ICP VEGETATION

38th Task Force Meeting

10th – 13th February 2025

Tirana, Albania

Programme & Abstracts

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University of Tirana
Faculty of Natural Sciences

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

Dr. Felicity Hayes
Dr. Katrina Sharps

Local organiser:

University of Tirana, Faculty of Natural Sciences

Dr. Pranvera Lazo

Local financial support is provided by

University of Tirana

Venue:

University of Tirana, Faculty of Natural Sciences, Tirana, Albania
(https://unitir.edu.al/eng/)
(https://unitir.edu.al/eng/fakulteti-i-shkencave-te-natyres/).

Monday 10th February, 2025

17:30 – 18:30 **Early Registration.** Faculty of Natural Sciences. Participants who attend the early registration can walk together to the welcome dinner

19:30 Welcome dinner at 19.30 in Mondial Hotel [about 2 km from the Faculty of Natural Sciences or 1.7 km from Tirana Centre (Skanderbeg Square). It is a public bus from Tirana Centre to Mondial Hotel.]

Tuesday 11th February, 2025

09:00 **Registration and putting up posters**

Session 1: 9:00 – 10:30 Plenary **Chair: Flora Qarri**

09:30 Opening of meeting

09:35 Welcome address:

Professor Dr. Anila Paparisto, Vice Rector, University of Tirana

Professor Dr. Eglantina Kalluci, Dean of the Faculty of Natural Sciences, University of Tirana.

09:45 *Pranvera Lazo* – An overview of the scientific contributions from the University of Tirana.

10:00 *Felicity Hayes* – An overview of the ICP Vegetation's work.

10:30 – 11:00 Coffee/tea and viewing posters

Session 2: 11:00 – 12:30 Plenary **Chair: Nensi Lsak**

11:00 *Felicity Hayes* – Current policy developments and other activities of UNECE.

11:15 *Marina Frontasyeva* – Collaborations with ESCAP.

11:30 *Oleg Travnikov* – Perspectives from MSC-E on moss measurements for model evaluation and complex analysis of heavy metal pollution.

11:50 *Marta Segura Roux* - Metal concentration in moss in comparison to deposition measured at EMEP background stations, in Sweden.

12:10 *Stefan Wallek* - Filling gaps in data time series with machine learning.

12:25 General discussion

12:30 – 14:00 Lunch

Session 3: **14:00 – 15:30 (Two parallel sessions: Ozone and Moss survey)**

Session 3a: **Ozone** **Chair: Giacomo Gerosa**

14:00 *Lisa Emberson* – Latest developments and applications of the DO_3SE model.

14:20 *Ignacio González Fernández et al.* – Phytotoxic ozone dose risk assessment for national air pollution effects monitoring network in Spain in the framework of the EU national emission ceilings Directive.

14:40 *Andrea Vannini* - Progress in understanding the protective effect of wood distillate against ozone phytotoxicity in ozone-sensitive plants.

15:00 *Ripley Tisdale* – Ozone impacts on soybean production, agroecosystems— and a solution, a newly developed climate-smart soybean.

15:20 *General Discussion*

Session 3b: **Moss survey** **Chair: Julian Aherne**

14:00 *Sébastien Leblond* – lead isotopes in urban mosses help identifying sources of atmospheric metal contamination.

14:20 *Isabel Garcia Arevalo* – Integrating Moss Biomonitoring and GLEMOS Modelling to Investigate the Spatial Distribution and Source Attribution of Polycyclic Aromatic Hydrocarbons (PAHs) in Europe.

14:40 *Zaida Ehrenmann* – Moss monitoring in Switzerland. Pilot analyses on PFAS.

15:00 *Aničić Urošević M.* – Should different moss species be included in a single survey?

15:20 *General Discussion*

15:30 – 16:00 Coffee and view posters

Session 4: **16:00 – 17:00 (Two parallel sessions: Ozone and Moss survey)**

Session 4a: **Ozone** **Chair: Anna Jones**

16:00 *Yasutomo Hoshika* – FO3X: Challenges of ozone FACE Experiments in the Mediterranean Europe.

16:20 *Giacomo Gerosa* – Performance of process-based and empirical models in predicting stomatal conductance (and ozone dose): a preliminary comparative analysis on a mature forest stand.

16:40 *John Jones* – Ozone impacts on carbon sequestration in mangroves.

Session 4b: **Moss survey** **Chair**: **Sébastien Leblond**

16:00 *Stefan Fränzel* - Lichens, chitin, nitrogen effects, chitin-modified HM electrochemistry and sensor development.

