EREM 72/4

Journal of Environmental Research, Engineering and Management
Vol. 72 / No. 4 / 2016
pp. 37-44
DOI 10.5755/j01.erem.72.4.16402

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Received 2016/10 | Accepted after revision 2016/12

http://dx.doi.org/10.5755/j01.erem.72.4.16402

Passive Lichenoindication as a Tool for Evaluation of Air Quality in the Environment of a Fertiliser Plant

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Air pollution remains one of the most important environmental problems not only in urban but also in industrial areas. The aim of the study was to evaluate air quality in the area surrounding the biggest fertiliser producers in the Baltic States by means of the passive lichenoindication method. The abundance of epiphytic lichen species, a factor characterising the condition of lichen community (index of poleotolerance PI), and nitrogen concentration in lichens were investigated at 6 study sites up to 30 km away from the pollution source. The highest lichen species diversity (n = 5.1) was in the study sites at a distance of 11–17 km from the factory, while the lowest diversity was at the control site (n = 3.6). The highest projection coverage was in the surroundings of JSC Achema (64%), and the lowest coverage was established in the zone of 23–30 km away from the factory (21%). The highest PI (7.1) was determined in the pollution source zone, and the lowest PI was in the control zone (5.8). The highest nitrogen concentration in *Xanthoria parietina* was in the premises of the factory (29.07 mg/g), whereas the lowest nitrogen concentration was found in the territory furthest from the factory (3.83 mg/g). According to the poleotolerance index, the cleanest environment was found in the control site and in the territory furthest (23–30 km) from the factory – study site 5 (according to projection coverage and nitrogen concentration in lichens).

Keywords: air quality, bioaccumulation, bioindication, lichens, nitrogen.

Introduction

Fast development of the industry and the growing need for agricultural production lead to an increase in the concentration of NO_x (NO_2 and NO) and NH_3 compounds in the atmosphere. The emissions of certain contaminants (such as SO_2) have been significantly reduced due to new strategies of the environmental policy; however, anthropogenic nitrogen emissions have increased more than 10 times since 1860 and that causes the changes in the global nitrogen cycle (Galloway et al., 2004). Industrial plants are among the main sources of anthropogenic nitrogen pollution, causing changes in the functioning of ecosystems (Fenn et al., 2008), chemistry of the soil (Breiner et al., 2007), biomass of plant roots, leaching from the soil (Baron et al., 2011, Fenn et al., 2003), it increases the spread of invasive species and changes composition and abundance of various communities, including those of lichens (Jovan et al., 2012).

Environmental quality can be assessed by means of a number of analytical methods that are very precise but cannot determine the negative impact on living organisms. Therefore, biological methods are increasingly used worldwide. These methods are based on bioindication and allow monitoring and evaluation of a complex negative environmental impact of known and unknown factors (Root et al., 2013).

Lichens are unique bioindicators because they are extremely reactive to the changes of the environment, such as climate change, eutrophication and air pollution, particularly SO_2 and NO_x. Lichens absorb solutes and gases over the entire thallus surface; therefore, they respond more sensitively to changes in atmospheric purity than vascular plants (Hauck, 2009). Nitrogen-containing aerosols may negatively affect the thallus of the lichen and cause the degradation of chlorophyll (Arb et al., 1990, Munzi et al., 2008). Gaio-Oliveira et al.'s (2004) research results have shown a positive correlation between the amount of nitrogen accumulated by *Xanthoria parietina* and chlorophyll. During wet periods, when photosynthesis is active, NH_3 alters the pH of the tree bark and the external surface of the lichen (Laurens, 2007), causes the slowdown in the intensity of photosynthesis and breathing (Gilbert, 1971, Arb et al., 1990) and the reactivation of glutamine synthesis (Hauck, 2009).

Since lichens lack a cuticle to control absorption or leaching of nutrients, these organisms dynamically concentrate nutrients roughly in proportion to the abundance in the atmosphere (Munzi et al., 2008). Biomonitoring with lichens is effective because when N deposition increases, nitrogen-loving eutrophic lichens become dominant over oligotrophic lichens (Root et al., 2013). In the areas where the concentration of ammonia exceeds 35 μg/m^3, all acidophilic species become extinct (Herk, 2001). It has been established that the nitrogen concentration in *Xanthoria parietina* strongly correlated with the deposition of dissolved inorganic nitrogen (Root et al., 2013) and *Xanthoria* sp. with the concentrations of atmospheric NH_3 (Conti et al., 2000). The aim of this study was to evaluate air quality in the area surrounding chemical factory JSC Achema by means of passive lichenoindication and bioaccumulation methods.

