ICP VEGETATION

36th Task Force Meeting

13 – 15 February 2023

Hosted by UNECE (*online*)

Programme & Abstracts

Working Group on Effects
of the
Convention on Long-range Transboundary Air Pollution

Organisers:

ICP Vegetation Programme Coordination Centre
UK Centre for Ecology & Hydrology
Bangor, UK

Felicity Hayes, Katrina Sharps, Mike Perring

Local Host
UNECE, Geneva, Switzerland

Anna Kaplina and colleagues

PROGRAMME

Venue: UNECE, Geneva (Online)
Times listed in Central European Time (CET) zone

Monday 13th February, 2023

Session: **Plenary** **Chair:** **Felicity Hayes/Katrina Sharps**

09:00 *Meeting link opens*

09:10 *Felicity Hayes* – Opening of meeting

09:15 *Anna Kaplina* - Welcome

Felicity Hayes – Interventions

09:20 *Felicity Hayes* - Overview of ICP Vegetation

09:50 *Marina Frontasyeva* – Moss Survey 2020-2021-2022. Sampling completed

10:10 *Katrina Sharps* – Reviewing the effectiveness of the Gothenburg Protocol: The impact of ozone on crops and deciduous forest in future policy-intervention scenarios

10:30 ***Comfort break***

Session: **Plenary** **Chair:** **Katrina Sharps**

11:00 *CCE of the ICP Modelling and Mapping* – Update of the current receptor map for the European domain

11:20 *Anne-Katrin Prescher* – Update on ICP Forests activities

11:40 *Yasutomo Hoshika* – Progress in setting flux-based critical levels for poplars

11:50 *Tania Carrasco-Molina* - Parametrization of the stomatal conductance response to soil moisture index for mediterranean forest and semi-natural vegetation species for flux-based ozone risk assessment

12:10 *Markus Guepel* – Review of ammonia critical levels and draft revision of the Mapping Manual

12:30 ***Comfort break***

Session: **Plenary** **Chair:** **Zaida Ehrenmann**

14:00 *Winfried Schröder* – German Moss Survey 2020 Part I: Accumulation of atmospheric metals and nitrogen deposition in mosses: temporal development between 1990 and 2020, comparison with emission data and tree canopy drip effects

14:20 *Carmen Wolf* – German Moss Survey 2020 Part II: Microplastics and persistent organic pollutants in moss samples

14:40 *Richard Cross* – Distribution of microplastics >25 µm in size across the United Kingdom as detected using µ-FTIR

15:00 *Julian Aherne* – Microplastics in Canada

15:05 *MADAME Team (Felicity Hayes)* – Microplastic Atmospheric Deposition Assessment using Moss in Europe (MADAME), Progress update including map of sites and timelines for next steps

15:10 *Alexander Uzhinskiy* – The future of air quality monitoring

15:25 *Felicity Hayes* – General Discussion and check of workplan

16:00 ***End of Day 1***

Tuesday 14th February, 2023

Session: **Moss 1** **Chair:** **Caroline Meyer**

09:00 *Meeting link opens*

09:10 *Inga Zinicovscaia* – A new approach for the determination of the origin of chemical elements emitted in the atmosphere based on the moss biomonitoring results

09:30 *Stefan Fränzel* - Chitin-based M ion monitoring put to the detail: empirical determination of partition factors between water, sediment and chitin and biomonitoring, ecological conclusions derived therefrom

09:50 *Zaida Ehrenmann* - Moss Monitoring in Switzerland - Results of the 2020 Moss Survey

10:10 *Guntis Tabors* – Moss biomonitoring of atmospheric pollution in Latvia: longterm of heavy metal concentration in *Pleurozium schreberi* moss

10:20 *Pawel Świsłowski* – Poster: Bioaccumulation of trace elements from aqueous solutions by selected terrestrial moss species

10:25 *Ya Bogdanova* – Poster: Monitoring of heavy metal atmospheric deposition in the Steppe zone of the European part of Russia

10:30 ***Comfort break***

Session: **Moss 2** **Chair:** **Mike Perring**

11:00 *Katerina Bačeva Andonovska* – Poster: Mosses as biomonitors to identify atmospheric deposition with minor and trace elements in North Macedonia

11:05 *Dinesh Saxena* – Atmospheric metals from Jammu, India: Pre-pandemic and post-pandemic measurements by the moss *Hypnum cupressiforme*

11:20 *Krmar Miodrag* – Seasonal changes in spatial distribution of 7Be atmospheric deposition measured using terrestrial moss

11:40 *Arlinda Cakaj* – Investigating the use of common weed species as bioindicators for heavy metal pollution: a study of *Trifolium pratense, Alcea rosea,* and *Lolium multiflorum*

12:00 *Kayla Wilkins* – Bryomonitoring Canada Project: Progress to date

12:10 *Konstantin Vergel* – Results of the moss survey-2020/2021 in central Russia

12:30 ***Comfort break***

Session: **Ozone 1** **Chair:** **Ignacio Gonzalez-Fernandez**

13:30 *Sabine Braun* – Epidemiological estimate of growth reduction by ozone in *Picea abies*: can we improve the fit with experimental data?

13:50 *Zhaozhong Feng* – Interactive effects of elevated ozone and nitrogen addition on physiology and growth in poplar

14:10 *Alexander Cheesman* – Developing ozone dose-response functions for tropical systems

14:30 *Flossie Brown* – Ozone and sugarcane

14:50 *Felicity Hayes* Ozone and floral VOCs

14:55 *Samuel Prieto-Benitez* – Poster: Tropospheric ozone hinders the adaptation of floral phenology to climate warming in Mediterranean alpine plants

15:00 *Bourbatache Mansour* – Biomonitoring ozone impacts in Algeria

15:05 ***Comfort break***

Session: **Ozone (and Nitrogen) 2** **Chair:** **Sabine Braun**

15:30 *Valda Araminiene* – Ground-level ozone and nitrogen dioxide pollution removal capacity by urban vegetation in Lithuania

15:50 *Granit Kastrati* – Study of nitrogen concentrations in bee pollen samples in Kosovo by Kjeldahl method

16:10 *Mike Perring* – NOx critical levels update

16:30 *Felicity Hayes and Mike Perring* – NOx discussion (if required)

17:00 ***End of Day 2***

Wednesday 15th February, 2023

Session: **Moss 3** **Chair:** **Arlinda Cakaj**

09:00 *Meeting link opens*

09:10 *Omari Chaligava* – Evaluation of air quality in Georgia based on moss survey 2019-2022

09:30 *Yu Aleksiayenak* - Fourth moss survey in the Republic of Belarus: Brest region case study

09:50 *Sébastien Leblond* – Influence of the environment on the concentration in mosses: comparison between cemeteries and forests

10:10 *Flora Qarri* – Poster: Trace metal atmospheric deposition in Albania and the impact from wind-blown dust

10:15 *Claudia Stihi* – Poster: Romanian moss surveys - heavy metals atmospheric deposition temporal trends

10:20 *Evgeniya Gatina* – Poster: Moss-biomonitoring method in the study of air pollution on the eastern part of the Russian Plain (Perm region, Russia)

10:30 ***Comfort break***

Session: **Moss 4** **Chair:** **Winfried Schröder**

11:00 *Gana Gecheva* – Moss walls; construction, prospects for detection of heavy metals, nanoparticles and PMs, biomarkers – a new project in Bulgaria

11:20 *Jana Borovská* – Biomonitoring of atmospheric deposition of heavy metals in Slovakia in 2020-2022

11:40 *Agnes Bálint* – Determining the concentration of heavy metals deposited from the air using a moss bioindicator on Szentenrei Island (Central Hungary)

12:00 *Felicity Hayes* – Future of the moss programme and general moss discussion

12:30 ***Comfort break***

Session: **Ozone (and Nitrogen) 3** **Chair:** **Melissa Chang**

14:00 *Kent Burkey* – Testing drought-tolerant soybean cultivars and breeding lines for ozone response

14:20 *Jo Cook* – Modelling wheat nutrition in India to understand climate and O3 impacts

14:40 *Yansen Xu* – Elevated ozone decreased leaf photosynthesis of winter wheat by accelerating leaf senescence in a warming world

15:00 ***Comfort break***

Session: **Ozone (and Nitrogen) 4** **Chair:** **Felicity Hayes**

15:20 *Divya Pandey* – ho pays the price? The economic implications of wheat production losses in India due to ozone

15:40 *Clare Brewster* – Effect of ozone on the nitrogen dynamics of wheat

16:00 *Nivedita Chaudhary* – Poster: Assessment of O3-induced yield and economic losses for crops in several areas of Rajasthan from 2018 to 2021, India

16:05 *Felicity Hayes* – Workplan discussion and AOB

17:00 ***Close of Meeting***

LIST OF POSTERS

OZONE

Author(s)	Title
Nivedita Chaudhary	Assessment of O3-induced yield and economic losses for crops in several areas of Rajasthan from 2018 to 2021, India
Samuel Prieto-Benítez	Tropospheric ozone hinders the adaptation of floral phenology to climate warming in Mediterranean alpine plants

MOSS SURVEY

Author(s)	Title
Pawel Świsłowski	Bioaccumulation of trace elements from aqueous solutions by selected terrestrial moss species
Ya Bogdanova	Monitoring of heavy metal atmospheric deposition in the Steppe zone of the European part of Russia
Flora Qarri, Pranvera Lazo*	Trace metal atmospheric deposition in Albania and the impact from wind-blown dust
Claudia Stihi., Ene A.,	Romanian moss surveys - heavy metals atmospheric deposition temporal trends
E. Gatina	Moss-biomonitoring method in the study of air pollution on the eastern part of the Russian Plain (Perm region, Russia)
Katerina Bačeva Andonovska	Mosses as biomonitors to identify atmospheric deposition with minro and trace elements in North Macedonia
Anastasia Zhuravleva	Analysis of data on the accumulation of trace elements in the biomass of mosses of the Udmurt Republic, Russia

ABSTRACTS

MOSS SURVEY 2020-2021-2022. SAMPLING COMPLETED

Marina Frontasyeva

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The Moss Survey of the UNECE ICP Vegetation 2020/2021/2022 has been completed. The traditional two-year moss survey was extended to the third year of 2022 due to the COVID-19 pandemic in 2020-2021. Since 1990, mosses have been used as biomonitors on a regular basis to study trends in the atmospheric deposition of trace elements and nitrogen. Since 2010 the Moss Survey was used to monitor persistent organic pollutants (POPs) and more recently radionuclides and micro-plastics in some countries in Europe [1, 2]. During this three-year survey, 3855 moss samples were collected. This was fewer than the 2015-2016 survey when the maximum number (5073) of moss samples for the entire collection history was reached when 39 countries reported their results to the Data Management System allocated at the JINR cloud platform (http://moss.jinr.ru). Some countries (approx. 15) will complete their reports in the near future. Sampling maps and preliminary distribution maps for the environmentally meaningful toxic elements are demonstrated. Access to the large amount of data allows the prediction of air pollution by potentially toxic elements over urban and rural areas by combining satellite imaginary, moss biomonitoring data and machine learning [3], which can be considered one of the main achievements of the ICP Vegetation Program.

