THE POSSIBILITY AND EFFICIENCY OF BIOINDICATION METHOD IN FOREST AIR QUALITY MONITORING

BEGU Adam

Abstract. The investigation concluded upon the existence of a sufficient number of indicator species of lichens which can be applied in monitoring the environment quality in the Republic of Moldova. The investigation also contributed to the establishment of legitimate facts that under the action of gaseous pollutants (i.e. SO_2 etc.) and depending on the source of pollution, geographic location, species sensitivity, duration of exposure induce the modification or total degradation of lichen thallus. Additionally, the Air Quality Gradation Scale (AQGS) and Lichens Toxitoleration Scale (LTS) towards different concentration of SO_2 in atmosphere air were developed. The efficiency of AQGS with some additional modifications was tested through assessing the quality of air in 62 forest ecosystems. Thus, in order to meet the country obligations under the Geneva Convention (1979), *Parmelia sulcata* species was proposed as a referent species (standard) in performing the monitoring of air quality at national and international level.

Keywords: lichens, indication, pollution, monitoring.

Rezumat. Posibilitatea şi eficacitatea metodei bioindicaţiei în monitoringul calităţii aerului din păduri. Lucrarea include rezultatele studiului premizelor implementării ecobioindicaţiei în evaluarea calităţii mediului ecosistemelor forestiere din Republica Moldova, stabilindu-se existenţa unui număr suficient de specii indicatoare de licheni, care pot sta la baza realizării monitoringului calităţii mediului. Sunt stabilite legităţi privind modificarea sau degradarea totală a talului lichenilor sub acţiunea poluanţilor gazoşi (SO_2 ş. a.), în funcţie de sursa de poluare, condiţiile geografice, sensibilitatea speciei, durata expunerii etc. Sunt elaborate Gradaţii de Evaluare a Calităţii Aerului (GECA) şi Scala Toxitoleranţei Lichenilor (STL) faţă de SO_2. A fost demonstrată eficienţa aplicării GECA, cu unele modificări, în testarea calităţii aerului din 62 ecosisteme forestiere. Astfel, în scopul îndeplinirii obligaţiilor ţărilor impuse de Convenţia de la Geneva (1979), specia *Parmelia sulcata* este propusă ca obiect de referinţă (standard) în realizarea monitoringului calităţii aerului la nivel naţional şi internaţional.

Cuvinte cheie: licheni, indicaţie, poluare, monitoring.

INTRODUCTION

The presence of lichens as such is not necessarily an indication criterion, as previously stated by VICTOROV *et al.* (1962) for higher plants. To have an indicative value the lichens must have a certain abundance. In our view, a coverage of 10% of the substrate surface could be a clear indicator. This threshold is very important, especially for toxitoleration grades I and II since we cannot state that the air is clean upon identifying a few plants of lichens very sensitive to pollution. For certain species which could be used as indicators for the Republic of Moldova there were no information or the available information was controversial. Based on our research, which included results from laboratory and field observation on lichens from natural habitats, transplanted lichens and trials in laboratory, there were established new toxitoleration gradations or their initial toxitoleration was modified.

MATERIAL AND METHODS

Proceeding from the indicators abundance and toxitoleration we elaborated a scale with gradations for the evaluation of the air quality (Table 1). The evaluation of air quality by applying the lichens indication method to 62 forest ecosystems throughout the Republic of Moldova, allowed us to identify 90 lichens species out of which 50 species are bioindicators.

Table 1. Scales in air quality assessment based on abundance of lichens with different toxitoleration (BEGU, 2011).
Tabel 1. Gradaţii de evaluare a calităţii aerului în baza abundenţei lichenilor de diversă toxitoleranţă (BEGU, 2011).