Materials and methods

JSC Achema is the biggest producer of nitrogen fertilisers and other chemical products in the country and the biggest plant of this type in the Baltic States (Armolaitis et al., 2003). Achema is considered as a major stationary air pollution source in Lithuania. The plant is situated in Jonava region (55° 4' 52.29", 24° 19' 31.71"), on the left shore of the river Neris. The main pollutants emitted by Achema are NO_x (33%) and CO (29%) as well as NH_3 (20%). The changes of Achema pollution (CO, NO_x, NH_3, PM and SO_x) emissions during 1979–2015 are presented in Figure 1. The comparison of the total pollution emissions of the last year with the whole period of the operation of the factory shows that they decreased significantly; however, the emissions into the environment during 2015 (2182.8 t) were by 74.04 t (3.4%) higher than during 2014 (2108.7 t), because the comparison of these years shows that the manufacturing of production increased by 8% (2015 data of the Laboratory Control Centre (LCC) of Achema).

The abundance of epiphytic lichen species, a factor characterising the condition of lichen community (index of poleotolerance PI), and nitrogen concentration in li-

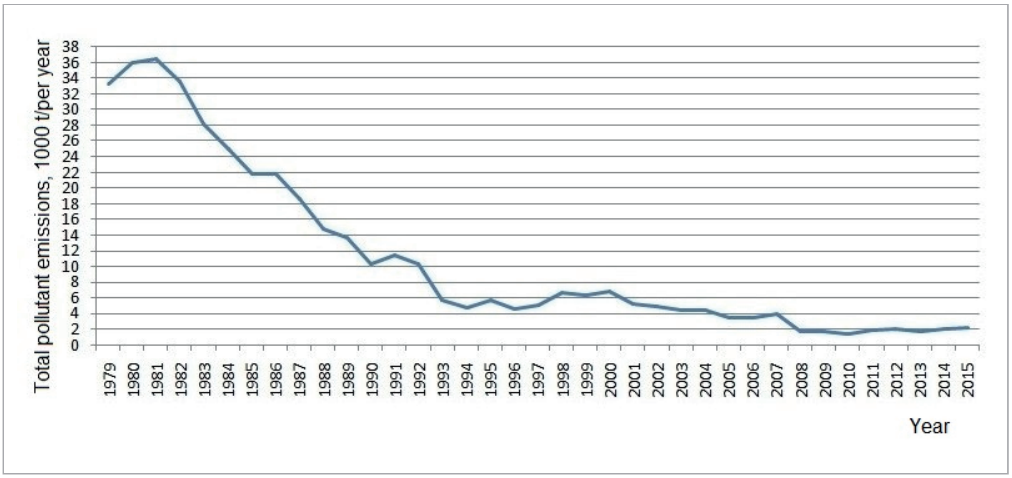


Fig. 1

Total emissions of the main pollutants of the factory (1000 t/per year) during the period of 1979–2015 (data of the Laboratory Control Centre of Achema)

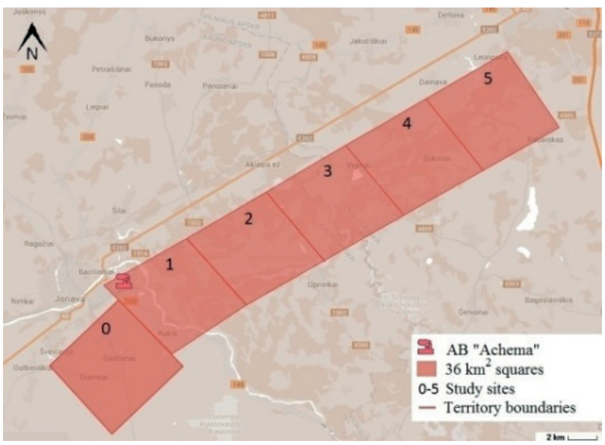
chens were investigated in 6 study sites: control zone (1–7 km distance to Achema), factory premises (0–5 km distance), and study sites at 5–11 km, 11–17 km, 17–23 km, 23–30 km away from the factory (Figure 2).

The study sites were selected in the downwind north-east direction and 1.5 km away from Jonava–Ukmergė road (road No. A6/E262).

The abundance of epiphytic lichen species and the index of poleotolerance PI were calculated in August, 2015, according to passive lichenoindication methodology (Trass, 1973). Ten trees were examined in the zone of each study site. The leafy trees were chosen for the assessment of the communities of the epiphytic lichen.

