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BIOMONITORING OF ATHMOSPHERE AIR POLLUTION IN THE FOREST ECOSYSTEMS AND ECO-TONE ZONE

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ABSTRACT

Within our research, the air quality of 62 forest ecosystems from Republic of Moldova was assessed, taking into consideration the lichens indicator species specific diversity, abundance and toxitolerance. It was established that the Moldavian forest ecosystems do not contain reserves concerning critical loads for SO_2 pollution, the annual average for the vegetation season for dendrological species being 0,02 mg/m^3 air, and for communities of lichens and cyanobacteria, organisms sensitive to pollution, represented only 0,01 mg/m^3. Lichen indication demonstrated that the current level of pollution is between 0,05 and 0,5 mg/m^3 SO_2 air, thus long-term harmful effects are manifested in all 62 studied forest ecosystems and the ecosystems from the eco-tone zone. We believe that for the Republic of Moldova lichen, indicator species can provide a scale of 6 levels: 5 levels characterized by species with different toxitolerance degree and the last step being an area in which lichens are completely missing, thus the most polluted area. Within the Republic of Moldova territory, there were reported 3 forest ecosystems in which the air is evaluated as clean air, 11- low polluted air, 31- moderate polluted air, 12- polluted air, 3- high polluted air and those with critical polluted air was missing.

Keywords: *licheno-indication, air quality, forest ecosystems, eco-tone zone.*

INTRODUCTION

The application of lichen indication in monitoring the quality of environment is one of the most indicated methods in speciality literature (Nylander,1865; Hawksworth and Rose, 1970; Tracc, 1984, Мэннинг. Федер,1985; Bartok, 1985; Кондратюк, Мартиненко, 2006; and Crisan, 2002)]. According to the synthesis analysis of scientific publications, concerning the Republic of Moldova lichens diversity, conducted by the author, currently, there are about 200 known species of lichens, covered in 12 orders, 35 families and 76 genus, which systematic belonging has been exposed according to *The Ainsworth & Bisby' s Dictionary of the fungi* (Hawksworth et al., 1995)] and nomenclature proposed by [8 (Kondratyuk, Khodosovtsev, Zelenko, 1998)], which constitutes a sufficient biodiversity basis to perform air quality monitoring.

The multitude of air quality assessment scales based on lichens toxitolerance degree form scales from 3 to 12 levels. Typically, those with 10 to 12 levels are applied in England, Pribaltic, Canada (Boreal region), which are areas very rich in lichen flora. For conditions of France, this has already been reduced to 7 levels [(Van Haluwyn et Lerond, 1986)]. We believe that for the Republic of Moldova lichen flora, indicator species can provide a scale of 6 levels: 5 levels characterized by species with different toxitolerance degree and the last step being an area in which lichens are completely missing, thus the most polluted area. The 20 scales analyzed by us were applied in different climatic regions (boreal, temperate, subtropical). Certain species were common in the testing of several authors, but were attributed different degrees of toxitolerance. Thus, our test, comprising gassing, transplantation and research in the field, have enabled us to select 40 bioindication species to be applied in monitoring of air quality in forest ecosystems: 3 species with toxitolerantion degree I, 15 species – II, 16 species – III, 4 species – IV and 2 species – degree V. High frequency of these species within the Republic of Moldova forest ecosystems, ensure and provide for the use of the same species by the European Monitoring Network, as many of these species are common for European space.

