 20 % (v/v) HNO_3;
shaking time of 0,5 h, room temperature
→ **Fraction IV** Organic form

Stage 5
3 mL 10M HNO_3 + 3 × 2 mL H_2O_2, time of 1 h
+ 10 mL H_2O, time of 0,5 h, boiling temperature
→ **FractionV** Residual form

Fig 5. Scheme of fractionation of chromium soil samples from ecotonic zones

Congeners and respective TEF values

Congener PCDDs /PCDFs	TEF
2, 3, 7, 8–TCDD	1
1, 2, 3, 7, 8–P_5CDD	1
1, 2, 3,4, 7, 8–H_6CDD	0,1
1, 2, 3, 6, 7, 8–H_6CDD	0,1
1, 2, 3, 7, 8, 9–H_6CDD	0,1
1, 2, 3, 4, 6, 7, 8–H_7CDD	0,01
OCDD	0,0001
2, 3, 7, 8–TCDF	0,1
1, 2, 3, 7, 8–P_5CDF	0,05
2, 3, 4, 7, 8–P_5CDF	0,5
1, 2, 3, 4, 7, 8–H_6CDF	0,1
1, 2, 3, 6, 7, 8–H_6CDF	0,1
1, 2, 3, 7, 8, 9–H_6CDF	0,1
2, 3, 4, 6, 7, 8–H_6CDF	0,1
1, 2, 3, 4, 6, 7, 8–H_7CDF	0,01
1, 2, 3, 4, 7, 8, 9–H_7CDF	0,01
OCDF	0,0001
Result of determination	ng PCDD/F-TEQ/kg

TCDD – tetrachlorodibenzodioxyne
TCDF – tetrachlorodibenzofuran
P_5CDD pentachlorodibenzodioxyne
P_5CDF – pentachlorodibenzofurane
H_6CDD – heksachlorodibenzoddioxyne
H_6CDF – heksachlorodibenzofurane
H_7CDD – heptachlorodibenzodioxyne
H_7CDF – heptachlorodibenzofurane
OCDD – oktachlorodibenzodioxyne
OCDF – oktachlorodibenzofurane

4. Conclusions

1. Chemical contamination generated by motor traffic form the biogeochemical condition of roadside forest ecotone zones.

2. Both the soil and roadside plant cover cummulate chemical pollutants and restrict their migration to the forest environment.

3. The results of monitoring roadside ecotone zones indicate the necessity of applying such technical appliances as oil-derivatives separators, filtering screens or geomembranes close to motor roads to limit the migration of chemical compounds and preserve the homeostasis of precious natural forest complexes.

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BIOLOGINĖ IR CHEMINĖ INDIKACIJA PAKELĖS APLINKOS ZONOSE

A. Poszyler-Adamska, A. Czerniak

S a n t r a u k a

Transporto kelių tinklas, kertantis miškus, daro didelę neigiamą įtaką natūraliai gamtinei aplinkai. Miškų zonos pakelių dirvožemis veikia kaip filtras, stabdantis transporto sukeltą cheminę taršą. Darbo tikslas – pristatyti metodus, leidžiančius identifikuoti transporto taršos įtaką pakelių miškų būklei. Pakelių zonų būklės stebėjimo rezultatai parodė, kad netoli kelių būtina įrengti technologines priemones, pavyzdžiui, naftos produktų gaudykles, filtrus ar geomembranas. Tai leistų sumažinti cheminių junginių migraciją ir išsaugoti vertingus natūralių miškų kompleksus.

Reikšminiai žodžiai: automobilių transportas, miškas, pakelės aplinkos zonos, pėdsekinis užteršimas, monitoringas.

БИОЛОГИЧЕСКАЯ И ХИМИЧЕСКАЯ ИНДИКАЦИЯ В ПРИДОРОЖНОЙ ЗОНЕ

А. Пошилер-Адамска, А. Черняк

Резюме

Сеть транспортных дорог, пролегающих через лес, оказывает отрицательное воздействие на естественную природную среду. Почва придорожной территории лесной зоны действует как фильтр, пропускающий через себя химические загрязнители, выделяемые автотранспортом. Целью работы было представить методики, позволяющие идентифицировать влияние загрязнителей, выделяемых транспортом, на состояние придорожных лесов. Наблюдения за состоянием придорожной зоны показали, что вблизи дорог следует оборудовать технологические устройства, например, по сбору нефтепродуктов, фильтры или геомембраны. Это позволит уменьшить миграцию химических соединений и сохранить ценные комплексы естественных лесов.

Ключевые слова: автомобильный транспорт, лес, придорожная зона, загрязнение, мониторинг.

Andrzej CZERNIAK. Dr, Assoc Prof (since 2005), Dept of Forest Engineering, August Cieszkowski Agricultural University of Poznań, Poland.

Research interests: forest protection and management.

Agata POSZYLER-ADAMSKA. Master, doctoral student (since 2005), Dept of Forest Engineering, August Cieszkowski Agricultural University of Poznań, Poland.

Research interests: environmental protection and management.