Fig. 2

Study sites: 0 (1–7 km to the factory), 1 (0–5 km from Achema), 2 (5–11 km), 3 (11–17 km), 4 (17–23 km), 5 (23–30 km)



The main focus was dedicated to the trees with the rich bark (*Tilia cordata* Mill., *Acer platanoides* L., *Quercus robur* L.), healthy and undamaged trees of a similar diameter (15–25 cm) and age, with no more than 10° inclination growing at the conditions of average density and receiving enough light. For the description of lichen communities, the square net was used: one cell of the net (22 cm) is equal to 1%, and there are 100 cells in the net, i.e., 100%. All epiphytic lichens were assessed, and the following indicators were recorded: lichen types that comprise the lichen community, coverage of each type (%) and total coverage of all types (%). The factor characterising the condition of the lichen community (PI) was calculated according to the formula (Eq. 1):

$$PI = \sum_{i=1}^{n} \frac{a_i \times c_i}{C_n} \quad (1)$$

where

PI – index of poleotolerance; C_n – sum of distributions of certain epiphytic species of lichens, %; n – number of lichen species; a_i – lichens species poleotolerance class; c_i – distribution of one lichen species, %.

The index of poleotolerance was calculated for each tree of accounting. The PI was used to determine air quality of the territory (Table 1).

The concentration of accumulated nitrogen in lichens was analysed following the Kjeldahl method (Kjeldahl, 1883). In the zone of each object, lichens were collected

Table 1

Atmosphere pollution zones according to the PI

PI	Pollution zone
1	2
0–3	Of natural landscape
3–6	Peripheral, relatively clean
6–9	Of average pollution
9–10	Highly polluted
10	*Lichen desert*

from 3 leafy trees. *Xanthoria parietina* was selected for the research of nitrogen concentration because it is a widely spread and cosmopolitan nitrophilous lichen that can tolerate high concentrations of nitrogen compounds (Gaio-Oliveira et al., 2004, Johansson et al., 2012, Yemets et al., 2015). The nitrogen concentration (mg/g) was calculated using the following formula (Eq. 2):

$$N = \frac{0.0014 \cdot V}{m} \cdot 100 \cdot 10000 \quad (2)$$

where

0.0014 – amount of nitrogen that is equal to 1 mL of 0.05 M H_2SO_4; m – mass of the sample, g; V – titrated volume of H_2SO_4, mL.

A one-way analysis of variance (ANOVA) was used to assess the effect of the territorial zones on variety of types, abundance, PI and nitrogen concentration in the lichen. Significant differences between the control and the study sites were determined by the Student *t* test, and $p < 0.05$ was considered to be significant. The statistical analysis was carried out using Statistica7 software.

Results and discussion

In the surroundings of Achema, 23 species of lichens were found and identified. It was established that the study sites had a statistically significant effect on the diversity of epiphytic lichens (one-way ANOVA, $F = 2.42$, $p < 0.05$). The number of the lichen species differed statistically significantly only in research locations 1 and 3 compared with the control ($p < 0.05$, *t* test). Study site 3 (11–17 km away from the factory) was characterised by the greatest diversity of the lichen species (n = **5.1);** the lowest diversity was established in the control (n = 3.6) (Figure 3a). There was no significant relationship between the diversity of the species of epiphytic lichens and the distance from the factory ($p > 0.05$). Anh et al. (2011) have reported an insignificant relationship between the diversity of lichen species and the distance from the Seoul centre. Paal et al. (2009) have also reported an insignificant correlation between the diversity of lichen species and urban and suburban study sites in Estonia.

The study sites had a statistically significant effect on the projection coverage (one-way ANOVA, $F = 11.47$, $p < 0.05$). The highest projection coverage (64%) was detected in the vicinity of the plant (study site 1), and it was by 2.2 higher than the control; the lowest value was established in the site situated at the highest distance from the plant (zone 5; 21%) (Figure 3b). Compared with the control, differ with statistical significance only in research zone 1 ($p < 0.05$, *t* test). The correlation analysis revealed that the projection coverage of lichens was inversely related to the distance from the factory ($r = -0.68$; $p < 0.05$). According to Castello et al. (2005), *Xanthoria parietina* communities are abundantly prevalent in well-lighted areas on the bark of trees with a lot of nutrients. The projection coverage of epiphytic lichens may also be connected with the diversity of pH values of the tree bark. Llop et al. (2012) have noted higher pH values of the tree bark in areas characterised by intense anthropogenic activities and high N emissions.