References

1. Frontasyeva M. V., Steinnes E. and Harmens H. Monitoring long-term and large-scale deposition of air pollutants based on moss analysis. Chapter in a book “Biomonitoring of Air Pollution Using Mosses and Lichens: Passive and Active Approach – State of the Art and Perspectives”, Eds. M. Aničić Urošević, G. Vuković, M. Tomašević, Nova Science Publishers, New-York, USA, 2016, pp.246.
2. Frontasyeva M., Harmens H., Uzhinskiy A., Chaligava O. *(and moss survey program participants).* Mosses as biomonitors of air pollution: 2015/2016 survey on heavy metals, nitrogen and POPs in Europe and beyond. Report of the ICP Vegetation Moss Survey Coordination Centre, Joint Institute for Nuclear Research, Dubna, Russian Federation, pp. 136. ISBN 978-5-9530-0508-1. http://www1.jinr.ru/Books/Books_rus.html
3. Uzhinskiy A., Aničić Urošević M., Frontasyeva M. Prediction of air pollution by potentially toxic elements over urban area by combining satellite imagery, Moss Biomonitoring Data and Machine Learning. *Ciencia e Tecnica Vitivinicola Journal*; 2020: Vol. 35, No. 12. ISSN:2416-3953.

Reviewing the effectiveness of the Gothenburg Protocol: The impact of ozone on crops and deciduous forest in future policy-intervention scenarios.

Sharps K.[(1)], Hayes, F.[(1)], Simpson D.[(2,3)] & Fagerli, H. [(2)]

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The Protocol to Abate Acidification, Eutrophication and Ground-level Ozone was adopted in Gothenburg in 1999. This establishes legally binding emissions reduction commitments for pollutants including sulphur dioxide, nitrogen oxides and VOCs. Amendments to the protocol came into force in 2019, triggering a review with questions to the UNECE Air Convention Working Group on Effects. As contribution to the review, ICP Vegetation investigated the future impact of ozone on crops and deciduous forest. Using modelled ozone data from the European Monitoring and Evaluation Programme (EMEP), estimates of losses for wheat production and forest biomass are presented for baseline, Maximum Feasible Reduction and Dietary scenarios, for 2015, 2030 and 2050. Although showing improvements compared to previous years, under the most stringent scenario ozone impacts are still predicted to be considerable, for example, 17 million tonnes of wheat production loss for Europe in 2050.

FOR SETTING FLUX-BASED CRITICAL LEVELS FOR POPLARS
–WORKING PROGRESS-

Hoshika Y.[1], Pollastrini, M.[2], Marzuoli, R.[3], Gerosa, G.[3], Calatayud, V.[4], Feng, Z.[5], Agathokleous, E.[5], Sicard, P.[6], Paoletti E.[1], Moura, B.B.[1]

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Poplars are widely used for wood production and as model plant in plant biology. They are generally known to be ozone-sensitive. However, our knowledge of flux-based ozone dose-response relationships is still limited. According to the meta-analytic review by Prof. Z. Feng (NUIST, China), hybrid poplars may be more sensitive to ozone than non-hybrid ones. An important question has therefore raised if there are different sensitivities to ozone between native poplars and clones. The main objective of this study was to carry out a synthesis of experimental results about the ozone effects on poplars to develop ozone dose-response (DR) relationships for biomass growth reductions using exposure-based (AOT40, Accumulated Ozone exposure over a Threshold of 40 ppb) and flux-based (POD1, Phytotoxic Ozone Dose per leaf area above a threshold of 1 nmol m^{-2} s^{-1}) indices. According to the result, we calculated a critical level (CL) for a 4% biomass reduction. We summarised literature data (Chinese Open-Top Chamber [OTC] experiments on five hybrid clones) and our own data in previous experimental studies at a Free-Air Controlled Exposure (FACE) and OTCs on hybrid clones (Oxford: FACE and OTC, and I-214: FACE) and one non-hybrid European native species (*P. nigra*). The flux-based POD_1 showed a slightly higher R^2 value of DR relationships than AOT40 for both hybrid (POD_1: R^2 = 0.61, AOT40: R^2 = 0.59) and non-hybrid native poplars (POD_1: R^2 = 0.37, AOT40: R^2 = 0.32). The flux-based CL corresponding to 4% biomass reduction was 6.6 mmol m^{-2} POD_1 for hybrid poplars while the CL for the non-hybrid native species was 9.5 mmol m^{-2} POD_1, suggesting that non-hybrid native species may be relatively less sensitive to ozone. Those CLs were higher than those previously investigated for the ozone sensitive species such as beech and birch (5.2 mmol m^{-2} POD_1). Considering the very high stomatal conductance of poplar species (g_{max} = 348-575 mmol O_3 m^{-2} PLA s^{-1}), the potential risk of negative impacts for this species should be high. The results will be included in the Scientific background document B “Critical levels for ozone-sensitive clones of poplar”.

REVIEW OF AMMONIA CRITICAL LEVELS AND DRAFT REVISION OF THE MAPPING MANUAL

Geupel M, Dragosits, U, Franzaring J , Hayes, F; Jones, M, Kelleghan, D, Meier, R, Moravek, A, Perring, M

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More than ten years after the recommendation of the updated CLRTAP critical levels for ammonia, new findings on the effects of ammonia on vegetation have been discussed in a workshop in Dessau in March 2022. Scientists dealing with research on effects of ammonia on vegetation and ecosystems and those involved in the monitoring of ammonia in the environment were asked to present their recent research. In total 19 presentations from presenters from nine countries were dealing with a current review, models and future trends of NH3 across Europe in the first session, different ammonia monitoring networks in the second session and with vegetation effects (recent research on different scales) in the third session. The report contains a thematic literature review on adverse ammonia-effects in vegetation, which was presented as a background document to the workshop and summaries of the talks. The proceedings document is about to be published by the German Environment Agency.
Main results of the workshop are currently transferred to the Mapping Manual. A group of interested participants to the workshop, and members of ICP Vegetation and ICP Modelling & Mapping discussed changes to the latest stage of chapter 3.2.3 Ammonia Critical levels of the Mapping Manual at a video meeting in January 2023. The elaborated proposal for a revision will be presented to ICP Vegetation, requesting the ICP for approval.

GERMAN MOSS SURVEY 2020 PART I
ACCUMULATION OF ATMOSPHERIC METALS AND NITROGEN DEPOSITION IN MOSSES: TEMPORAL DEVELOPMENT BETWEEN 1990 AND 2020, COMPARISON WITH EMISSION DATA AND TREE CANOPY DRIP EFFECTS

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The German Moss Survey 2020 aims at "Pilot studies on the suitability of bioindication with mosses for the detection of atmospheric deposition of persistent organic pollutants as well as microplastics" and comprises three main working packages funded by the Germany Environment Agency: One package deals with POPs accumulated in mosses, and another one is on microplastics accumulated in mosses. Both will be presented by Carmen Wolf under the title "GERMAN MOSS SURVEY 2020 PART II: MICROPLASTICS AND PERSISTENT ORGANIC POLLUTANTS IN MOSS SAMPLES". The third working package of the German Moss Survey 2020 is on the statistical foundation of the moss sampling network, the statistical data analysis and GIS-mapping. This part was added by measurements of metals and nitrogen accumulation in mosses, funded by own financial resources. This topic is the subject of this presentation, focusing on: 1. Analysis of temporal trends of metal and nitrogen accumulation in mosses between 1990 or 2005, respectively, and 2020 in Germany; 2. Comparison of the accumulation trends with emission data; and 3. Determination of the effect of tree canopy drip on metal and nitrogen accumulation in mosses. For the temporal trend analysis, the minimum sample number required for a reliable estimation of arithmetic mean values and statistical parameters based on it was calculated. It was only achieved for nitrogen, but not for metals. Therefore, the temporal trends of the bioaccumulation of metals and nitrogen were calculated on the basis of median values. For the analysis of tree canopy effects on element accumulation in mosses, 14 vegetation structure measures were used, which together with 80 other descriptors characterise each moss collection site and its environment. The comparison of the data obtained during the first monitoring campaign with those of the 2020 survey showed a significant decrease in metal bioaccumulation. However, in contrast to the emission data, an increase in the accumulation of some metals was observed between 2000 and 2005 and of all metals from 2015 to 2020. Trends in Germany-wide nitrogen medians over the last three campaigns (2005, 2015 and 2020) show that nitrogen medians decreased by −2% between 2005 and 2015 and increased by +8% between 2015 and 2020. These differences are not significant and do not match the emission trends. Inferential statistics confirmed significantly higher metals and nitrogen accumulation in mosses collected under tree canopies compared to adjacent open areas. Measured concentrations of metals and nitrogen were significantly higher under tree canopies than outside of them, by 18–95%.

GERMAN MOSS SURVEY 2020 PART II

MICROPLASTIC AND PERSISTENT ORGANIC POLLUTANTS IN MOSS SAMPLES

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Following their transport, atmospheric pollutants are deposited on the ground, on plants or on water. It was shown that mosses can be used as biomonitor for the detection of heavy metals, nitrogen, and certain persistent organic pollutants (POP). POP were investigated for the first time in Germany in the Moss Survey of 2015/2016 and they were also analyzed in the moss survey 2020/2021. During the moss survey 2020/2021 it was also tested if mosses can also be used as biomonitor for the deposition of microplastic. Therefore, a sample preparation and detection method using Thermo-Extraction-Desorption-GC-MS and RAMAN spectroscopy was established to analyze the microplastic concentration as well as its number in the moss samples.

Analyses for POP were performed as described by Dreyer et al.[2] with slight modifications. Overall, about 120 compounds (PAH, PCDD/F, PCB, PFAS, HBCD, PBB, PBDE, alternative halogenated flame retardants (HFR)) were analysed.

Results for metals and nitrogen concentration in the mosses will be presented by Winfried Schröder in a separate presentation. Here, we are presenting results for microplastic and a variety of POP from the 2020/2021 moss survey in Germany.

In all Moss samples, microplastic was detected. The highest concentration in all samples was observed for polyethylene, followed by polyethylene terephthalate, polypropylene and styrene-butadiene and in one sample polystyrene. Microplastic concentrations were highest at the two sampling sites near the sea. However, no correlation of the microplastic concentration with other form of land use (urban, agriculture, forest) could be detected. PBB and indicator PCB were not observed above the LOQ in any sample. PFAS and dioxin-like PCB were very rarely found above the LOQ. In contrast, certain PCDD/F, PAH, HBCD, PBDE and HFR were frequently observed. Current concentrations at sampling sites compared to those of sites that have also been investigated in 2015/2016 were in the same order of magnitude or declined. For HBCD, concentrations declined distinctly by a factor of up to 9.

Microplastic and many POP were observed in moss samples indicating their suitability to monitor atmospheric deposition of these substance groups. Challenges exist for PBB, PCB or PFAS either because environmental concentrations are too low with respect to the LOQ or the pollutants' environmental behavior limit accumulation in moss. Within the past five years, most POP concentrations in moss samples from Germany remained more or less the same or decreased.

Acknowledgements:
We are thankful to the German Environment Agency (Umweltbundesamt) for funding this study (FKZ 3720632010).

References:

1. UNECE ICP VEGETATION (2020) Heavy metals, nitrogen and POP in European mosses: 2020 survey monitoring manual. https://icpvegetation.ceh.ac.uk/sites/default/files/ICP%20Vegetation%20moss%20monitoring %20manual %202020.pdf
2. Dreyer A, Nickel S, Schröder W. (2018). *Environ. Sci. Eur.* 30 (43): 1-14.

DISTRIBUTION OF MICROPLASTICS >25 µM IN SIZE ACROSS THE UNITED KINGDOM AS DETECTED USING µ-FTIR

Richard Cross[1], Ruairidh Cox[1], Monika Jurgens[1], Felicity Hayes[2]
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[2]*UK Centre for Ecology & Hydrology, Bangor*

To evaluate whether mosses may be used as a bio-monitor of microplastic deposition from the atmosphere, first a robust method for the isolation and quantification of microplastics must be established. Here we report on a novel isolation method to extract microplastics > 25 µm in size from mosses, enabling larger masses of moss to be processed and thus a more representative sample analysed. QA/QC of the method will be presented demonstrating good recovery and reproducibility of the method. Lessons from alternative separation techniques including density separation and oxidation will also be presented in the context of maximising sample size to be as representative of the scale to which we wish to monitor microplastics. Initial results for microplastic detection across the United Kingdom will be presented.