MATERIAL AND METHODS

Given the fact that at present there is rich information on the concentration of toxic pollutants in the atmosphere, which cause disturbances in lichens vital activities [1 Atlas, Schofield, 1975; 4 Burton, 1986; 12 Richardson, Nieboer, 1980; 21Tracc, 1977; 14 Блюм,1986; 18 Михайлова, Воробейчик, 1995], some scale authors specify degrees to SO_2 concentrations [6 Hawksworth and Rose, 1970; 9 LeBlanc et Rao,1972; 17 Лийв et al., 1982]. Indicated concentration vary widely from one author to another, perhaps this is due to the fact that some data has been obtained in laboratory conditions whereas other in the field, as well as due to different emissions structure, climate conditions, research methodology etc. Analysis of gradations allows us to see that at most authors the SO_2 concentration <0,05 mg/m^3 air is indicated for zone with clean air and the harmful effects start at 0,1 up to 0,3 mg/m^3 air, some indicating level> 0,3 mg/m^3 as very polluted air, others indicating that fatal for lichens is the concentration SO_2 > 0,5 mg/m^3 air. Thus, based on data published by other authors and based on our testing by gas and transplantation, we suggest Lichens Toxitolerance Scale (LTS) in respect to different concentrations of SO_2 in air (Table 1).

Considering that not any presence of lichens is a factual criterion of indication [15 Викторов, 1962], fact previously exposed for higher plants, in the case of lichen indication, air quality assessment will be true when the thallus of the indicator species comprehends the substrate coverage in a range of over 10% of the total area. This threshold is very important, especially for toxitolerance degree I and II because we can not say that the air is clean, when the investigated sector displays only one sample (or even 2-3) which are indication species which are very sensitive to air pollution, by covering only a very small surface of the substrate and by having a diminutive feature of development. Thus, given the bioindicators abundance, the following criterion is proposed for application within air quality assessment works (Table 2).

Table 1. Lichens Toxitolerance Scale (LTS) in respect to different SO_2 concentration in the air

Toxitolerance	Zone Characteristics	SO_2 concentration in the air, mg/m^3 air	Presence of lichens with different degree of sensibility to pollution
I	Not polluted	< 0,05	Very sensible
II	Low polluted	0,05 – 0,1	Sensible
III	Moderate polluted	0,1 – 0,2	With moderate resistance
IV	Polluted	0,2 – 0,3	With increased resistance
V	High polluted	0,3 – 0,5	With high resistance
VI	Critical polluted	> 0,5	Complete absence of lichens

Table 2. Air Quality Assessment Scales (AQAS) based on the abundance of lichen species with different toxitolerance degree to SO_2

The quality of atmosphere air	SO_2 concentration in the air, mg/m^3	Lichens species abundance with different degree of toxitolerance, % from substrate	Conventional colour
Clean	<0,05	I > 10 or I < 10 and II > 75	Blue
Low polluted	0,05–0,1	I – 0–10 or II – 50–75	Light blue
Moderate polluted	0,1–0,2	II – 10–50 or III > 50	Green
Polluted	0,2–0,3	III – 10–50 or IV > 50	Orange
High polluted	0,3–0,5	IV – 10–50 or V – 1–100	Red
Critical polluted	>0,5	Complete absence of lichens	Brown

As objects for our research served 62 forest ecosystems, in which the sources of pollution and the state of ecosystem components: such as air, water, soil and biota have been assessed. The location scheme of objects includes and spreads over 8 sectors with high environmental risk (large cities, industrial centres), deployed in all five landscape regions of the Republic of Moldova (Figure 1).