Air quality	SO_2 content in the air, mg/m^3	Abundance of species with different toxitoleration degree, % of substrate surface	Conventional colour
1. Clean	<0,05	I > 10 or I < 10 and II > 75	blue
2. Slightly polluted	0,05-0,1	I – 0 -10 or II – 50-75	light blue
3. Moderately polluted	0,1-0,2	II - 10-50 or III > 50	green
4. Polluted	0,2-0,3	III - 10-50 or IV > 50	yellow
5. Heavily polluted	0,3-0,5	IV - 10-50 or V - 1-100	red
6. Critically polluted	>0,5	Complete absence of lichens	brown

RESULTS AND DISCUSSIONS

Basing on this method, four forest ecosystems were evaluated as clean air (Ocniţa-Hădărăuţi, Bahmut, Selişte-Leu, and Potoci); the number of ecosystems with slightly polluted air reaches 11, moderately polluted - 31, polluted - 13, heavily polluted - 3 (Criva, Saharna, Copanca), while those with critical pollution level are not present (Fig. 1). The

air quality from the ecosystems which were reported as clean is confirmed by the presence of lichens species very sensitive to pollution, the coverage of which was over 10% of substrate surface (i.e. *Usnea hirta* in Ocniţa-Hădărăuţi, *Peltygera canina* - in Bahmut and *Ramalina fraxinea* - in Selişte-Leu).

The ecosystems with slightly polluted air (SO_2 = 0,05–0,1 mg/m^3 air) are primarily located in the North of the country (Trebisăuţi, Feteşti, La Castel, Zabriceni, Lipnic, Donduşeni) and some of them in the central part (Bujor, Cimişeni, Logăneşti) and in the middle part of the Dniester (Lopatna) and the Prut (Cotul Morii) river basins.

The ecosystems with moderately polluted air (SO_2 = 0,1–0,2 mg/m^3 air) are more numerous (31) and have a wide distribution throughout the country, often being subject to impact from local pollution sources (i.e. - Hâjdieni, Criva, Orhei, Selişte, Durleşti, Budeşti, Văleni, Giurgiuleşti etc.) or from transboundary sources, particularly areas on hillsides with Western exposition (e.g. Bălăneşti, Cobac). The number of ecosystems with polluted air (SO_2 = 0.2–0.3 mg/m^3 air) is 13, prevailing in the vicinity of the cities and industrial pollution sources (e.g. Trinca, Chetroşica Nouă, Mândreştii Noi, Papauţi, Şoldăneşti, Tohatin, Hârbovăţ, Ciobruciu). Heavily polluted air (SO_2 = 0.3–0.5 mg/m^3 air) is set for 3 ecosystems - Criva, Saharna, and Copanca, which have a location in the immediate vicinity of pollution sources and are positioned in the path of the prevailing winds. The ecosystems with critical polluted air (SO_2 > 0.5 mg/m^3 air) were not recorded.

A more pronounced air pollution with SO_2 is specific for the ecosystems located around obvious sources of pollution. Here, the bioindicators with toxitoleration degree II and III do not exceed 5% of the substrate coverage (sometimes over 10% in case of nitrophilous species - Văleni, Giurgiulesti, Criva region), and the persistent species with the toxitoleration III, IV, V are most of the times nitrophilous species. In addition, the ecosystems with polluted air are poor in diversity (often only 4 – 6 species).

Typically, the ecosystems with slightly polluted air are located at altitudes above 200 m and those with polluted air - below 200 m, but there are many exceptions, because the distance from the pollution source and the direction of prevailing winds are also important factors (for example the sites Trinca, Călăraseuca, Chetroşica Nouă, Mândreştii Noi, Saharna – are situated at altitudes above 200 m but are still rather polluted). Compared with Potoci site (mountain type), most forest ecosystems in the Republic of Moldova are hilly type (200-600 m) or flat (0-200m). Rather enhanced can be considered the effects of pollution in ecosystems located on plain areas for instance those around Valea Mare, Nemţeni, Crihana Veche, Vilcovo (Ukraine), and for Criva, Hâjdieni, Orhei, Tohatin, Copanca, Hârbovăţ, Cioburciu; the determining role was played by the distance from the pollution source of and the direction of prevailing winds.