THE FUTURE OF AIR QUALITY MONITORING

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Environmental problems like global warming, acid rain, air pollution, waste disposal, ozone layer depletion, and many more affect every human, animal, and nation on the Earth. Over the last few decades, the exploitation of our planet and the degradation of our environment has gone up at an alarming rate. There are regional and international environment control programs. They use different techniques and tools to determine the current state of the environment and predict how it will evolve. Generally, studies are based on the data obtained at the sampling sites in manual or automatic mode. In most cases, such research is limited, both spatially and temporally. Modeling can be a good option for overcoming gaps in data gathering. Remote sensing is a unique source of information about Earth. Some mission has high-resolution spectrometer systems operating in the ultraviolet to shortwave infrared range. Sentinel-5 is focused on air quality and composition-climate interaction with the main data products being O3, NO2, SO2, HCHO, CHOCHO, and aerosols. Sentinel-5 will also deliver quality parameters for CO, CH4, and stratospheric O3 with daily global coverage for climate, air quality, and ozone/surface UV applications.

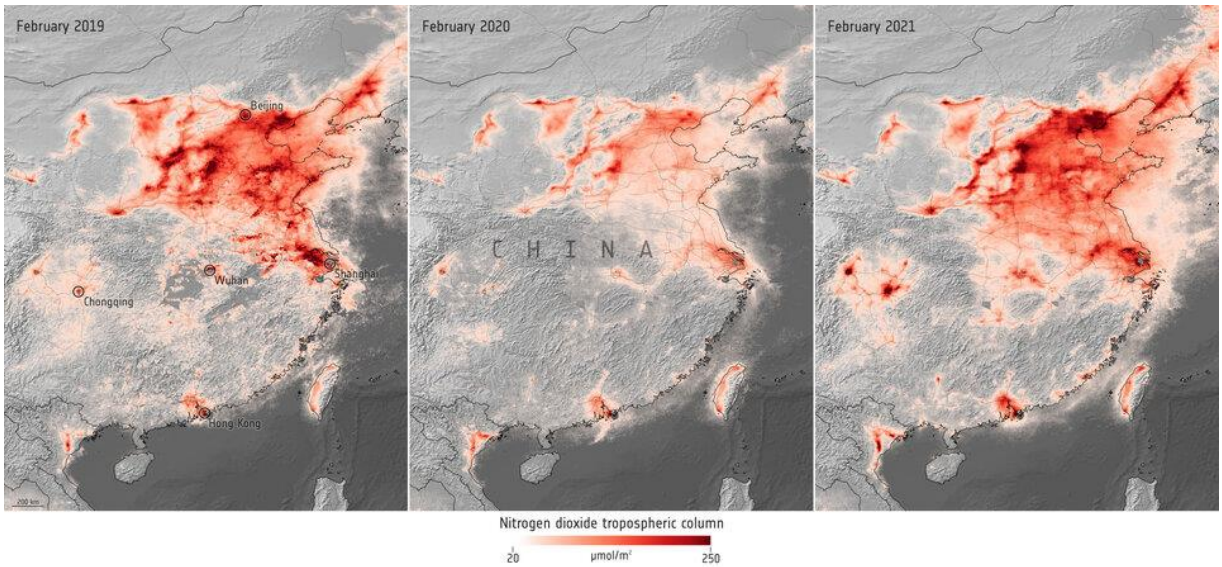

Figure 1. Decline in air pollution coinciding with nationwide lockdowns in China in 2020 (source www.esa.int)

Such missions themselves could provide lots of data about environmental status. Unfortunately, missions are limited by orbital cycle time and resolution, but commercial programs show us a great perspective. In situ measurements, remote sensing, and machine learning can open new horizons for air quality monitoring.

A NEW APPROACH FOR DETERMINATION OF THE ORIGIN OF CHEMICAL ELEMENTS EMITTED IN THE ATHMOSPHERE BASED ON THE MOSS BIOMONITORING RESULTS

Inga Zinicovscaia[1,2,3,*], Konstantin Vergel[1,4],

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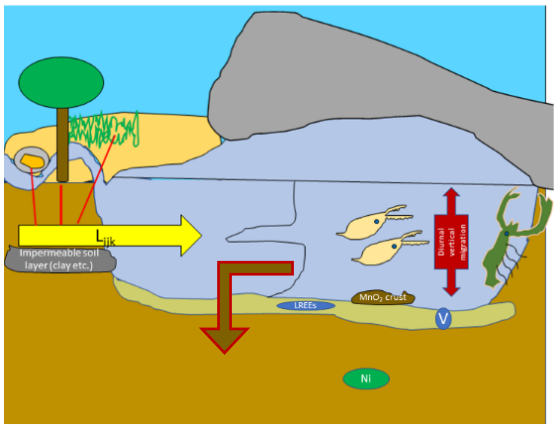
Various chemical elements are emitted into the air from both natural and anthropogenic sources. Their quantities may range from hundreds to millions of tonnes annually. In moss biomonitoring studies often is difficult to determine the exact origin of the determined elements. In the present work an approach was proposed, which may help to distinguish the lithogenic and anthropogenic origin of the elements. The approach is based on the use of widespread elements in the earth's crust, for example scandium or rubidium, as normalizing trace elements. The high coefficients of correlation of Me/Rb or Me/Sc ratios indicate geogenic origin of elements, while low values of Me/Rb or Me/Sc ratios point at the anthropogenic origin of elements. The examples of the implementation of the approach for moss biomonitoring data obtained in the Republic of Moldova and Moscow region, Russian Federation are presented.

Chitin-based M ion monitoring put to the detail: empirical determination of partition factors between water, sediment and chitin and biomonitoring, ecological conclusions derived therefrom

Stefan Fränzle, TU Dresden

In sets of local (E Saxony, FRG) water bodies both animals carrying chitin (crayfish *Faxonius (Orconectes) limosus* [non-digging, benthic]) and grafted chitin were dislocated. Relationship between chitin/water partition factor PF and $[M]_{aq.}$ was determined for some 20 elements, including most members of IW series, many trivalent ions and V, Mo over a sizable range of $[M]_{aq.}$, each. Adsorption partition factors for both grafted chitin and different parts of crayfish differ somewhat; those for M^{2+} ions on chitin in sediment considerably depend on kind of metal ion. Numerical integration of this function gives the partition (bioaccumulation) factor for chitin located in either water or sediment including living matter, usual values being 1.5 – 2.6 except stated before. The function for the latter sediment was derived using sets of elements not known to be significantly involved in biogeochemistry (Ba, Co, Pb, Cd, and Al, Cr, Y, Dy, respectively). Thus partition function $chitin_{sedim./water}$ vs. M could be recalculated from first principles which was previously shown to respond to uptake by organisms on and inside sediment, e.g., concerning Ni with methanogenic Archaea or La with bacteria oxidizing methanol and other primary alcohols.



If the latter uptake in sediment does not happen, measured values are shown to be close to expectations. Due to redox stratification in inundated limnetic sediments, signals for La (meaning oxidizing top of sediment) and Ni (implying strongly reducing conditions) may coexist when there are thick sediment deposits. Numerical integration of the bioconcentration factor vs. a equation yields partition factors from all water, wet sediment, indicating when there is effective detection of highly toxic or radioactive ultratrace elements or an indication of biochemical activities taking place in sediment which involve measured elements not always operating in biochemistry, like Ni, LREEs like La, Nd, or V (figure).
Ni readings refer to likelihood of enhanced radiative feedback from changed peatbogs, melting permafrost, etc., by methanogenesis while other element signals afford pieces of information on other possibly hazardous processes in a changing setting. Ecological implications of chitin-related element transport by diurnally migrating zooplankton and by benthic organisms climbing slopes at shores, around islands and their possible predation (fishes, birds, dragonfly larvae) and of M injection into sediments with respect to biomagnification and to determination of fallout radionuclides (M^{2+} and M^{3+} [LREEs] fission products, ^{241}Am) are also discussed.

MOSS BIOMONITORING OF ATMOSPHERIC POLLUTION IN LATVIA: LONGTERM OF HEAVY METAL CONCENTRATION IN *PLEUROZIUM SCHREBERI* MOSS

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Atmospheric pollution is one of the most significant global problems in the world due to industrial activities which influence many environmental processes. Mosses are one of the best bioindicators in the assessment of atmospheric pollution by heavy metals. Moss biomonitoring provides spatial and temporal information about distribution of atmospheric pollution because pollutants are extremely variable in space and time.

The aim of this study was a focus on the temporal changes in metal concentrations in Latvia.

In Latvia, mapping of atmospheric pollution using moss was started in 1990, and starting from 1995, *Pleurozium schreberi* was sampled in each survey between August and October. In this study, we included 78 plots which were sampled continuously in all years (1995; 2000; 2005; 2015; 2020) with fixed coordinates. The sampling and chemical analyses of heavy metals (Cd, Cr, Cu, Fe, Ni, Pb, V, and Zn) were done by strictly following the Monitoring Manual Survey of the ICP Vegetation.

The main results are that the atmospheric air pollution with heavy metals has been decreasing in Latvia due to loss of some major point sources. Pollution in Latvia is still influenced by transborder pollution from Lithuania and Western Europe, but this type of pollution has also decreased. An important issue in Latvia has been the loss of permanent sampling sites due to intensification of forest cutting, creating a need to choose sites only in protected territories. We are proposing to continue using moss monitoring for determination of atmospheric heavy metals deposition.

Keywords: Latvia, moss biomonitoring, air pollution, heavy metals

BIOACCUMULATION OF TRACE ELEMENTS FROM AQUEOUS SOLUTIONS BY SELECTED TERRESTRIAL MOSS SPECIES

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The interrelationship between the metal concentration in mosses and their surroundings prompts research towards examining their accumulation properties, as it is particularly important in biomonitoring studies with use mosses. In this study, the kinetics of elemental sorption in three moss species (*Pleurozium schreberi*, *Dicranum polysetum* and *Sphagnum fallax*) were investigated under laboratory conditions. Sorption from metal salt solutions was carried out under static conditions with decreasing elemental concentration. Functional groups responsible for binding metal cations to the internal structures of the mosses were also identified. It was shown that the equilibrium state was reached after about 60 minutes. Under the conditions of the experiment, in the first 10 minutes of the process, about 70.4-95.3% of metal ions were sorbed from the solution to the gametophytes by *P. schreberi* (57.1-89.0% by *D. polysetum* and 54.1-84.5% by *S. fallax*), with respect to the concentration of this analyte accumulated in the mosses at equilibrium. It can be assumed that exposure of mosses little contaminated with heavy metals in an urbanized area under active biomonitoring, will cause an increase in the concentration of these analytes in proportionally with their concentration in atmospheric aerosol. In the case of *P. schreberi*, *D. polysetum* O-H/N-H band is enormously affected by the adsorption process. On the other hand, FTIR (Fourier-transform infrared spectroscopy) of *S. fallax* after adsorption shows slight changes for the most of the bands analyzed. Based on the study, it can be concluded that mosses can be used, for example, as a biomonitor in monitoring of urban ecosystems but also in the phytoremediation of surface waters.