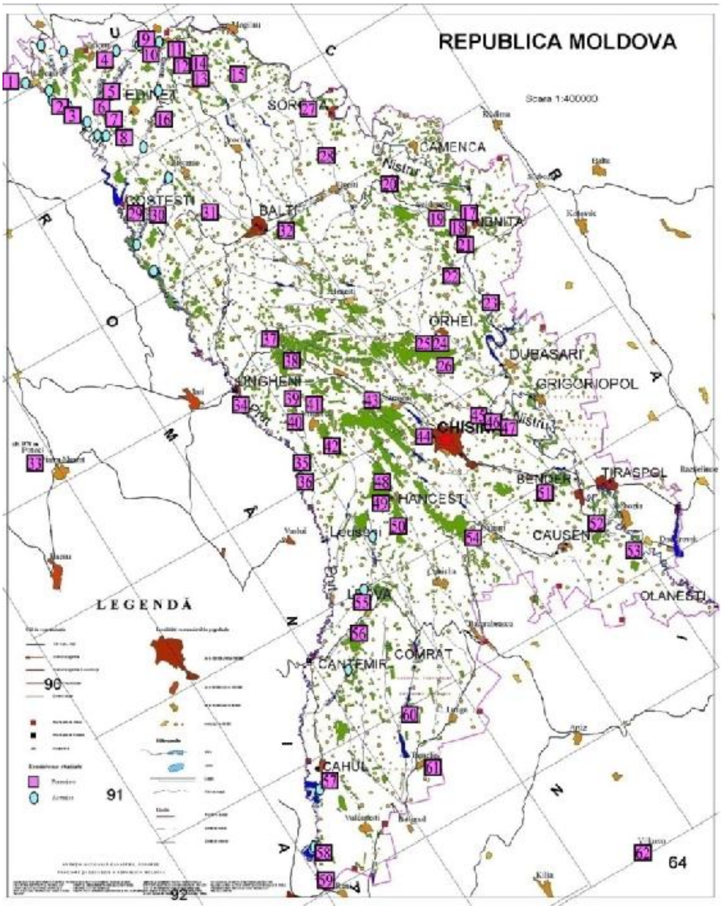

Figure 1. Map representation of investigated areas

Silvosteppe zone:

***A. Plateaus and silvosteppe plateau region includes**: I) 8 ecosystems located within the influence area of Lipcani and Edinet towns within a radius of 80 km, with forests near the settlements: 1-Criva, 2-Pererata, 3-Teţcani, 4-Trebisăuţi, 5-Trinca, 6-Fetesti, 7-La Castel, 8-Zăbriceni; II) 8 ecosystems located within the influence area of Edinet and Mogilau town, within a radius of 100 km, with forests near the settlements: 9-Clocusna, 10-Ocnita-Hădărăuţi, 11-Lipnic, 12-Cernoleuca, 13-Donduşeni, 14-Climauti, 15-Călărăşăuca-Mosana, 16- Chertroşica Noua; III) 10 ecosystem within the influence area of Ribnita and Rezina towns, within a radius of 90 km with forests near the settlements: 17-Ciorna, 18-Popauti, 19-Şoldăneşti, 20-Cuhurestii de Sus, 21-Saharna, 22-Pohribeni, 23-Lopatna, 24-Orhei, 25-Seliste, 26-Ivancea.*

***B. Plateaus and plains with grassland regions from Balti steppe:** IV) 6 ecosystems located within the influence area of Balti and Floresti towns, within a radius of 70 km with forests near the settlements: 27-Rublenita, 28-Rădulenii Vechi, 29-Stanca Mare, 30-Hâjdieni, 31-Iabloana, 32-Mândreştii Noi.*

***C. Plateau region with Codri forest:** V) 10 ecosystems in the influence area of Ungheni and Iasi towns, within a radius of about 120 km, with forests near the settlements: 33-Potoci (Romania),34-Valea Mare, 35-Neamteni,* *36-Cotul Morii, 37- Corneşti, 38-Bahmut, 39- Bălăneşti, 40-Seliste Leu, 41-Cobac, 42-Bujor, VI) 8 ecosystems located within the influence area of Chisinau and Hincesti towns, within a radius of 60 km with forests near the settlements: 43-Capriana, 44-Durlesti, 45-Tohatin, 46-Budeşti, 47-Cimişeni, 48-Logăneşti, 49-Sarata-Mereşeni, 50- Sărata Galbenă.*

Steppe zone:

D. Steppe region of the lower Nistru flood plain: *VII) 4 ecosystems under the influence area of Bender, Tiraspol and Dnestrovsc towns, within a radius of about 40 km, with the forests around the settlements: Hârbovăţul Nou-Balmaz, 52–Copanca, 53–Cioburciu-Răscăieţi, 54–Cărbun.*

E. Fragmented plains region from Bugeac steppe*: VIII) 8 ecosystems located under the influence of the Cahul and Comrat towns, within a radius of about 170 km, with forests near the settlements: 55–Sărata Nouă, 56–Codrii Tigheci, 57–Crihana Veche, 58–Văleni, 59–Giurgiuleşti, 60–Congaz, 61–Taraclia, 62–Vilcovo (Ukraina).*

RESULTS AND DISCUSSION

The assessment of air quality in 62 forest ecosystems throughout the Republic of Moldova was carried out taking into account the specific diversity, abundance and indicator species toxitolerance, applying the Lichens Toxitolerance Scale (LTS) and Air Quality Assessment Scale (AQAS) developed by us [3Begu, 2008].