It was established that the study sites had a statistically significant effect on the poleotolerance index (one-way ANOVA, $F = 2.87$, $p < 0.05$). The highest poleotolerance index (PI = 7.1) was in the vicinity of the plant (study site 1), while the lowest value was established in the site situated at the highest distance from the plant (zone 5, PI = 5.8) (Figure 4a). All the study sites, except control, were attributed to the medium pollution zone (PI > 6). The study sites at the distance up to 11 km and 17–23 km had a statistically significantly higher PI than the control ($p < 0.05$, *t* test). Study site 0 falls into the peripheral, relatively clean zone (PI < 6). Zocchi et al.'s (1997) research results indicated that the highest PI index was determined in those areas where the concentrations of NO_x and SO_2 were the highest. The correlation analysis revealed that the poleotolerance index was inversely related to the distance from the factory ($r = -0.29$; $p < 0.05$). A statistically significant correlation between the concentration of NO_2 and the air purity zones was identified by Rowe et al. (1998).

It was established that the zones of the territory had a statistically significant influence on the concentration of accumulated nitrogen (one-way ANOVA, $F = 4316.08$, $p < 0.05$) (Figure 4b).

The nitrogen concentration in the thallus of *Xanthoria parietina* from all the study sites differed significantly from the control ($p < 0.05$, *t* test). The highest nitrogen concentration in *Xanthoria parietina* was in the lichens from the vicinity of the factory (29.07 mg/g), and the nitrogen concentration decreased with the distance from the factory ($r = -0.43$; $p < 0.05$). It has been established that the nitrogen concentrations in the lichen at different districts in Germany differed statistically significantly compared with the territory of suburbs (Boltersdorf et al., 2014). Vingiani et al. (2004) have observed that the highest N concentrations in *Xanthoria* sp. thallus were in the lichens from Naples industrial district zone and the lowest N concentrations in the lichens from the suburbs. Dependence of nitrogen concentrations in *Xanthoria parietina* on the atmospheric NH_3 concentrations has been shown in several studies (Frati et al., 2006, Geiser et al., 2007, Olsen et al., 2010, Root et al., 2013). Gallo et al. (2013) have reported a significant relationship between heavy metals in the lichen thallus and the distance from a cement factory.

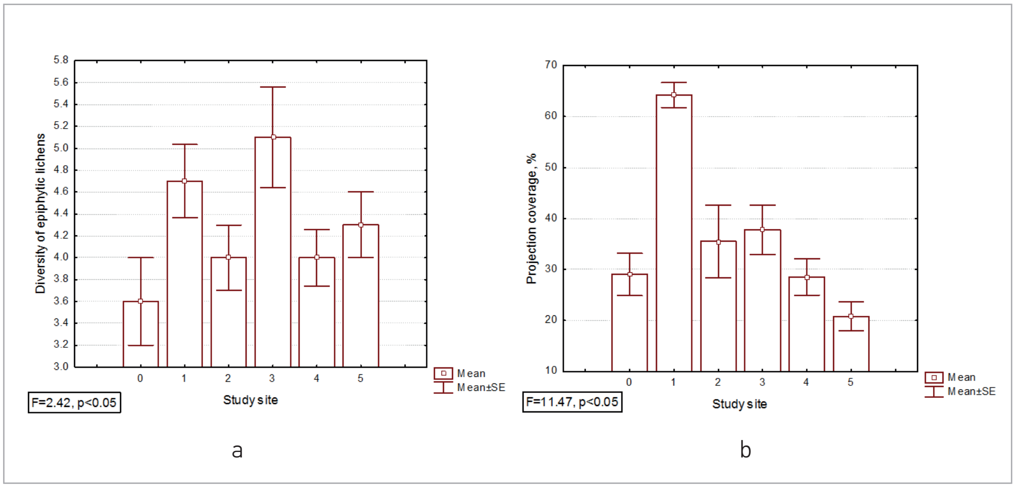


Fig. 3

Diversity of epiphytic lichens (a) and projection coverage (b) (%) in the study sites: 0 (1–7 km to the factory), 1 (0–5 km from Achema), 2 (5–11 km), 3 (11–17 km), 4 (17–23 km) and 5 (23–30 km)