MONITORING OF HEAVY METAL ATMOSPHERIC DEPOSITION IN THE STEP ZONE OF THE EUROPEAN PART OF RUSSIA

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The organization of monitoring of heavy metal atmospheric deposition in the steppe zone of the European part of Russia is described on the example of the Samara and Orenburg regions as study areas. At the initial stage, background territories were identified in the study area. For this, in the Krasnosamarsky forest area (Samara Region) and the Buzuluksky Bor National Park (Orenburg area), where for several years research has been carried out on species diversity and ecological features of bryophytes, samples of moss *Pleurozium schreberi* (Willd. ex Brid.) Mitt. were collected. Multi-element analysis of moss phytomass was carried out by the epithermal neutron activation analysis at the reactor IBR-2 of the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research in Dubna. The results obtained made it possible to reveal the features of metal accumulation in the moss *Pleurozium schreberi* in the conditions of the Krasnosamarsky forest and Buzuluksky pine forest. A reduced content of the majority of the determined elements (Ti, V, Cr, Fe, Co, As, Se, Rb, Sr, Mo, Cd) in the phytomass of *Pleurozium schreberi* from both forest areas was established. It indicates a high level of their biogeochemical similarities. Differences appeared in relation to the elements with the maximum accumulation: ($K_к$ > 1): Cu and Zn - in the Krasnosamarsky forest area, Mn and Ni - in the Buzuluk forest. The high level of accumulation of these elements by the moss *Pleurozium schreberi* does not reflect characteristics of their content in the soil, but depends on other factors, including of the chemical composition of atmospheric flows over the Buzuluksky pine forest and Krasnosamarsky forest area. The obtained data were compared with earlier ones on the accumulation of heavy metals in the phytomass of bryophytes from the technigenically affected central part of the Samara region: the right bank on the Samarskaya Luka and left bank in the coastal zone of the city of Samara. Average concentrations of most determined elements in the phytomass of mosses from polluted habitats turned out to be 1-2 orders of magnitude higher than in the phytomass of *Pleurozium schreberi* from the Krasnosamarsky forest and the Buzuluk pine forest. A certain similarity was found in content of Mn, As, Se, Rb, Cd, Br. Thus, the relatively low content most of the analyzed heavy metals and metalloids in the soil of the studied territories and in the phytomass of the moss biomonitor *Pleurozium schreberi* allows one to consider the Krasnosamarsky forest area and the Buzulksky pine forest as background territories for steppe zone of the European part of Russia (Bogdanov et al, 2022). At the next stage of monitoring of heavy metal atmospheric deposition in the steppe zone of the European part of Russia during the growing season of 2022 phytomass samples of the mosses *Pleurozium schreberi* (17) and *Abietinella abietina* (Hedw.) C. Muell. (3) were taken out of 20 phytocenoses within the transect passing along the border steppes and forest-steppes across the entire territory of the Samara region from west to east, also exciting part of the Orenburg region.

Reference

Bogdanova Y.A., Prokhorova N.V., Vergel K.N., Frontasyeva M.V. The features of heavy metals and metalloids accumulations in the phytomass of the amphipodous moss *Pleurozium schreberi* (Brid.) Mitt. in the conditions of the Krasnosamarsky Forest area (Samara Region) and the National Park "Buzuluksky Bor" (Orenburg Region) // Samara Journal of Science. - 2022 - Vol. 11 - N. 1 - P. 24-30. doi:10.55355/snv2022111101

MOSSES AS A BIOMONITORS TO IDENTIFY ATMOSPHERIC DEPOSITION WITH MINOR AND TRACE ELEMENTS IN NORTH MACEDONIA

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The present work was carried out to obtain and highlight the fifth comprehensive baseline data on atmospheric deposition of trace elements and to assess air quality in North Macedonia. During the period from August to October 2020, a total of 72 moss samples were collected in accessible areas in North Macedonia. The content of 28 elements (Ag, Al, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Sr, Ti, U and Zn) was determined by inductively coupled plasma - atomic emission spectrometry (ICP-AES) and inductively coupled plasma - mass spectrometry (ICP-MS).

Using data obtained for moss collected in 2020, a factor analysis was performed to identify and characterize different sources of pollution. Distribution maps for all elements were also created to show the regions most affected by anthropogenic activities. The survey conducted in 2020 showed that air pollution from potentially toxic metals in Macedonia has slightly decreased compared to the results of the 2015 survey. This is due to the fact that all mining and metallurgical activities operated at the same capacity during this five-year period, but there were government regulations for the installation of filters and other rules to reduce pollution. However, the highest anthropogenic influence on air pollution with heavy metals is a smelter for ferronickel near Kavadarci (Ni and Cr) in the southern part and lead and zinc mines near Probištip, Makedonska Kamenica and Kriva Palanka, in the eastern part of the country (Cd, Pb and Zn).

Keywords: moss, atmospheric deposition, trace elements, air quality, North Macedonia

ATMOSPHERIC METAL FROM JAMMU, INDIA: PRE-PANDEMIC, PANDEMIC AND POST-PANDEMIC MEASUREMENTS BY MOSS HYPNUM CUPRESSIFORME

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Moss *Hypnum cupressiforme* Hedw was identified and inducted amongst available moss species to evaluate the intensity and seasonal trend of atmospheric deposition of Zn, Cu, Cd, and Pb around Manasbal Lake of Jammu (34° 15' 0.1224" N, 74° 40' 13.0656" E) and from east of Jammu city, India (22° 51' 22.4676" N & 88° 24' 23.2344" E), for a period of three years, 2014 to 2016. Trend of metals precipitation of this periods were compared with metals in moss species during pandemic (2021) and post-pandemic period (2022). Moss *Hypnum cupressiforme* Hedw exposed seasonally, representing summer, monsoon, and winter periods, and upon the analysis provided time-integrated patterns of metal bioavailability of the study sites. The biomonitoring was performed by transplanting moss *Hypnum cupressiforme*, after validating its tolerance potentials against metals using a photosynthetic efficiency analyzer. Percent increase for metals was more towards the east of the city, which could be due to the high volume of traffic,

An attempt was made to compare atmospheric metal data from moss transplants pandemic period (2021) and post-pandemic period i.e. 2022 with previous studies made from 2014 to 2016. Extremely low metal values were measured in moss transplants during the pandemic period, however, a gradual increase in metal values was measured in moss samples post-pandemic (Fig 1). Findings exhibited significant seasonal variations in metals nevertheless values were high during monsoon. followed by summer which attracts a lot of tourists as a result high metal load in the atmosphere and cannot be ruled out leaching of metals along with water droplets during the rainy season (Fig 2). The gradient of the metal load was in the order of Cd>Cu>Zn>Pb. It is worth mentioning here that biomonitoring on atmospheric metals has never been done before for this region.

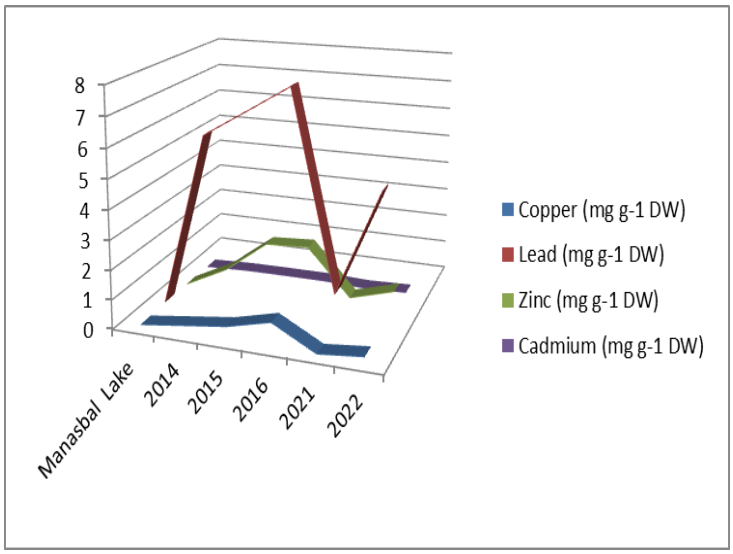

Fig 1. Comparison of the four metals belongs to pandemic and post pandemic periods with the data from 2014 to 2016.

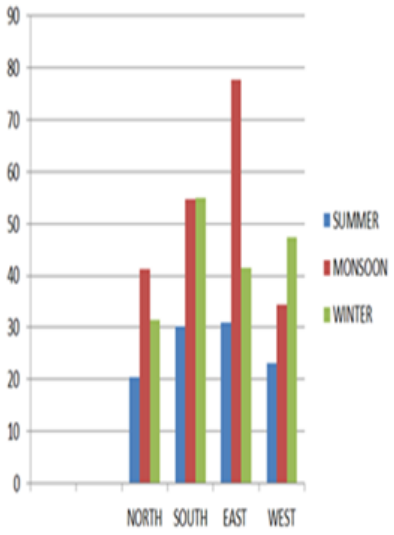

Fig 2.Seasonal percentage increase of metals

SEASONAL CHANGES IN SPATIAL DISTRIBUTION OF ^{7}Be ATMOSPHERIC DEPOSITION MEASURED USING TERRESTRIAL MOSSES

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Cosmogenic radionuclide ^{7}Be is frequently used as a tracer in atmospheric studies. Air samplers or deposition collectors are usually used to measure air concentration or deposition rate of ^{7}Be. A limited number of institutions equipped with mentioned devices do not provide the possibility to observe the atmospheric deposition of aerosols, naturally traced by ^{7}Be, with high spatial resolution. By using mosses, this problem can be overcome and high resolution maps can be obtained.

In order to evaluate existence of some areas with preferentially higher or lower atmospheric deposition, a three-year project, in which periodic moss sampling and measurement of ^{7}Be activity is carried out, has been started. Moss sampling was performed at 70 locations in the northern part of Serbia. Dried samples, compressed into 200 ml plastic containers were measured in anti-Compton NaI detector adapted for this purpose to serve as a high efficiency well-counter. Till now, two campaigns have been carried out, in the spring and autumn of 2022, and two maps of the spatial deposition of ^{7}Be have been created.

The obtained ^{7}Be activity values (in Bq/kg) are in relative broad range and in both cases the lowest and the highest measured activity differ by one order of magnitude. By analyzing and comparing the results obtained in two sampling and measurement campaigns, significant differences are observed in the range of measured values, the mean and median, but also in the spatial distribution of the atmospheric deposition of ^{7}Be.

The authors acknowledge financial support of the Provincial Secretariat for Higher Education and Scientific Research of Autonomous Province of Vojvodina (Project title: Investigation of atmospheric aerosol deposition pathways with atmospheric pollutants on the territory of AP Vojvodina using biomonitors and natural radioactive markers; Grant No. 142-451-3139/2022-01/2)

INVESTIGATING THE USE OF COMMON WEED SPECIES AS BIOINDICATORS FOR HEAVY METAL POLLUTION: A STUDY OF *TRIFOLIUM PRATENSE*, *ALCEA ROSEA*, AND *LOLIUM MULTIFLORUM*

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Heavy metals, such as copper, zinc, cadmium, and lead, are toxic and persistent pollutants that can have detrimental effects on the environment and living organisms. These elements can accumulate in soil, water, and biotic systems, leading to bioaccumulation and biomagnification, which can ultimately affect the health of both humans and wildlife. Bioindication, the use of living organisms as indicators of pollution, is a valuable tool for detecting and measuring heavy metal concentrations in the environment. Despite its potential, there is a scarcity of research on the use of wild plant species as bioindicators for heavy metals in natural conditions.