Within the Republic of Moldova territory, there were reported 3 forest ecosystems in which the air is evaluated as clean air, 11- low polluted air, 31- moderate polluted air, 12- polluted air, 3- high polluted air and those with critical polluted air was missing. The quality of air in ecosystems evaluated as clean (SO_2 <0,05 mg/m^3 air) is confirmed by the presence of species sensitive to pollution, with coverage of the substrate over 10% (i.e. *Usnea hirta* – at Ocniţa–Hădărăuţi, *Peltygera canina* – at Bahmut et *Ramalina fraxinea* – at Selişte Leu). Ecosystems with low polluted air (SO_2 = 0,05 to 0,1 mg/m^3 air) are located primarily in the north (6 – Trebisăuţi, Feteşti, La Castel, Zăbriceni, Lipnic, Donduşeni) and in the centre part of the country – Codri region (3 – Bujor, Cimişeni, Logăneşti), and 2 respectively located in the middle course of the Nistru River (Lopatna) and Prut River (Cotul Morii). Ecosystems with moderate polluted air (SO_2 = 0,1 to 0,2 mg/m^3 air) are the largest in number (31) and have a wide distribution in northern, central and southern part of the country, often being subject to impact from local sources (i.e. – Hâjdieni, Criva, Orhei, Selişte, Durleşti, Budeşti, Văleni, Giurgiuleşti etc.) or cross-border sources of pollution, particularly via acid precipitation (i.e.– Bălăneşti, Cobac). Others probably are subject to common effects, because they are slightly away from the sources of pollution (i.e.– Teţcani, Clocuşna, Rubleniţa, Stânca Mare, Sărata Galbenă, Sărata Mereşeni, Cărbuna etc.). The share of ecosystems with polluted air (SO_2 = 0,2 to 0,3 mg/m^3 air) is 12, these primarily dominating the surrounding areas of pollution outbreaks, such as Bălţi, Rezina–Râbniţa, Chişinău, Tiraspol, Cuciurgan (i.e.– Trinca, Chetroşica Nouă, Mândreştii Noi, Păpăuţi, Şoldăneşti, Tohatin, Hârbovăţ, Cioburciu etc). High polluted air (SO_2 = 0,3 to 0,5 mg/m^3 air) is evaluated for 3 ecosystems – Criva, Saharna, Copanca which have a dislocation in the immediate vicinity of the pollution sources and are located on the path of dominating winds, which move the emitted pollutants. Ecosystems with critical polluted air (SO_2> 0,5 mg/m^3 air) were not recorded.

Certainly, the air quality in the investigated ecosystems, may be influenced and be subject to a range of factors, via direct dependence effects, emission of certain pollutants, but also by synergistic effects of these. Important are orographic parameters (altitude, exposition), climatic (precipitation, wind), and the effects of air pollution – type and quantity of emitted pollutants, the location/distance of the ecosystem in respect to source of pollution, frequency and emission cycles and the effects of transboundary pollution. Classically, ecosystem with low polluted air are located at altitudes above 200 m whereas those with polluted air – less than 200 m. Nevertheless, there are some exceptions and these are subject to the ecosystem location in respect to the source of pollution and the direction of prevailing winds (i.e. Trinca, Călărăşeuca, Chetroşica Nouă, Mândreştii Noi, Saharna – located at altitudes above 200 m, but rather polluted). The majority of forest ecosystems in the Republic of Moldova are of hilly type (200-600 m), rarely plains (0-200 m). More pronounced are the effects of pollution on lowland ecosystems surrounding localities Valea Mare, Nemţeni, Crihana Veche, and for Criva, Hâjdieni, Orhei, Tohatin, Copanca, Hârbovăţ, Cioburciu, in which the decisive role has been played by the distance of the ecosystem from the sources of pollution (distance from the source and the direction of the prevailing winds).