16:20 *Riccardo Fedeli* – Assessing the potential of x-ray fluorescence in biomonitoring surveys.

16:40 *Konstantin Vergel* – Accumulation of elements in mosses: passive versus active biomonitoring.

17:00 - 18:30 Walking Tour through city centre

Wednesday 12th February, 2025

Session 5: 09:00 – 10:30 Plenary **Chair Zaida Ehrenmann**

09:00 *Mehriban Jafarova* – Microplastic Atmospheric Deposition Assessment using Moss in Europe: MADAME.

09:20 *Stefano Loppi* – Biomonitoring with moss and lichen: issues for consideration.

09:40 *Julian Aherne* - In search of an optimal moss transplant biomonitor for airborne microplastics

10:00 *Lisa Grifoni* - Comparative study on the use of lichen and moss transplants as bioindicators of atmospheric microfiber deposition.

10:20 *Sonila Kane Shehu* – Active moss biomonitoring in Tirana city, Albania during summer and winter of 2023.

10:30 – 11:00 Coffee/tea and poster viewing

Session 6: 11:00 – 12:30 (Two parallel sessions: Ozone and Moss survey)

Session 6a: Ozone **Chair: Yasutomo Hoshika**

11:00 *Katrina Sharps* – Reductions in methane emissions could reduce the ozone yield penalty for crops.

11:20 *Pierluigi Guaita* – Global flux-based analysis of changes to O3 risk for wheat during the 21st century under different climate and emission scenarios.

11.40 *Sara Campos-Saelices* - A plant-insect-atmosphere interaction case study: differential herbivory between cyanogenic and non-cyanogenic white clover under increasing ozone levels.

12.00 Ozone discussion session – workplan, cooperations and priorities.

Session 6b: Moss survey **Chair: Musaj Paçarizi**

11:00 *Jana Borovská* – The moss survey 2020-23 in Slovakia.

11:20 *Marina Frontasyeva* – Atmospheric deposition of radionuclides: assessment based on passive moss biomonitoring.

11:40 *Omari Chaligava* – Tracking environmental changes in Moscow region with mosses: from pre-pandemic to post-restriction periods.

12:00 Moss discussion session – including workplan and potential cooperations with MSC-East.

12:30 – 14.00 Lunch

Session 7: 14:00 – 15:30 (Two parallel sessions: Ozone and Moss survey)

Session 7a: Ozone **Chair: Ignacio González-Fernández**

14:00 *Anna Jones* – Hyperspectral detection of ozone damage in broadleaf trees.

14:20 *Felicity Hayes* – Ozone impacts on crops.

14.40 Ozone discussion session – including planning for a position paper on assessing impacts of ambient ozone on vegetation.

Session 7b: Moss survey **Chair: Stefano Loppi**

14:00 *Musaj Paçarizi* – Biomonitoring of atmospheric deposition of potentially toxic elements in Kosovo in 2020.

14:20 *Inga Zinicovscaia* – Active moss biomonitoring in areas affected by ashfalls of Shiveluch volcano (Kamchatka).

14:40 *Pranvera Lazo* – Moss biomonitoring an important tool for air quality assessment – a national study in Albania.

15:00 Moss discussion session – including workplan and potential cooperations with MSC-East.

15:30 – 16:00 Coffee and take down posters

Session 8: 16:00 – 17:00 Final plenary session **Chair: Felicity Hayes**

16:00 *Ignacio González-Fernández* - Report back of main ozone decisions / discussions.

16:10 *Caroline* Meyer - Report back of main moss decisions/discussions.

16:20 Final discussions: workplan, decisions, AOB.

19:30 **Conference Dinner** at 19.30 in Mondial Hotel [about 2 km from the Faculty of Natural Sciences or 1.7 km from Tirana Centre (Skanderbeg Square). It is a public bus from Tirana Centre to Mondial Hotel.]

Thursday 13th February, 2025

Excursion Berat

Abstracts
Plenary

ICP VEGETATION OVERVIEW

Hayes, F., Sharps, K.
and the participants of the ICP Vegetation

ICP Vegetation Programme Coordination Centre, UK Centre for Ecology and Hydrology, Bangor, Gwynedd LL57 2UW, UK

The ICP Vegetation was established in 1987 and reports to Working Group on Effects of the Long-range Transboundary Air Pollution Convention. The programme conducts research and monitors impacts of air pollution on vegetation, which is used to inform international policy on emissions reduction. Current major topics include:
Ozone impacts (global), in current and future scenarios
Nitrogen (impacts on vegetation and deposition to mosses)
Metal deposition (mosses as biomonitors) in Europe and beyond.