The aim of this study was to investigate the feasibility of utilizing common weed species, such as *Trifolium pratense*, *Alcea rosea* and *Lolium multiflorum*, as bioindicators for four specific heavy metals: Copper, Zinc, Cadmium and Lead. The study was conducted at experimental sites situated near air monitoring stations and the plant samples were exposed for analysis. The concentrations of these heavy metals were determined using inductively coupled plasma optical emission spectrometry (ICP-OES). The research also includes the measurement of chlorophyll measurement, hydrogen peroxide content, determination of antioxidant enzyme activities, measurement of lipid peroxidation and situ detection of hydrogen peroxide.

The results of the study showed that *Trifolium pratense* was the best bioindicator among the three plant species for Copper, Zinc, Cadmium and Lead. Furthermore, the species had a significant response to the heavy metal pollution and demonstrated a strong correlation between the heavy metal concentrations and the physiological parameters. The study suggests that the utilization of *Trifolium pratense* as bioindicator for heavy metal pollution in natural conditions is a promising alternative for air pollution monitoring. Additionally, standardizing the cultivation conditions and incorporating a combination of plant species may enhance the quality and comparability of the results obtained.

CANADIAN MOSS BIOMONITORING SURVEY UPDATE

Wilkins K., Aherne J.

Given Canada's large area and extensive remote regions, it is logistically challenging to contribute representative moss biomonitoring survey data to ICP Vegetation. In an effort to increase our spatial coverage of moss samples, a community science approach was piloted, called the Canadian Bryomonitoring Project. Community volunteers could sign up for the project using the online hub (URL: www.bryomonitoring.ca), learn about species identification (*Hylocomium splendens* and *Pleurozium schreberi*) and sampling methods, and request a sampling kit with a postage-paid return envelope. Samples were received from every province and territory; a total of 300 samples were received. About 250 suitable samples with the correct moss species (Figure 1) are currently being prepared for analysis of trace elements and nitrogen content. A community science approach did result in an increased sample coverage compared to what would otherwise be achievable; however, for future surveys we plan to increase marketing to remote areas.

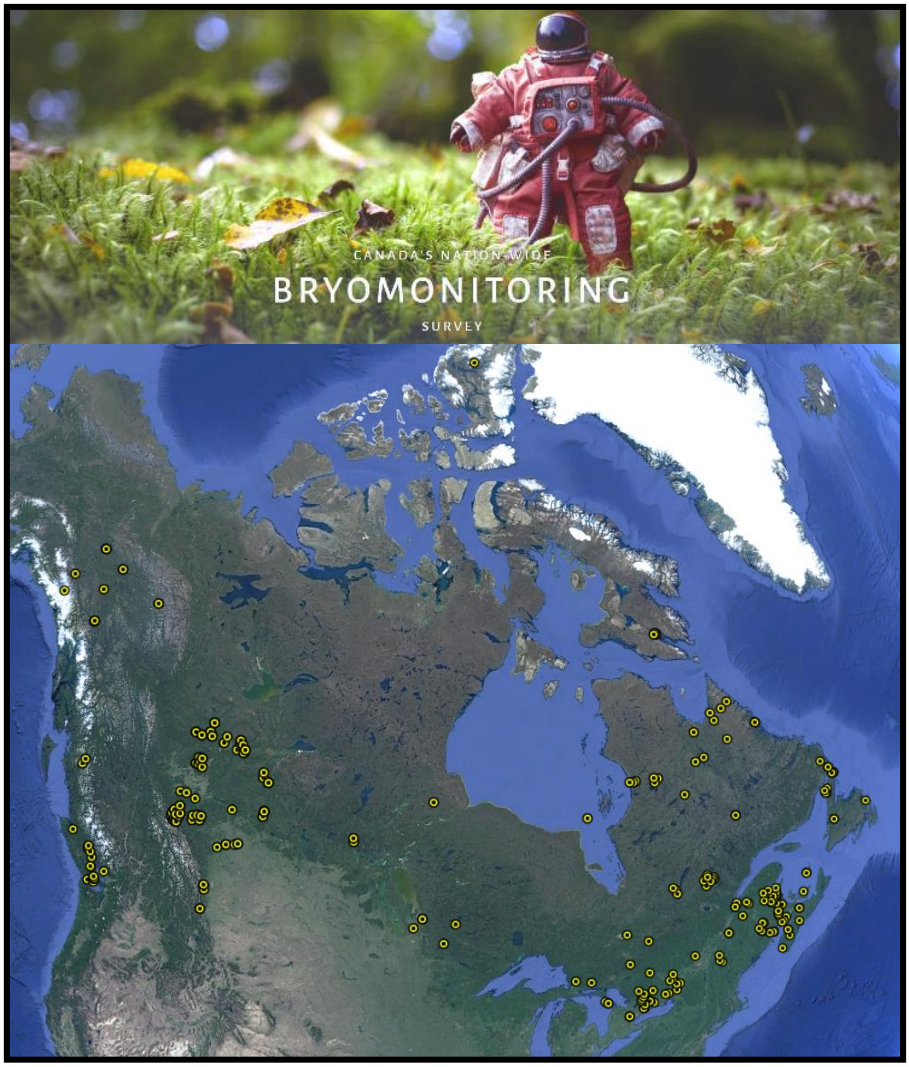

Figure 1: Bryomonitoring Canada website banner and map showing sample locations.

RESULTS OF MOSS SURVEY-2020/2021 IN CENTRAL RUSSIA

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The results of moss survey conducted it regions of Central Russia: Moscow, Vladimir, Yaroslavl and Tver covering area of 193 000 km^2 are presented. During 2019-2021 425 samples of *Hylocomium splendens* were collected in studies regions. Elemental composition (up to 40 elements) of samples collected in Moscow, Vladimir and Yaroslavl regions was determined using neutron activation analysis and in Tver region using ICP-OES (16 elements). Statistical tools were applied to reveal possible pollution hot-spots in the studied areas, as well as to conduct a comparative analysis of the obtained results with those from the previous surveys. Distribution maps were build using GIS software. The main air pollution source in all investigated regions is transport, while industrial enterprises contributed to local contamination of the environment.

INTERACTIVE EFFECTS OF ELEVATED OZONE AND NITROGEN ADDITION ON PHYSIOLOGY AND GROWTH IN POPLAR

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Ground-level ozone (O_3) and nitrogen (N) deposition are major environmental pollutants, often occurring concurrently. However, research of their interactive effects on physiology and growth of plants is still scarce. Poplar saplings were exposed to two O_3 levels (NF, non-filtered ambient air; NF60, NF + 60 ppb O_3) and four N treatments (N0, no N added; N50, N0 + 50 kg N ha^{-1} yr^{-1}; N100, N0 + 100 kg N ha^{-1} yr^{-1}; N200, N0 + 200 kg N ha^{-1} yr^{-1}) in open-top chambers for 95 days. Leaf photosynthetic parameters, N metabolism indicators, biomass parameters and isoprene release rate were analysed. The results showed that (1) NF60 decreased light-saturated net photosynthesis (A_{sat}), mesophyll conductance (g_m) and apparent maximum rate of carboxylation (V_{cmax}), and N fertilization increased A_{sat}, g_m, V_{cmax} and the maximum rate of electron transport (J_{max}). No E-O_3 or E-O_3 x N interaction effects on the temperature response parameters were detected, simplifying the inclusion of O_3 impacts on photosynthesis in vegetation models. (2) NF60 stimulated the activities of nitrate reductase (NR) and glutamine synthetase (GS) relative to NF, but O_3 did not significantly affect total soluble protein (TSP) and even reduced total amino acid (TAA). Simultaneously, high N treatment significantly promoted leaf N metabolism by increasing NO_3^--N contents, NH_4^+-N contents, TAA contents and the activities of NR and GS. There was no significant interaction between O3 and N for N metabolism indicators. (3) Elevated O_3 significantly inhibited while N addition stimulated total plant biomass and root biomass, with more pronounced effects on fine roots than on coarse root. (4) Increasing O_3 exposure decreased isoprene emission, while N load increased isoprene emission. N did not mitigate the negative effects of O_3 on isoprene emission, i.e. the combined effects were additive and did not interact. These findings highlight that the physiology and growth exhibit differential responses to environmentally realistic levels of O_3 and N, and provide an important perspective for understanding and predicting the processes of carbon and N cycling in ecosystems in O_3-polluted and N-enriched environments.

DEVELOPING OZONE DOSE RESPONSE FUNCTIONS FOR TROPICAL SYSTEMS

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Tropical systems are an important component of understanding the global impacts of ozone pollution on carbon cycling and agronomic productivity. Although suspected as being highly vulnerable to ozone, and especially given projections of ozone exposure into the near future, little information currently exists on the impacts of ozone on tropical trees or crop species beyond those commonly grown as commodities.

Here we present our findings from a new experimental research facility (TropOz) housed at the Nguma-bada campus James Cook University, Cairns, Australia. The TropOz facility is a collaboration between the University of Exeter, the UK's Centre for Ecology and Hydrology and James Cook University, and allows for the growing of tropical species across nine open top chambers (each 3.5 m diameter) under a range of ozone concentrations.

We present our initial findings; including the comprehensive measurement of ozone effects on eleven tropical tree species, and important crop species such as sugarcane and banana. By calculating stomatal flux of ozone we are able to generate so called dose-response functions and use these relationships to parameterize the global land-surface model JULES. Applying the calibrated model over tropical regions using contemporary near-surface ozone concentration fields we are able to quantify the likely impact on contemporary tropical productivity.

Figure 1: Overview of open-top chambers (OTC's) part of the TropOz experimental facility housed at the at the Nguma-bada campus, James Cook University, Cairns, in Far North Queensland, Australia

Tropospheric ozone hinders the adaptation of floral phenology to climate warming in Mediterranean alpine plants

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Climate warming and tropospheric ozone (O_3) are the two of the most relevant stress factors for the Mediterranean upland vegetation (Prieto-Benitez et al., 2023). Flower phenology is a crucial trait in plant response to global warming, with flowering time ocurring earlier to adapt to the increasingly earlier onset of soil moisture limited conditions of the summer in Mediterranean mountains. However, the high O3 levels recorded in Mediterranean mountains (Elvira et al., 2016) may be hindering this phenological adaptation, harming alpine plant reproduction. An O3 fumigation experiment in open-top chambers was conducted to evaluate how temperature and O3 influence in different flower phenology traits (flower onset, flowering peak, and flowering length). The results highlight the opposite pressures exerted by O3 and temperature increase on the flower phenology.

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GROUND-LEVEL OZONE AND NITROGEN DIOXIDE POLLUTION REMOVAL CAPACITY BY URBAN VEGETATION IN LITHUANIA

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More than 3.5 billion people currently live in cities worldwide, and this number is expected to increase to 6.5 billion by 2050. Over 70% of the EU's and 67% of Lithuania population lives in cities. Typically, in urban environment, citizens are exposed to about 200 air pollutants or classes of them and it is one of major concern affecting life quality, citizens well-being and human health in cities (Sicard et al., 2011). In terms of adverse impacts on human health, nitrogen dioxide (NO_2) and tropospheric ozone (O_3) are among the most harmful air pollutants in cities leading to millions of premature deaths worldwide every year (EEA, 2021).

Green infrastructure, as an integral part of the city environment, plays an important role in improving air quality (Nowak et al., 2018). Green urban infrastructure has been proposed by European Commission as a strategy to support climate adaptation capacity and sustainable development in the urban areas. Urban trees can offer great potential to remove various air pollutants, especially nearby sources, by absorbing gaseous air pollutants through their stomata.