Thus, the highest SO_2 emissions from local sources in 2005 were typical for the areas located in the southeast part of the Republic of Moldova, pollution outbreaks Tighina–Tiraspol–Cuciurgan, over passing Chisinau about 20 times, 100 times Bălţi and over 700 times Cahul. This outbreak has led to the pollution of the country southeast ecosystems, mainly due to the northwest winds rose direction towards southeast, fact conformed as well by us via bioindication. SO_2 emissions from Soroca – 154 t/year and Balti – 85 t/year were determinative in the degradation of Hâjdieni ecosystem, whereas geological explorations in Criva and Trinca, the later being affected as well by unauthorized burning of tire for lime production, placed these ecosystems in the category of ecosystems with high polluted air. High emissions of SO_2 are characteristic to Hincesti town (332 t/year), which have left its mark on the state of atmospheric air in surrounding ecosystems – Sărata Galbenă and Sărata Mereşeni. Chisinau emissions have obviously contributed to the pollution of Balmaz–Hârbovăţ ecosystem, towards southeast and Tohatin–Budeşti towards east. To a large extend the effects of pollution from the outbreak Rezina–Râbniţa was expressed only in the immediate vicinity on Saharna, Ciorna, Păpăuţi and this is due to wind rose northwest towards southeast, thus did not affect Pohrebeni and Lopatna ecosystems. Possible adverse effects on vegetation from the outbreak Cuciurgan were more pronounced for Copanca and slightly less for Cioburciu–Răscăieţi, as well due to rose wind northwest towards southeast.

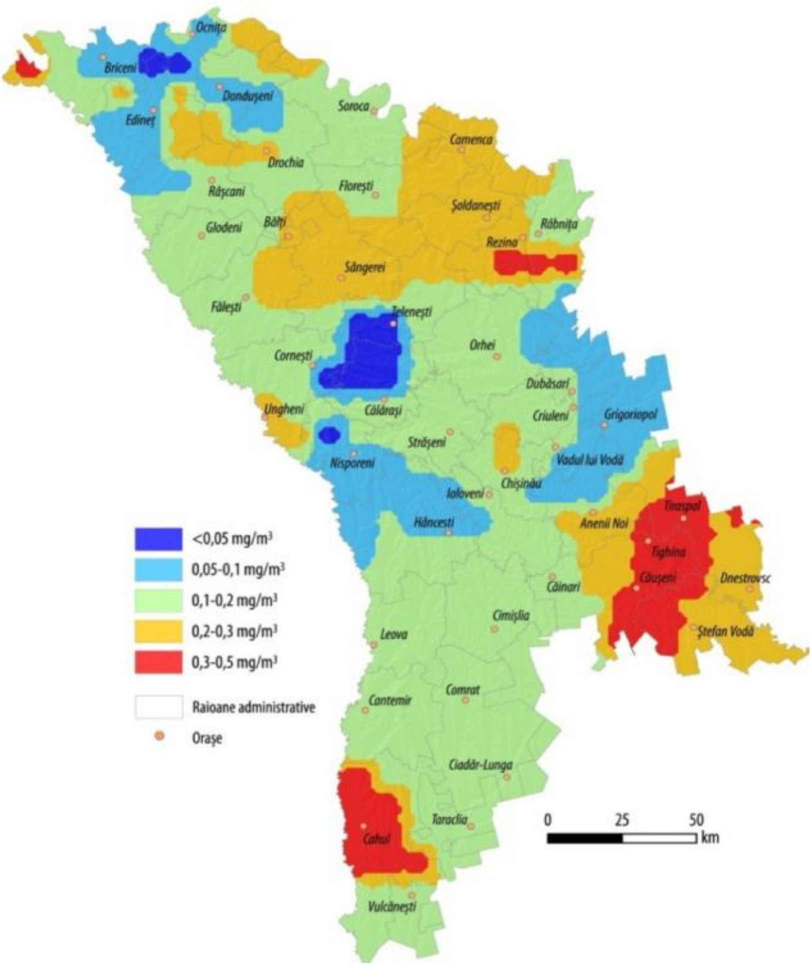

Figure 2. Spatial distribution of air pollution with SO2, based on lichen indication