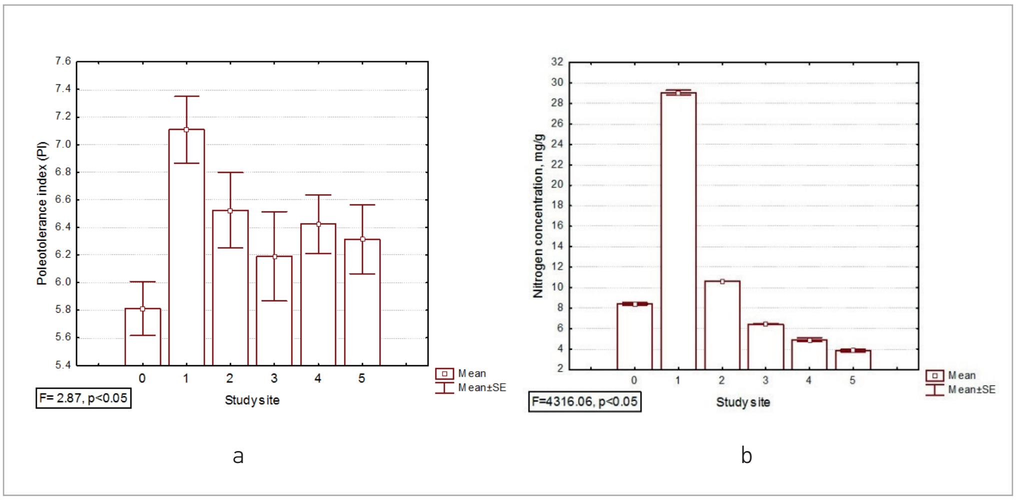


Fig. 4

Poleotolerance index (PI) (a) and accumulated total nitrogen (mg/g) (b) in the epiphytic lichen in the study sites: 0 (1–7 km to the factory), 1 (0–5 km from Achema), 2 (5–11 km), 3 (11–17 km), 4 (17–23 km) and 5 (23–30 km)

Conclusions

The present study revealed that the highest lichen projection coverage, poleotolerance index and nitrogen concentration in the lichen were observed in the vicinity of the plant. Air quality could be classified as the worst air quality in the vicinity of the plant. The cleanest environment was established in the control site and in the territory situated at the highest distance from the plant as here the lowest lichen projection coverage, poleotolerance index and concentration of accumulated nitrogen were recorded. In these territories, the projection coverage and nitrogen concentration in the thallus of *Xanthoria parietina* were by 3.1 and 7.6 times, respectively, smaller than in the vicinity of the plant.

Acknowledgements

The authors' report was presented in the 10th International Scientific Conference The Vital Nature Sign 2016.

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Gauta:
2016 m. spalis
Priimta spaudai:
2016 m. gruodis

Pasyvioji lichenoindikacija kaip priemonė trąšų gamyklos oro kokybei vertinti

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Oro tarša ir toliau išlieka viena aktualiausių aplinkos problemų, kuri būdinga ne tik miestų, bet ir pramonės objektų aplinkoms. Šiuo tyrimu siekiama įvertinti didžiausios Baltijos šalyse pramoninių chemijos produktų gamyklos AB „Achema" aplinkos oro kokybę pasyviosios lichenoindikacijos metodu. Buvo ištirtos epifitinių kerpių rūšys, jų gausumas, kerpių bendrijų būklę charakterizuojantis rodiklis (poleotolerantiškumo indeksas (PI)) ir nustatyta kerpėse akumuliuoto azoto koncentracija šešiose tyrimo vietose, kurios buvo skirtingu atstumu nutolusios nuo gamyklos: kontrolinė zona (1–7 km iki AB „Achema"), gamyklos teritorija (0–o5 km nuo jos) ir 5–11 km, 11–17 km, 17–23 km, 23–30 km tyrimo zonos nuo AB „Achema". Didžiausia kerpių rūšių įvairovė nustatyta 11–17 km teritorijoje (n=5,1), o mažiausia – kontrolėje (n=3,6). Didžiausias projekcinis padengimas buvo AB „Achema“ teritorijoje (64 %), mažiausias nustatytas 23–30 km teritorijos zonoje (21 %). Didžiausiu poleotolerantiškumo indeksu išsiskyrė AB „Achema“ teritorija (7,1), o mažiausiu – kontrolinė zona (5,8). Vertinant *Xanthoria parietina* akumuliuoto azoto koncentraciją tyrimo zonose nustatyta, kad didžiausia azoto koncentracija buvo gamyklos tyrimo vietoje (29,07 mg/g), mažiausia – 23–30 km teritorijos zonoje (3,83 mg/g). Tyrimo rezultatai parodė, jog gamyklos teritorija (0–5 km nuo AB „Achema") pasižymi blogiausia oro kokybe (didžiausias projekcinis padengimas, PI, ir akumuliuoto azoto koncentracija), o švariausia aplinka išsiskyrė kontrolinė zona (pagal poleotolerantiškumo indeksą) ir toliausia (23–30 km) tyrimo vieta nuo gamyklos (pagal projekcinį padengimą ir azoto koncentraciją kerpėse).

Raktiniai žodžiai: azotas; bioakumuliacija; bioindikacija; kerpės; oro kokybė.