Based on the methodologies established by Sicard et al. (2023) and Manzini et al. (2023), we have i) detected and classified the dominant tree species and ii) quantified the capacity of urban trees to remove both NO_2 and O_3 in Kaunas. By using satellite-based approach with Worldview-3 satellite imagery at very-high spatial and spectral resolution, we have detected and classified most common tree species (a total of 284,305 trees) in Kaunas with an overall accuracy of about 88% e.g., *Acer* spp. (10%), *Aesculus hippocastanum* (11%), *Pinus* spp. (9%), *Quercus* spp. (24%), and *Tilia* spp. (5%) in both private (e.g., residential gardens) and public areas over a large study area (56 km^2). The green cover of Kaunas city represents 64% of the total study area. In 2022, the 284,305 trees detected in Kaunas city have removed approximately 2,084 tons of NO_2 while dominant trees formed more O_3 than they absorbed (1,204 tons released) mainly due to the high ozone formation potential of *Quercus* spp.

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STUDY OF NITROGEN CONCENTRATIONS IN BEE POLLEN SAMPLES IN KOSOVO BY KJELDAHL METHOD

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Pollen is the male gametophyte, collected as a nutrient from various flowers by the honey bee colonies (*Apis mellifera* L.) to feed the larvae and bees in their early stages of development. The sample was taken as grain pollen collected by bees to be stored in hives. The nitrogen content in bee pollen were studied for the first time in the Republic of Kosovo. In total 67 bee pollen samples were collected during May to August 2019. Pollen samples were collected by a plastic trap was placed at the entrance of each hive, equipped with a mechanism collecting pollen from the wings of bees entering the hive. The concentrations of nitrogen in mosses samples were determined by Kjeldahl method. The descriptive statistics and distribution map were prepared. The minimum content of nitrogen in the bee pollen collected was 1.39% and the maximum value was 4.99%, while the median value was 2.98%. High concentrations of nitrogen (≥3.8%) were found mainly in industrial locations: Fushë Kosovë, Obiliq, Vushtrri and Mitrovicë, as the result of agricultural activities, industry, and traffic.

Keywords: Kosovo; nitrogen, bee pollen; Kjeldahl method.

NO_x CRITICAL LEVELS: REVIEW UPDATE

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The ICP Vegetation is responsible for Chapter 3 of the Modelling and Mapping Manual (LRTAP Convention, 2017), which provides the methodology to model and map critical levels of the air pollutants ozone (O_3), sulphur dioxide (SO_2), ammonia (NH_3) and nitrogen oxides (NO_x), and their exceedances across Europe. These critical levels are used within the Working Group on Effects (WGE) of the Convention on Long Range Transboundary Air Pollution (CLRTAP).

The annual critical level for NO_x (the combination of nitric oxide (NO) and nitrogen dioxide (NO_2)), recommended for use within CLRTAP, has been set at 30 $\mu g/m^3$ since this value was proposed and ratified at workshops in Bad Harzburg (1988) and Egham (1992). Air pollution characteristics have radically altered across Europe since that time. In the last 30 years, background O_3 concentrations have tended to increase while episodic peaks have declined, NH_3 concentrations have increased through intensive agricultural practices, and there have been large decreases in SO_2 concentrations and subsequent acid deposition.

These dynamics are particularly pertinent to the setting of NO_x critical levels:

- high SO_2 concentrations were associated with adverse vegetation impacts at lower NO_x concentrations;
- O_3 can affect stomatal opening and plant uptake of air pollutants;
- NH_3 may increase total N uptake into the plant at a given level of NO_x.

Given this changed atmospheric context, and the availability of additional published studies since 1992, ICP Vegetation are reviewing critical levels for NO_x. This presentation will present key messages from this review and targeted literature search, summarising recent findings on how dynamics in NO and NO_2 are projected to affect vegetation and other ecosystem components in contemporary and future atmospheres. It will also reflect on the complications in separating direct effects on the vegetation, key to the definition of critical levels, from indirect effects via N deposition processes (e.g. soil eutrophication and acidification).

The presentation will provide an updated methodology to assess whether the current critical level is fit-for-purpose, comparing our approach with that used in previous iterations. The suggested methodology aligns with that now implemented in the Mapping Manual for O_3. Together with evidence from observational studies of lichen and bryophyte community change in atmospheres of raised pollutant concentrations, our revised methodology may suggest a revision to the annual critical level for NO_x. Next steps in the review process will be communicated to the Task Force and we would welcome feedback.

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EVALUATION OF AIR QUALITY IN GEORGIA BASED ON MOSS SURVEY 2019-2022 RESULTS

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During 2019-2022 moss survey in Georgia, 96 samples were collected, covering most of the country territory. Four moss species (*Hylocomium splendens* (Hedw.) Schimp. (n=10), *Hypnum cupressiforme* Hedw. (n=59), *Pleurozium schreberi* (Brid.) Mitt (n=13), and *Abietinella abietina* (Hedw.) M. Fleisch) (n=14)) were selected for the survey. A total of 15 elements, namely Al, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, S, Sr, V, and Zn, were determined in moss samples by inductively coupled plasma atomic emission spectroscopy. Univariate and multivariate statistical analyses were implemented for data processing. Principal Component Analyses allowed to reveal the association between elements in the study area. To identify the most polluted sites Pollution load index was calculated and mapped using GIS technology. The elements concentrations were compared with the previous surveys in Georgia and literature data.

FOURTH MOSS SURVEY IN THE REPUBLIC OF BELARUS: BREST REGION CASE STUDY

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The moss biomonitoring technique was applied at the territory of the Republic of Belarus for the fourth time. This moss survey was conducted in a few stages. First stage of survey was done in 2020 in the Brest region. 30 samples of moss *Pleurozium schreberi (Brid.) Mitt.* were collected in the southwestern border region of Belarus. According to the previous surveys this region is more exposed to transboundary pollution than other regions of the country. 33 elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Br, Se, Rb, Sr, Sb, I, Cs, Ba, La, Ce, Sm, Tb, Hf, Ta, Th, W and U) were determined using neutron activation analysis (NAA).

To control the temporal variability of transboundary transport and quantitative assessment of atmospheric precipitation the median concentrations of trace elements in the mosses at the same sampling sites in 2010 were compared (Fig. 1). For some elements such as chromium, cobalt, antimony, iron, manganese and zinc concentration decrease is observed, while for vanadium, nickel, arsenic there is slight increase in concentrations.

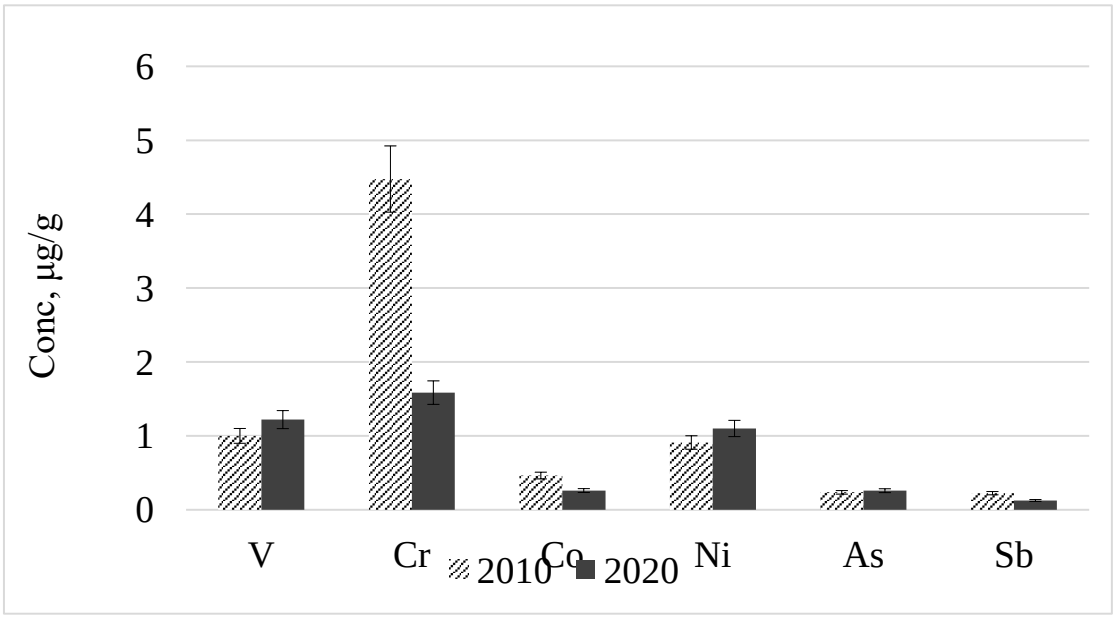

Figure 1. Median concentrations for some elements in moss surveys 2010 and 2020

INFLUENCE OF THE ENVIRONMENT ON THE CONCENTRATION IN MOSSES: COMPARISON BETWEEN CEMETERIES AND FORESTS

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Moss surveys are convenient tools to monitor the exposition of ecosystems to local or long-distance pollution. It is a relative method of biomonitoring, which compares the concentration value measured in the samples, between collecting sites. It is traditionally accepted that these values are quantitative estimates of atmospheric deposition. However, various biotic and abiotic factors can interfere with the capture and retention of atmospheric elements by mosses. It is therefore necessary to characterise the station parameters that may affect the comparison between sites.

In our study, we compared mosses collected in different environments but in close proximity. In 22 sites, we collected terricolous mosses in forested area following the protocol used by France in the framework of the european moss survey. Nearby, the same day, we collected mosses in urban fabric, in cemeteries, following an adapted protocol. On concrete graves or flat top of the perimeter walls, cushions of *Grimmia pulvinata* were sampled. All samples are then cleaned, grinded and digested with HF before being analysed by ICP MS or ICP AES.

The difference between the 22 pairs was tested statistically for the 24 elements analysed. The assumption is that the concentration values in mosses should be higher in urban fabric than under forest cover. This has been verified for a majority of elements but not all. Three groups of elements emerge from this comparison (Wilcoxon test for paired samples):
_ elements with higher levels in urban environment than in forest (Al, As, Ca, Cd, Co, Cr, Cu, Fe, Mo, Na, Ni, Pb, Pd, S, Sb, Sr, V, Zn)
_ elements with higher levels in forest than in urban environment (Hg, K, Mn)
_ elements not different between the two environments (Mg, N, P)

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TRACE METAL ATMOSPHERIC DEPOSITION IN ALBANIA AND THE IMPACT FROM WIND BLOWN DUST

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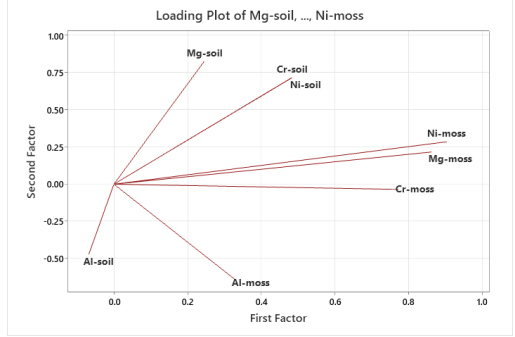
This research was carried out to assess the atmospheric deposition of certain trace metals in the whole territory of Albania, a country with diverse lithology and topography, and to investigate the effects of the elements on wind-blown dust and substrate soils. Only four elements (Cr, Ni, Al, and Mg) are considered here because: Cr and Ni were identified in high concentrations compared to the reported values of the European moss surveys of 2010 and 2015; Al is a typical lithogenic and pedogenic element; and Mg is an easily leached element from soils. Previous moss surveys in Albania revealed several sources of element concentrations in mosses, including long-range atmospheric transport of anthropogenic elements from other parts of Europe, transboundary atmospheric transport of elements from neighbouring countries, local anthropogenic sources, sea-spray emission from the marine environment, and windblown dust mineral particles (Lazo et al. 2019, 2018). The possibility of uptaking moss elements from substrate soils was observed by analyzing moss (Hypnum cupressiforme Hedw.) and topsoil samples collected from 75 sites throughout Albania with a density of 2.6 samples per 1000 square kilometres. Topsoil samples were collected at 0–10 cm depth in the same position as the mosses. Cr, Ni, Al, and Mg were determined by inductively coupled plasma-mass spectrometry (ICP-MS) (Agilent, 7800). Quality control of sampling and analytical methods was performed using sampling and analytical duplicates, reference materials, and reagent blanks. Concentration data were analyzed by statistical analysis using MINITAB 19 software. The results of the factor analysis are shown here.

