LICHENS AS BIOINDICATORS OF AIR POLLUTANTS

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Лишайники как биоиндикаторы загрязнителей воздуха

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The specific sensitivity of lichens to air pollutants enables us to use them for monitoring the effects of airborne toxic gases, such as sulphur dioxide and nitrous oxides. The monitoring can be carried out by mapping the epiphytic lichen biodiversity and the exposure of sensitive lichen species to the environment. Because of their anatomical structure and the relatively high absorption layer of lichens they are able to accumulate heavy metals and radionuclides. Thus the spatial distribution of manmade radionuclides and of heavy metals originating from traffic and industrial processes can be demonstrated by using lichens as monitoring organisms.

Keywords: lichens, air pollution, sulphur dioxide, nitrogen compounds, radionuclides.

Избирательная чувствительность лишайников к загрязнителям воздуха позволяет нам использовать их для мониторинга воздействия воздушных токсичных газов, таких как диоксид серы и оксиды азота. Мониторинг может быть осуществлен путем сопоставления биоразнообразия эпифитного лишайника и воздействия на чувствительные виды лишайников к окружающей среде. Из-за их анатомической структуры и относительно высокого абсорбционного слоя они способны накапливать тяжелые металлы и радионуклиды. Таким образом, пространственное распределение искусственных радионуклидов и тяжелых металлов, происходящих в результате движения и промышленных процессов, может быть продемонстрировано с использованием лишайников в качестве контролирующих организмов.

Ключевые слова: лишайники, загрязнение воздуха, диоксид серы, соединения азота, радионуклиды.

Lichens are symbiotic organisms comprising fungi and algae or cyanobacteria as photosynthetic active partners (photobionts). Lichens rank as the most resistant living organisms against natural stress factors such as temperature, drought and radiation. In scientific experiments they are able to survive in the moist (hydrated) state at temperatures from — 196 °C and in the dry state up to +80°C. They can also survive more than two years of absolute dehydration and 15 days of long-term exposure under space conditions (Sancho et al. 2007). In the hydrated state they are very sensitive to temperatures over 35°C. Lichens from Antarctica and from cold sites in the high altitudes of the mountains maintain photosynthetic CO_2-uptake down to — 18°C [9—11, 16].

However, the anatomical, morphological features and the physiological conditions between the symbiotic partners in lichens result in a very high sensitivity to chemical stressors such as air pollutants and diverse biocides used in agriculture. Lichens do not develop any dermal tissue like the epidermis of higher plants with wax layers. The symbiotic coexistence of the partners requires complicated physiological adaption processes, which can be severely disturbed by external chemical compounds. In the presence of gaseous or dusty air pollutants or aerosols they absorb these foreign substances through their open surface. In the moist and physiological active state the poisonous substances can disturb — depending on the concentration — the physiological processes in the photobiont and the interactive processes between the mycobiont, photobiont and the involved bacteria.

Besides air pollutants, the occurrence and frequency of epiphytic lichens in conurbation (metropolitan) areas is a function of urban heat island effects and common climate changes [18]. Thus lichens also indicate changes in urban climate, climatic change and levels of air pollution.

Since the nineteenth century it is known that the gas sulphur dioxide is poisonous for epiphytic lichens. Many investigations on the epiphytic lichen vegetation in cities, industrial conurbations and around factories with high emission of smoke and gaseous compounds showed a decline in the diversity and abundance of macro-lichens. Only some very resistant crustose lichens were able to survive in areas with high emission rates. Observations on the differential growth of various lichen species in regions with high deposition rates led to the choice of lichens as bio-indicators for air pollution (e. g. [6, 7]). The observations of the differing SO_2 resistance of various lichen species in the field were confirmed by physiological studies on the SO_2-resistance of lichens under laboratory conditions [15, 22, 26].