Most of SO_2 emissions from local sources are concentrated in the South East of the country with a mega-source in Tighina - Tiraspol - Cuciurgan area. This led to the pollution of ecosystems located in the SE due to prevailing winds from NW to SE, which were confirmed by us through bioindication. The emissions of SO_2 from Soroca and Bălţi sources led to the Hâjdieni ecosystem degradation. The geological exploration of Criva and Trinca, the later being as well affected by unauthorized burning in the lime production process, have placed these ecosystems in the category with highly polluted air. High emissions of SO_2 are characteristic for the town of Hânceşti that left their prints on the state of bordering ecosystems air - Sărata Galbena and Sărata-Mereşeni. Chişinău emissions have evidently contributed to the pollution of ecosystems Balmaz - Hârbovăţ located in the South East and Tohatin - Budeşti located towards East. The effects of pollution from the Rezina - Rabniţa source were reported only in direct vicinity (Saharna, Ciorna, Popăuţi), due to the direction of winds from NW to SE, leaving unaffected the ecosystems Pohribeni and Lopatna. The possible harmful effects, catastrophic for vegetation, from the Cuciurgan source were more pronounced in Copanca and less in Cioburciu - Răscăieţi, again due to the direction of winds from the NW to SE. The South part of the country is affected by transboundary pollution (Galaţi city, Romania), especially Crihana Veche, as well as Giugiuleşti and Văleni. The effects of pollution from the sources located in Iaşi, inseparable from those of Ungheni, strengthen the pollution of ecosystems in the region around - Valea Mare, Nemţeni, less Bălăneşti, Cobac, but fortunately pollution does not reach Bahmut and Corneşti, located NE of the pollution sources; as a result, they are protected by the high relief of Codrii forest reservation.

According to the EMEP Report 1/2003 issued by the Meteorology Institute, Norway, transboundary pollution is manifested in many countries in Europe. Moldova is located in the area of annual SO_2 deposition equal to 700 - 1000 kg/km^2. The comparison between the results of lichen indication applied to 62 ecosystems, to the EMEP results, presented in table 2, shows that the EMEP network (50x50 km grid) hinders the real environmental state, probably because pollution effects are more pronounced within the 25-30 km from the pollution source. For example, in the 86/64 sectors the 11 studied ecosystems showed the air as clean (e.g. Ocniţa), slightly polluted (Feteşti, Trebisăuţi, Zăbriceni ecosystems), moderately polluted (Clocuşna and Cernoleuca) or polluted (Trinca and Chetroşica Nouă). In the same time, the EMEP matrix characterizes the state of the air as polluted.

The 50x50 km grid is likely to be indicative in large forest areas and/or plain landscape (for instance Belarus, the Baltic states, Poland, Russia, etc.) but is less meaningful for the Republic of Moldova, a country with low forest coverage and fragmented landscape, which can re-direct pollution effects. Thus, at the national level it is recommended the application of 25x25 km grid.