Results from Factor Analysis



Sorted Rotated Factor Loadings and Communalities

Variable	Factor1	Factor2	Communality
Ni-moss	**0.904**	0.000	0.898
Mg-moss	**0.862**	0.000	0.790
Cr-moss	**0.773**	0.000	0.599
Mg-soil	0.000	**0.825**	0.741
Cr-soil	**0.484**	**0.716**	0.748
Ni-soil	**0.481**	**0.713**	0.740
Al-moss	0.000	**-0.639**	0.516
AI-soil	0.000	**-0.469**	0.225
Variance	2.796	2.460	5.257
% Var	0.350	0.308	0.657

Two main factors (F1 and F2) were extracted that contain 65.7% of the total variance. F1 is composed of high loadings of Ni, Cr, and Mg in moss and moderate loadings of Ni and Cr in soil. As Cr is considered an insoluble element in soil, the association of moss Ni and Cr with soil Ni and Cr indicates the effects of wind blowing soil dist into moss. Soil dust and mineral particles seemed to be the main source of the high Cr, Ni, and Mg concentration values in moss. Couto et al. (2004) showed that dust or particulate input plays an important and often underestimated role in determining moss chemistry. Higher concentrations of moss elements were found in areas of very high element content in soil characterized by no or a thin humus layer and sparse vegetation that stimulates soil dust generation. F2 is linked with soil elements and moss Al loadings. The association of moss and soil Al with the same factor confirms the effects of wind blowing dust into moss. Different distribution patterns were observed in this study. It showed that substrate soil constituents have a minor effect on the concentration of elements in mosses within the studied area, with the exception of areas with high mineral contents and a high effect from anthropogenic sources. It is a compelling test for mosses as a suitable biomonitor of the atmospheric deposition of metals, even in areas dominated by mineral soils, such as Albania.

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Romanian moss surveys - heavy metals atmospheric deposition temporal trends

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Through the Romanian moss surveys, carried out in the frame of the *International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops*, data on the levels of heavy metals in naturally growing mosses were provided. The surveys have been repeated at five-years intervals, beginning in 2010 and continuing in 2015 and 2020.

The analytical techniques used for the quantification of heavy metals (V, Cr, Fe, Ni, Cu, Zn, As, Cd and Pb) in moss samples were: atomic absorption spectrometry (2010), inductively coupled plasma mass spectrometry (2015, 2020) and instrumental neutron activation analysis (2010, 2015, 2020).

Using the data for the reported concentrations in moss samples collected from each survey, maps of heavy metals atmospheric deposition were built. A decreasing trend of Cd and Pb concentrations has been detected in the northern and western parts of Romania.

Based on the metals data in moss samples, statistical analysis of the temporal trends (2010 – 2020) of atmospheric deposition across Romania was performed and a comparison of the mean and median values per metal and per survey year with other European countries was done.

MOSS-BIOMONITORING METHOD IN THE STUDY OF AIR POLLUTION ON THE EASTERN PART OF THE RUSSIAN PLAIN (PERM REGION, RUSSIA)

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Numerous studies have shown that there is a correlation between atmospheric deposition of pollutants, including heavy metals, and their concentrations in mosses. Since the 1980s, pollutant levels in mosses have been investigated in European countries and in Russian Federation. Europe International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops has been set up (ICP Vegetation) (United Nations Economic Commission..., 2022). According to Cooperation agreement between Joint institute for nuclear research and Perm State University moss-biomonitors samples were taken from the Perm region in 2022. The aim of this Cooperation agreement is obtaining new data on air pollution by heavy metals and other toxic elements, as well as radionuclides in the Perm region based on the use of the moss-biomonitors method and nuclear and related analytical techniques.

The Perm region is situated on the eastern part of the Russian Plain (80%) and the western slope of the Urals (20%). The Perm region's weather is mainly influenced by westerly and northwesterly atmospheric processes. One of the atmospheric circulation's features in Perm region is the higher frequency of cyclones (74%) compared to anticyclones (26%) throughout the year. Annual variations in atmospheric pressure result in south-western, western, southern and south-eastern winds prevailing in winter, while in summer winds of the western, north-western or northern directions are more frequently recorded (Shklyaev, 2006).

The Perm region economy has an industrial character. The sectors of specialization are: oil extraction and production of oil products, chemical production, pulp and paper production, timber industry complex. The cities of Perm, Berezniki, Solikamsk and Gubakha are the core of the region's industrial framework (Report, 2022).

Pleurozium schreberi (Brid.) Mitt. and *Hylocomium splendens* (Hedw.) Bruch et al. were chosen as biomonitors. Both species are recommended for research by ICP Vegetation. Moss samples were collected from 131 locations in the Perm region. In addition, moss samples were collected within the city of Perm. We want to find out the concentration gradient and assess the contribution of the polluted atmosphere in the city. Sampling was carried out according to international methods (Heavy metals..., 2003). Sampling of mosses was carried out from May to October 2022 in various types of forests growing mainly on sod-podzol soils, less often on sandy soils. Elevation differences did not exceed 150 m in the flat part of the region.For the first time air pollution studies in Perm region will be carried out using the moss biomonitoring technique and neutron activation analysis. The results obtained will be compared to similar data from different areas of Russia.

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ANALYSIS OF DATA ON THE ACCUMULATION OF TRACE ELEMENTS IN THE BIOMASS OF MOSSES OF THE UDMURT REPUBLIC, RUSSIA

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The results of the analysis of atmospheric precipitation of microelements during the examination of mosses in the autumn of 2020 in the Udmurt Republic, Russia are presented. The sampling site coordinates were very close to those used in the first moss count in Udmurtia conducted in 2005-2006. (Pankratova et al., 2007, 2008), as well as during similar counts in 2016-2017. (Bukharina et al., 2017, Bukharina et al., 2018, Bukharina et al., 2020). 35 elements were determined by neutron activation analysis and atomic absorption spectrometry. Analysis of the results of determining the accumulation of chemical elements in the biomass of the moss Pleurozium schreberi (Brid.) Mitt. and Hylocomium splendens (Hedw.) Bruch et al. on the territory of the Udmurt Republic was carried out using the program Statistica 10. The analysis of the results of descriptive statistics showed that the content of 22 chemical elements, Na, Al, Cl, Sc, Ti, V, Cr, Fe, Co, Ni, Zr, Mo, Sb, La, Ce, Sm, Tb, Hf, Ta, W, Th, U vary widely; the content of a chemical element in the biomass of moss of the same species differs by several times or orders of magnitude. In this connection, it can be assumed that there are emission sources that include these chemical elements. No such fluctuations were found for other elements.

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MOSS WALLS: CONSTRACTION, PROSPECTS FOR DETECTION OF HEAVY METALS, NANOPARTICLES AND PMs, BIOMARKERS – A NEW PROJECT IN BULGARIA

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Urban air pollution in densely populated areas is a growing challenge to human health and well-being. To address this issue, we start a project based on interdisciplinary approach integrating several research areas: technological solutions based on mosses, analytical and organic chemistry, molecular data analysis and modelling. Within this project, we propose green technologies based on environmental monitoring with data analyses and construction and management of moss walls. The aim of the research is to (i) implementation and improvement of moss walls with selected moss species; (ii) study the accumulation capacity of mosses with regard to PMs, heavy metals and toxic elements, and nanoparticles and (iii) genome-wide expression analysis of the moss small RNA populations related to plant environmental plasticity.

The selected key species is *Hypnum cupressiforme* - the main species proposed for moss surveys (ICP Vegetation programme) in South-eastern Europe (Yurukova 2007). Constructed moss walls will be installed in 3 areas in urban environment (Plovdiv, Bulgaria) specified as follows: a heavy traffic area, a moderate traffic area and an urban green space area. The project will try to establish a relationship between PMs, heavy metals and toxic elements, and nanoparticles in the air and in moss tissues. In addition small RNA molecules, mainly microRNAs, will be identified and classified in *H. cupressiforme*, and their expression profiles under polluted air will be established. The impact of pollutants on the lipid composition of the moss tissues will also be examined.

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BIOMONITORING OF ATMOSPHERIC DEPOSITION OF HEAVY METALS IN SLOVAKIA IN 2020-2022

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The use of bryophytes for biomonitoring of changes in atmospheric deposition of heavy metals in Slovakia started in 1990. The basic grid of monitoring sites was arranged in a scale of 16x16 km. From 2020-2022 were collected moss samples from 204 sites (Fig.1) including sites with high potential of heavy metal exposure and background localities. Predominant moss species were from genus *Pleurozium, Hylocomium, Hypnum* and *Dicranum*.
Collected mosses from 91 sites (Fig.1) were analysed by EA-TCD (N, C, S), AES-ICP (Al, P, Ca, Mg, K, Na, Fe, Mn, Zn, B, Cu), AES-ICP-U (As, Cr, Co, Cd, Ni, Pb) and by AAS-AMA (Hg) techniques in a laboratory of the National Forestry Centre in Zvolen (SK).

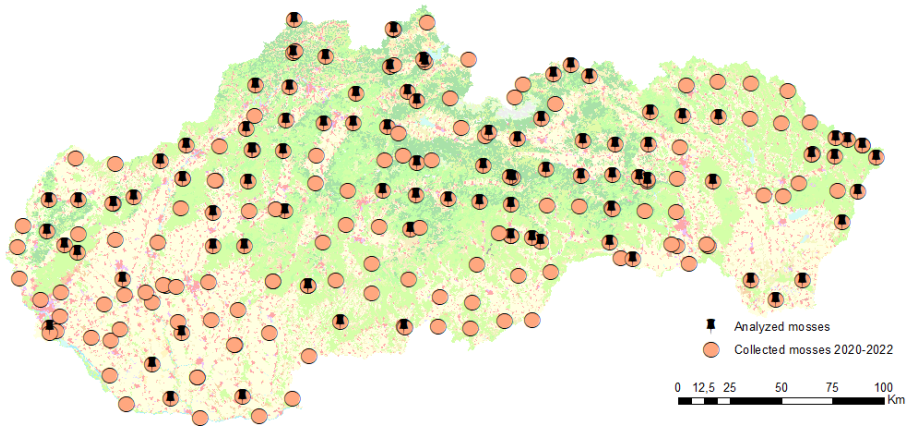

Figure 1: Map of Slovakia with sampling sites.

In analysed moss samples were detected concentration of nitrogen from 0.97 – 3.22 % with median value 1.76%. The concentration of carbon was in the range from 34.60 – 51.70 % with mean value 45.01 % and concentration of sulfur was from 0.07 – 1.47 % with median value 0.14 %. The results from analyses of selected metals are presented in the table 1.

Table 1: Results of statistical analyses of selected heavy metals (n = 91sites).