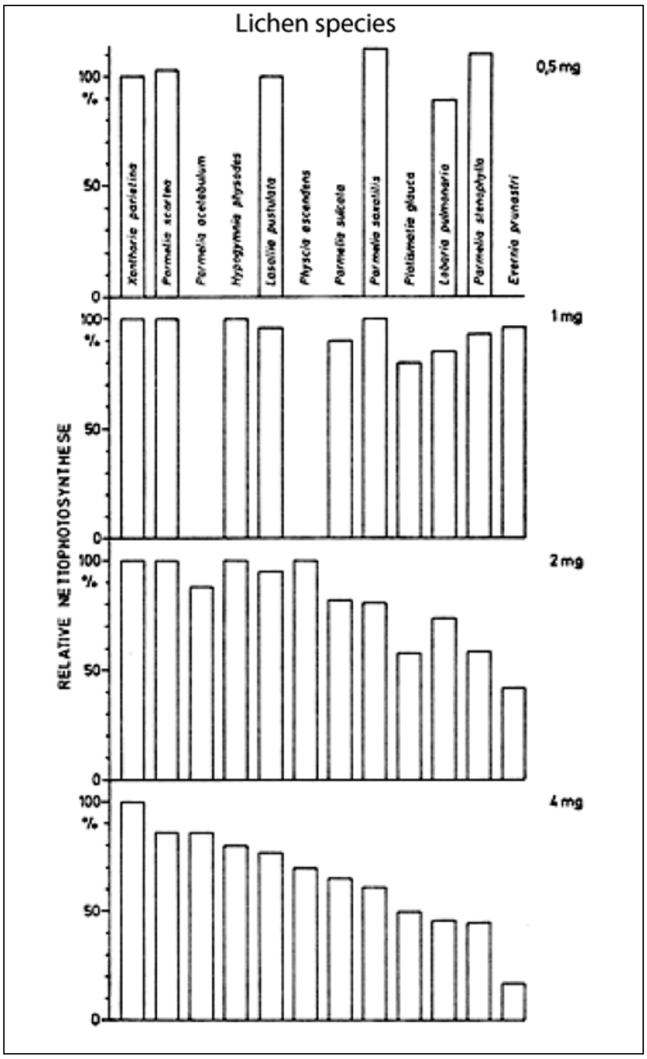

Fig. 1. Means of the net photosynthesis (in % of the normal value) after 14 hours gassing with SO_2 concentrations 0,5, 1, 2 and 4 mg SO_2 m^{-3} air (from: Türk et al. [19]).

These studies showed that the SO_2 resistance of lichens is species specific, dependent upon the growth form, the moisture status during the emission level of sulphur dioxide and the intensity of the physiological activity. Also the pH of the substrate and the thalli is an essential factor of the SO_2 resistance. At a low pH the damaging effect is more pronounced than at a high pH. The species specificity of SO_2 sensitivity is shown in Fig 1. The nitro- and neutrophytic species *Xanthoria parietina* and *Parmelina scortea* (syn. *Parmelina tiliacea*) are the most resistant, whereas the acidophytic species *Platismatia glauca, Parmelia stenophylla* (syn.: *Xanthoparmelia stenophylla*) and the foliose macrolichen *Lobaria pulmonaria* and the fruticose *Evernia prunastri* are the most sensitive lichens.

Thus the difference in the sensitivity of lichens to SO_2 in concentrations which occur due to specific emissions in the environment is an important precondition for the interpretation of the distribution of lichens found by mapping studies in areas with different concentrations of this air pollutant. In Central Europe many lichen species of the fruticose genera (*Usnea, Bryoria* and *Evernia*) as well as the foliose species (*Lobaria, Nephroma, Hypogymnia* and *Parmelina*) became extinct in wide areas. «Lichen deserts» in which absolutely no macrolichens occured were registered in the course of mapping studies in the city of Salzburg [19] and industrial conurbation areas of Linz, [1]. Both are located in Austria, where the climatic conditions are commonly well suitable for the growth of epiphytic lichens. Mapping studies on the diversity of epiphytic lichens as an indicator of air quality play an important role for determining the effects of air pollutants in the environment. In the Federal Republic of Germany applicable guidelines have been established (VDI-Richtlinie 3957 [25]).

Furthermore transplant experiments were initiated to evaluate the effects of SO_2 pollution on lichens [2, 12, 17]. Fast results could be obtained after the exposure of the lichens at varying locations by measuring the CO_2-gas exchange. In the city of Salzburg transplanted samples of Hypogymnia physodes and Parmelia sulcata ceased net photosynthesis after an exposition time of six weeks between November 1977 and March 1978 («heating season») [20]. The lower concentration of SO_2 during spring and summer caused no physiological effect on the exposed specimens (Fig. 2).

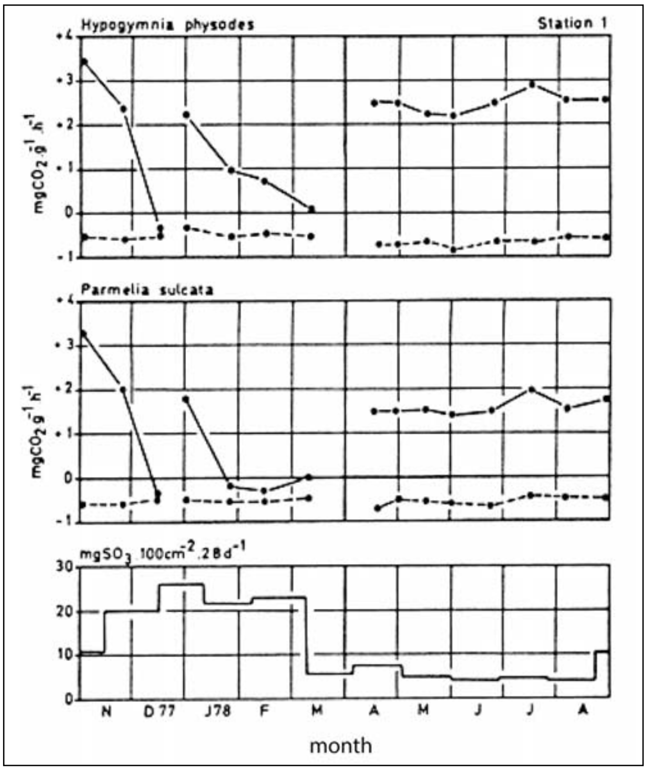

Fig. 2. Net photosynthesis and dark respiration of transplanted *Hypogymnia physodes* and *Parmelia sulcata* at station 1 (in the city of Salzburg) and the average SO_2-concentration during the exposure time (Türk & Christ [20]).