The south part of the country is affected by transboundary pollution (Galati town, Romania), especially Crihana Veche and Giurgiulesti and Valeni. . Effects of pollution from sources located in Iasi town, inseparable from those originating from Ungheni, strengthen the pollution in ecosystems located in eco-tone zone – Valea Mare, Nemţeni, to a slighter extend Bălăneşti, Cobac, however not crossing Bahmut and Corneşti situated in the northwest part from the outbreak and protected by the landscape dominated with high altitude. According to EMEP Report 1/2003 [11 Rewiew and Revision, 2003] developed by the Norwegian Meteorological Institute, transboundary pollution remains an issue for many European countries, including Moldova, which is situated in the annual deposition of SO_2 700-1000 mg/m^2. As well, in the last five years a trend appears in relation to increased atmosphere emissions due to increasing economic potential of south east European countries. The lichen indication in connection to the 62 investigated ecosystems, and the EMEP 50x50 km grid, reveals that the real environmental situation is camouflaged, probably because the effects of pollution are more pronounced up to about 25-30 km from the source of pollution. In the case of EMEP network, the ecological situation is levelled throughout the 50x50 km grid which does not correspond to reality.

The foundation of a sustainable environmental balance in the functioning of forest ecosystems in the Republic of Moldova, serve the critical levels established by the Geneva Convention (1979) for SO_2, NOx and NH_3. Thus, forest ecosystems from the Republic of Moldova do not provide reserves concerning the critical tasks of SO_2 pollution, as dendrospecies annual average or growing season, being 0,02 mg/m^3 air, and for lichens communities and cyanobacteria – organisms sensitive to pollution, representing only 0,01 mg/m^3. Lichen indication have demonstrated that the current level of pollution is between 0,05 and 0,5 mg/m^3 SO_2 air, thus long-term harmful effects are manifested in all the 62 investigated forest ecosystems. Broadly speaking, we can say that there are only 3 ecosystems, assessed by lichen indication, with clean air (SO_2 <0,05 mg/m^3air) and which have a good structural stability and functionality (Ocniţa-Hădărăuţi, Bahmut and Selişte-Leu). Thus, increasing industrial activities require us to maintain control and monitor this index to identify ways to mitigate the impact on forest, agricultural and urban ecosystems deployed in the area of eco-tone.

CONCLUSIONS

Based on the performed research there were established the premises of ecobioindication in the Republic of Moldova, expressed by the presence of 40 species of lichens, which form certain associations sensitive to air pollution with SO_2 and accumulate in their body concentrations of heavy metals.

The results obtained via passive and active biological monitoring allowed us to argue on the theoretical possibility and effectiveness of ecobioindication application in monitoring of air quality within forest, agricultural and urban ecosystems deployed in the area of eco-tone.

Parmelia sulcata species, common in forest ecosystems, has proved to be most responsive to air chemical pollutants, particularly with SO_2, registering obvious morphological and biochemical changes (colour change, degradation of thalus and photosynthetic pigments).

Recommendations

Widespread, high frequency and dominance of *Parmelia sulcata* species prevalent in forest ecosystems, as well as the possibility of being easy transplanted into urban, agricultural and industrialized ecosystems, allows its use as a standard in geographical mapping of air pollution with SO_2 and heavy metals, a requirement introduced by European Committee for Standardization Programme, Measurement and Testing.

In order to assess the environmental state of forest, agricultural and urban ecosystems, ecobioindication method is recommended – efficient and easily realizable method by applying the Air Quality Assessment Scale (AQAS), which has been developed taking into consideration the specific diversity of lichens, the indicator species toxitolerance degree and substrate coverage.

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