	Al	Fe	Mn	Zn	B	Cu	As	Cr	Co	Cd	Ni	Pb	Hg
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
mean	963.62	724.25	214.01	31.53	9.84	7.28	0.45	2.10	0.51	0.20	1.52	3.78	0.03
std	974.49	653.22	189.19	10.41	5.81	2.45	0.62	1.77	0.40	0.10	1.15	2.62	0.02
min	138.86	173.13	23.13	17.47	2.00	3.51	0.04	0.51	0.02	0.06	0.22	0.59	0.01
0.25	320.98	299.11	88.03	25.59	5.62	5.70	0.20	1.13	0.22	0.12	0.80	2.22	0.02
0.50	579.18	535.35	147.87	29.28	8.77	6.62	0.32	1.54	0.46	0.19	1.21	3.06	0.02
0.75	1272.94	903.71	293.03	36.31	11.93	8.63	0.54	2.21	0.64	0.24	1.79	4.33	0.03
max	5794.17	4116.01	841.79	79.40	35.43	16.54	5.13	11.25	2.23	0.65	6.79	16.84	0.15
90th	1968.36	1407.21	476.28	42.05	16.57	10.11	0.67	4.27	0.99	0.34	2.97	6.09	0.05

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DETERMINING THE CONCENTRATION OF HEAVY METALS DEPOSITED FROM THE AIR USING A MOSS BIOINDICATOR ON SZENTENREI ISLAND (CENTRAL HUNGARY)

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The authors' investigations aimed to map five airborne heavy metals (Ni, Cu, Cd, Pb, Co) in moss bioindicators on Szentendrei Island (Central Hungary). The moss species studied: *Hylocomium splendens, Pleurozium schreberi*.
Before the studies were carried out, it was expected that the southern part of Szentendrei Island would be much more polluted due to its proximity to Budapest and the construction of the Megyeri Bridge in 2008, and that the values obtained would be much lower than those obtained in a survey carried out in 2003.
Three sampling points (with 5 sub-sampling points each) have been designated in the forested parts of the island, one in the south between Szigetmonostor and the Megyeri bridge, one in the central part of the island south of Tahitótfalu and one south-east of Kisoroszi.
The samples were collected on an autumn day according to the ICP Vegetation recommendations. After sampling, the collected mosses were dried at 70 ^{o}C for 24h, followed by grinding and digesting using a microwave digester (Multiwave 3000, Antor Paar). Atomic absorption spectrometry (iCE 3000 C113500065 v1.30, Thermo Science) was used to determine the concentrations of the heavy metals analysed.
The hypothesis that the southern part of the island was the most polluted was not confirmed, since the highest values, except for cadmium, were measured near Kisoroszi, and the lowest values for cadmium, cobalt and nickel were measured in the southern part.
The results obtained were compared with those of a previous national survey. The measured concentrations of lead and copper decreased significantly, cadmium decreased only slightly, but nickel more than doubled compared to the previous values.
As there is no industrial activity on and near Szentendre Island to explain this increase in nickel concentrations, further investigations are needed to investigate the reasons for the high nickel concentrations on Szentendre Island compared to previous years, which would require the installation of instrumentation stations in the northern, central and southern parts of the island. The results obtained at these stations would need to be complemented by the moss biondication process carried out and the condition of the island would need to be mapped once a year to determine the source of pollution.

MODELLING WHEAT NUTRITION IN INDIA TO UNDERSTAND CLIMATE AND O3 IMPACTS

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Wheat is a staple crop in India, responsible for providing around 50% of dietary calories and protein. Climate change and ozone pollution threaten not only wheat yields but the quality of the crop as well. With rising temperatures and increasing precursor emissions, the threats to wheat from climate change and ozone pollution are expected to increase over the coming years. Integrating nutrition into crop models will allow for simulations of how different future scenarios could impact on crop quality. The present study will parameterize both the InfoCrop and DO3SE crop models for two Indian wheat cultivars to simulate ozone impacts on photosynthesis/ RUE and biomass, and their subsequent impacts on the amino acid content of the crop. Future work will use the existing parameterizations, along with future ozone and climate scenarios to simulate potential changes in crop quality across India.

ELEVATED OZONE DECREASED LEAF PHOTOSYNTHESIS OF WINTER WHEAT BY ACCELERATING LEAF SENESCENCE IN A WARMING WORLD

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Tropospheric ozone (O_3) pollution and warming have become the major climate change factors to affect the crop production. However, the effects of O_3 and warming on leaf photosynthetic traits of winter wheat have not been well-understood. Here, a field experiment of winter wheat was conducted using free air O_3 and temperature-controlled enrichment (O_3-T-FACE) during two growth seasons in Jiangsu province, which is the main wheat region of the Yangtze River Delta (Figure 1). This experiment consistent of two levels of O_3 concentration (ambient air: AA and elevated O_3: E-O_3) and two levels of canopy temperature (ambient temperature: AT, ambient +2 ^oC: ET). Across two-year results, elevated O_3 significantly decreased leaf photosynthesis by declines in stomatal conductance and photosynthetic biochemical capacity at the late stage of grain-filling, but had little effects on the duration of phenological stages. In contrast, warming shorted the length of pre-anthesis while no changed post-anthesis growth duration. At post-anthesis stages, warming significantly reduced stomatal conductance, but increased the maximum carboxylation capacity, which resulted slightly increases in leaf photosynthesis. On the other hand, there were significant interaction effects between elevated O_3 and temperature on leaf photosynthesis of wheat. Elevated O_3 accelerated leaf senescence at grain-filling stage, which caused declines of leaf chlorophyll content and photosynthetic capacity. Shorted post-anthesis growth duration and lower leaf photosynthesis under combination of elevated O_3 and temperature. Therefore, our results indicated that yield of wheat would be further reduced by O_3 pollution in a warming world.

Figure 1 Overlook of the free air O_3 and temperature-controlled enrichment (O_3-T-FACE)

WHO PAYS THE PRICE? THE ECONOMIC IMPLICATIONS OF WHEAT PRODUCTION LOSSES IN INDIA DUE TO OZONE.

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We assess the economic burden of ozone pollution on wheat producers, consumers, and the government taking into account the key policies that regulate the grain market in India. Applying an ozone flux-based dose-response relationship, we show that ambient levels of ozone caused a mean reduction of 14.18% in wheat yields during 2008-2012. Furthermore, irrigated wheat was more sensitive to ozone-induced yield losses, suggesting that ozone could undermine climate-change adaptation efforts through irrigation expansion. By applying an economic model, we assess the changes in wheat prices, producers and consumers' welfare, as well as government costs in comparison with a counterfactual, 'pollution-free' scenario. We investigate three policy scenarios in which the government supports farmers at observed levels of either procurement prices (fixed-price), procurement quantities (fixed-procurement), or procurement expenditure (fixed-expenditure). Without ozone pollution, wheat supply increases, which in the absence of any government intervention would cause wheat market prices to decline. The fixed-price scenario absorbs the fall in prices thus increasing producer welfare by USD 2.7 billion. However, as government costs increase (USD 2.9 billion), total welfare decreases by USD 0.24 billion. In the fixed-quantity and fixed-expenditure scenarios, ozone mitigation allows wheat prices to fall by 38.19-42.96%. Producers lose USD 5.10 to 6.01 billion, but the gains to consumers and governments (USD 8.7 to 10.2 billion) outweigh the losses.

These findings suggest that the cost of ozone pollution's impact on wheat loss is borne by the government and consumers. Results also highlight that: i). to maximize wheat production and social welfare through pollution mitigation, the current policy of fixed-price grain procurement need to be reviewed and alternative means of supporting producers must be found. ii) programs aiming to adapt agriculture to climate change should consider the potential trade-offs with air pollution impacts.

EFFECT OF OZONE ON THE NITROGEN DYNAMICS OF WHEAT

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Efforts to maximise global wheat yields are being compromised by ground-level ozone which persists at phytotoxic levels in wheat-growing areas in many parts of the world. Through applied, experimental plant physiology, this research investigated important inter-related questions regarding ozone's effect on wheat growth, grain yield and grain quality, as well as interactions with nitrogen during wheat's growth stages. In this context, it also explored wheat's ozone sensitivity and the potential for breeding more ozone tolerant lines.
Nitrogen fertilisation is critical for maintaining and improving wheat yields, but little is known about ozone's effect on nitrogen storage and translocation, aspects of the senescence process which are critical for grain yield. In lines of cv. Skyfall, increasing levels of ozone triggered increasingly early starts to visible senescence in all four leaf cohorts (4th, 3rd, 2nd, and flag) and even earlier reductions in leaf chlorophyll, particularly in the lower, older leaves. This has implications for whole canopy photosynthate production and therefore for both floret fertility and subsequent grain fill. These detailed chlorophyll data from all four leaf cohorts can contribute to future modelling of the effects of ozone on wheat. At anthesis there was no effect of ozone apparent on nitrogen storage in the upper plant parts. However, between anthesis and harvest ozone reduced Nitrogen Remobilisation Efficiency and increased levels of residual nitrogen found in 'source' plant parts at harvest, which in turn reduced C:N ratios. A comparison of data from three plant trials suggested that this increase in residual nitrogen in shoots at harvest occurs irrespective of the size of the grain 'sink'.
A 15N trace experiment, with nitrogen applied at mid-anthesis, revealed that ozone did not affect the uptake of post-anthesis nitrogen, although this late addition of nitrogen did ameliorate the effect of ozone on other parameters, highlighting the need to ensure rates of nitrogen fertilisation, and the timing of applications, are taken into account in ozone research and modelling.

ASSESSMENT OF O_3-INDUCED YIELD AND ECONOMIC LOSSES FOR CROPS IN SEVERAL AREAS OF RAJASTHAN FROM 2018 TO 2021, INDIA

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Ozone (O_3) in the troposphere is a major pollutant due to its adverse effects on agriculture, particularly in India. Crop yield loss brought on by surface O_3 has a significant influence on the Indian economy and the food supply for a billion people. In this study, we use hourly O_3 concentrations from 2018 to 2021 in Rajasthan, India, districts to calculate the yield and economic losses caused by O_3 exposure to major crops. The two primary crop-growing seasons in northern India are rabi (winter) and Kharif (summer monsoon). Rice, cotton, maize, sugarcane, soybeans, and other Kharif crops are grown in Rajasthan. Wheat, gram, barley, maize, and other rabi crops are grown in Rajasthan. Ozone data were obtained from Rajasthan State Pollution Control Board, and the data for crop production in six districts of Rajasthan was obtained from the Crop Production Statistics Information System (2018-2021); the economic cost loss was derived by multiplying the CPL by the matching minimum support price for a crop chosen by the Indian government for the 2018–21 season.

We have used the equations developed by Sinha et al., 2015 for rice and wheat, Singh et al., 2014 for maize, and Mills et al., 2007 for barley and cotton to calculate relative yield (RY). All prior ozone exposure dose–response relations in the literature were based on field research done in the United States or Europe. According to two O_3 exposure indices used in this study—the AOT40 and the 7-h seasonal daytime mean measured O_3 concentration (M7)—crop yield losses were estimated. According to our observations, using the AOT40 index, the relative yield loss for wheat ranges (40 to 60%), barley (2 to 3%), maize (12 to 13%), and cotton (30 to 32%). The most considerable agricultural output loss was in wheat, which lost 3.6 million tonnes in the fiscal year 2018–2019, 4.95 million tonnes in the fiscal year 2019–2020, and 1.8 million tonnes in the fiscal year 2020–21. Economic cost losses totalled INR 66.7 billion, INR 95.4 billion, and INR 36 billion in the fiscal years 2018–2019, 2019–2020, and 2020–2021, respectively. Our research identifies the necessity for long-term ozone monitoring near agricultural areas and creating an annual emission database to provide further assessments for policymaking in India.

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