In the summer, the photosynthetic rate was determined depending upon the local climatic changes, especially moisture availability from precipitation. On days with moist, rainy weather the net photosynthesis was higher than during dryer weather periods.

The improvement in the air quality as a result of the reduction of the SO_2 concentration by stricter environmental laws between 1980 and 1990 led to a reinvasion of lichens into former highly polluted areas within five to eight years. However, since the beginning of the 1990s until present the emission of gaseous nitrogen compounds has increased dramatically in Central Europe. In the northern parts of the Austrian Alps the deposition of these airborne nitrogen compounds have reached such high levels that they have detrimental effects on the forest ecosystems and their biodiversity [3, 14]. Long term (1993—2010) monitoring results of lichens from a remote site in Austria, showed that the lichen cover on tree trunks has decreased significantly. N-sensitive species vanished significantly, whereas the amount and the coverage of nitrophytic species increased. Epiphytic lichens with cyanobacteria as photobiontes (e. g. species of the genera *Collema, Leptogium, Lobarina, Nephroma, Peltigera, Pannaria, Sticta*) disappeared almost entirely along the slopes of the northern Alps up to the ascent of the calcareous mountains in Austria. Acidophytic and sensitive macrolichens (e.g. *Lobaria pulmonaria, Ramalina* spec., *Parmelia saxatilis* etc.) also vanished [21, 28]. In the pre-Alpi foothills nitrophilous and nitrotolerant species (*Xanthoria* spec., *Physcia* spec., *Phaeophyscia* spec.) dominate the epiphytic eutrophic associations not only on broadleaf trees with neutral bark, but also surprisingly on trees with acidic bark (*Abies alba, Picea abies, Larix decidua*). These observations agree very closely with the results of mapping studies in the Netherlands and other countries in Europe [24].

Studies on the effects of nitrogen compounds and other air pollutants on the growth rates of lichens in the city of Linz, Upper Austria showed clearly, that the annual growth of the nitrophytic species *Phaeophyscia orbicularis* increases with higher traffic impact. The growth rate of the more sensitive *Parmelia sulcata* decreases with higher traffic density [27]. A survey of epiphytic lichen populations in a side valley of the river Salzach in the province of Salzburg confirmed the negative effect of vehicle exhaust pollution. The diversity of lichens was reduced and the lichen community altered.

Biomonitoring of heavy metals and radionuclides in the environment with lichens depends on the favorable accumulation properties of chemical and radioactive pollutants. Eckl et al. [4, 5] found that lichens are much more efficient in the accumulation of radioactive cesium than higher plants. Hence they are suitable bioindicators of the radioactive fallout. The large surface area relative to their mass is one of the main reasons for their high capacity to accumulate radionuclides or other elements. Long term studies on the Cs-137 concentration in lichens made it possible to determine the biological half-life of ^{137}Cs. For the epiphytic lichen *Pseudevernia furfuracea* a biological half-time of 12.9 years was found [11].

Acknowledgement: The author expresses his gratitude to Prof. Dr. Walter Kofler (Innsbruck) for the suggestion to write this article and Dr. Wolfhard Ruetz (Laufen) for valuable discussions and assistance with the text.

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О ПРОБЛЕМЕ СТРАТЕГИЧЕСКОГО ПРОСТРАНСТВЕННОГО РАЗВИТИЯ: НА ПРИМЕРЕ ГОРОДА ГРОЗНЫЙ И ГРОЗНЕНСКОЙ АГЛОМЕРАЦИИ

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About the Problem of Strategic Spatial Development on the Example of the City of Grozny and the Grozny Agglomeration

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В статье дается описание и анализ стратегического пространственного развития (на примере транспортной инфраструктуры генерального плана городского округа «город Грозный» на современном этапе его развития). Грозный рассматривается как ядро Грозненской городской агломерации. Приводится краткий исторический анализ транспортной составляющей генеральных планов прошлых лет. Рассматриваются основные направления перспективного развития городской транспортной системы.

Ключевые слова: пространственное развитие, город Грозный, городская агломерация, генеральный план, городская транспортная система

In article the description and the analysis of strategic spatial development is given (on the example of transport infrastructure of the master plan of the city district «city of Grozny» at the present stage of his development). Grozny is considered as a kernel of the Grozny city agglomeration. The short historical analysis of a transport component of master plans of last years is provided. The main directions of perspective development of the city transport system are considered.

Keywords: spatial development, city of Grozny, city agglomeration, master plan, city transport system

Грозный как центр формирующейся агломерации

Новая общественно-политическая ситуация в России, становление местного самоуправления, изменившиеся экономические, земельно-имущественные отношения в городах и других населенных пунктах требуют иных подходов и методов регулирования, планирования и организации градостроительной деятельности в регионах [1].