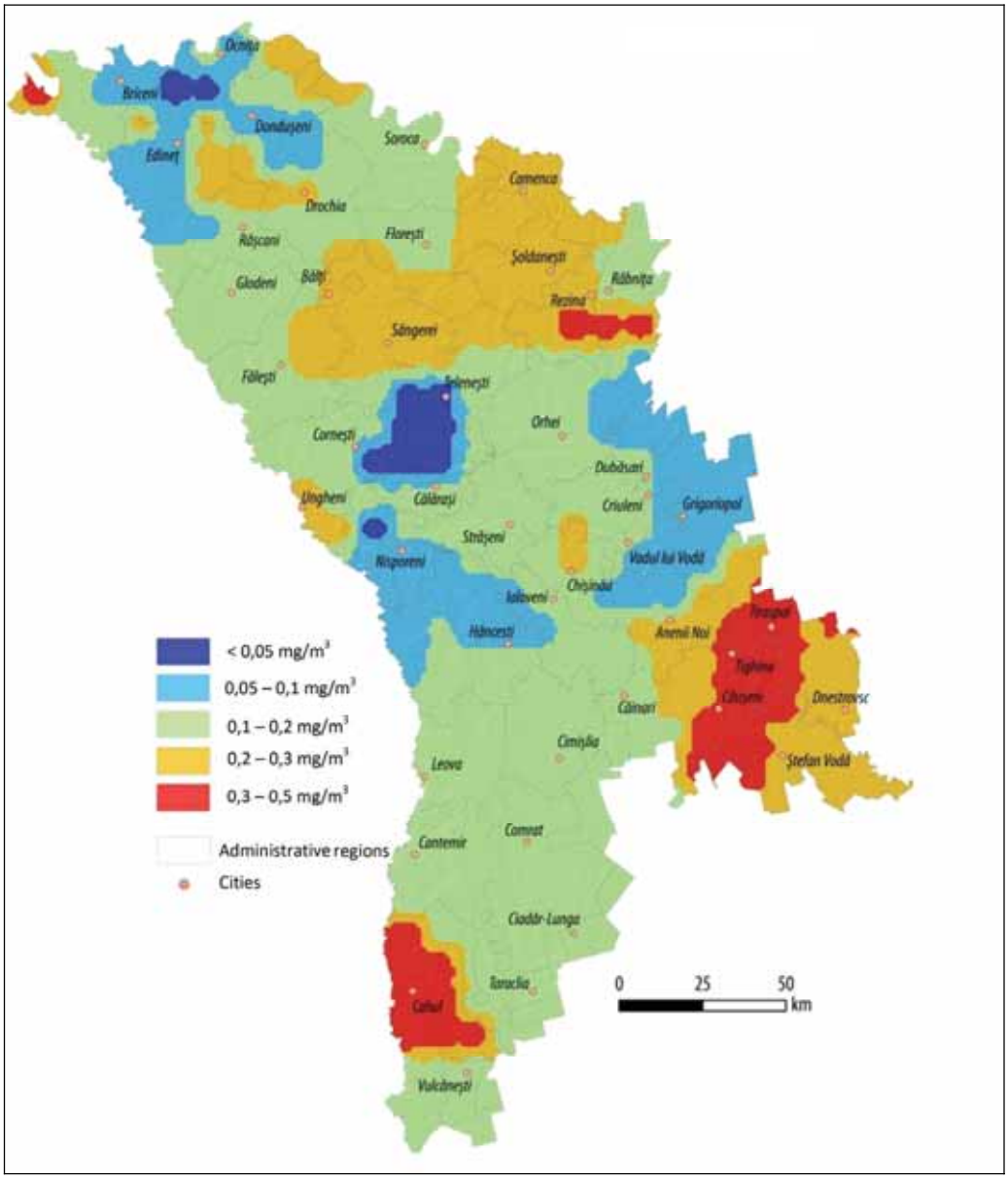

Figure 1. Spatial distribution of air pollution with SO_2, based on lichen indication. / Figura 1. Distribuţia spaţială a poluării aerului cu SO_2, bazată pe lichenoindicaţie.

Table 2. Air quality of researched forest ecosystems, according to EMEP 50x50km (large rectangles) comparing to our evaluations based on AQGS (small squares). / Tabel 2. Calitatea aerului din ecosistemele forestiere studiate, conform EMEP 50x50km (dreptunghirile mari) comparative cu evaluările noastre pe baza GECA (dreptunghiurile mici).

North -South Direction	Ecosystems EMEP networking distribution (32dials 50x50km grid) West – East Direction						
	62	63	64	65	66	Total	Ro, Ua
85	Ro				Ua	1	
86	Ro				Ua	14	
87	Ro				-	5	
88	Ro		2	1	-	7	1- Ro
89	Ro		6	4	1	14	
90	Ro		4	3	-	8	
91		2	1	3	-	6	
92	3	2	-	-	-	5	
93	-	Ua	Ua	Ua	Ua	-	
94	Ua	Ua	1- Ua	Ua	Ua	-	1- Ua
Total	3	13	25	14	5	60	2

Legend: Ro - Romania; low polluted air; polluted air; Ua - Ukraine; moderate polluted air; highly polluted

CONCLUSIONS

1. The Republic of Moldova Lichens Register was elaborated, based on literature review and own research, which includes about 200 species and varieties (22 set by the author).

2. The premises of lichens eco-bioindication were established basing on the presence of 40 indicator species, sensitive to air pollution with SO_2, NOx, etc.

3. Two criteria for the evaluation of the state of environmental components were proposed: a Lichens Toxitoleration Scale (LTS) with 6 steps, taking into account the degree of air pollution with SO_2, the similarity of geographical conditions, and the results of own testing through gasification, transplantation and studies in the field; and Gradations for Air Quality Assessment (GAQA) in forest based ecosystems, based on indicator abundance/coverage, toxitoleration and correlation between different bioindicator species.

4. The results obtained from the biological monitoring of 62 forest ecosystems allowed us to argue the possibility and efficiency of lichens indication method in air quality monitoring.

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Begu Adam
Institute of Ecology and Geography, Chişinău,
Republic of Moldova, Str. Academiei No. 1 MD 2028
E-mail: adambegu@gmail

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