Recent work includes an assessment of how global efforts to address methane emissions could reduce ozone-induced yield losses of crops (see abstract by Katrina Sharps.

For the moss survey analysis has been completed for the 2020/21 survey. For many heavy metals the lowest concentrations were generally found in the north and west of Europe and higher concentrations in the south-east of the region. For some metals the influence of point sources within the region could be identified (e.g. antimony and cadmium), whereas others had either more dispersed sources within the region (e.g. lead), or more homogenous distribution (e.g. zinc) suggesting long-range transboundary sources from outside of the region.

Many (but not all) of the measured heavy metals have shown a decline in concentration within the moss tissue since 1990. In some cases, such as lead, this has mirrored the decline in emissions within the EU27 countries, however, in many cases the decline in concentration in moss tissue has been more modest (e.g. chromium and nickel). The reductions in metal concentration in moss tissue between 1990 and 2020 (based on all countries that participated in four or more surveys since 1990) were 82.6% for lead, 62.7% for cadmium, 50.9% for vanadium, 29.4% for copper, 28.9% for nickel, 17.7% for zinc, 14.8% for chromium, 2.9% for iron.

For arsenic and mercury there has been very little change. For arsenic there was a decline of 11.6% since 1995. For mercury the concentration in moss increased by 4.8%.

Aluminium and antimony concentrations in moss tissue have only been measured since 2005 and have shown a reduction of 73.6% and 36.4% respectively between 2005 and 2020.

A small increase in nitrogen concentration in moss tissue of 3.1% was observed over the period 2005-2020. Highest concentrations of nitrogen in moss tissue were generally found in central Europe.

For further details, see our website http://icpvegetation.ceh.ac.uk

Acknowledgement
We thank the UK Department for Environment, Food and Rural Affairs (Defra, project AQ0846) for funding the ICP Vegetation Programme Coordination Centre. Further financial support was provided by the UNECE.

PERSPECTIVES ON MOSS MEASUREMENTS FOR MODEL EVALUATION AND COMPLEX ANALYSIS OF HEAVY METAL POLLUTION

Oleg Travnikov

Meteorological Synthesizing Centre - East of EMEP (EMEP/MSC-E), Jožef Stefan Institute, Slovenia, oleg.travnikov@ijs.si

Chemical transport modelling is widely used to assess airborne pollution by various toxic contaminants, including heavy metals and persistent organic pollutants (POPs). In particular, it is an integral part of a complex approach, alongside anthropogenic emission estimates and background air monitoring, used to support policy decision-making under the Convention on Long-range Transboundary Air Pollution (Air Convention). Given significant uncertainties associated with the modelling process and limited availability of the air monitoring data, integrating biomonitoring data, such as moss measurements, into model evaluation allows improving the modelling results and enhancing the pollution analysis. Long-term collaboration between ICP-Vegetation and the Meteorological Synthesizing Centre – East (MSC-E) has demonstrated the successful application of moss measurements and atmospheric modelling for for complex analysis of temporal trends and spatial patterns of heavy metal pollution. The wide coverage and high density of moss data are particularly valuable for fine-resolution studies at the national scale. Additionally, biomonitoring data is indispensable for regions with limited traditional air monitoring, such as Eastern Europe, the Caucasus, Central Asia (EECCA), and the Western Balkans. Moss and lichen measurements are therefore a crucial component of a new MSC-E pilot study focused on assessing heavy metal and POP pollution in the Western Balkan countries. The study aims to incorporate country-specific emissions and monitoring data alongside high-resolution simulations, with an emphasis on spatial variations and pollution source attribution in the region.

METAL CONCENTRATION IN MOSS IN COMPARISON TO DEPOSITION MEASURED AT EMEP BACKGROUND STATIONS, IN SWEDEN

Marta Segura Roux and **Michelle Nerentorp**

IVL Swedish Environmental Research Institute, Aschebergsgatan 44, 411 33 Gothenburg, Sweden, (marta.seguraroux@ivl.se)

Metals (As, Cd, Co, Cr, Cu, Hg, Ni, Mn, Pb, V and Zn) in air particles PM10 and precipitation are measured at four background stations in Sweden (Hallahus, Råö, Norunda and Bredkälen) and at one background station in northern Finland (Pallas). The stations are part of the EMEP (European Monitoring and Evaluation Programme) network and the aim of the measurements is for evaluating long-range Transmission of Air Pollutants in Europe.

In the EMEP stations, heavy metals precipitation sampling (excl. Hg) is collected monthly with three bulk samplers. Total mercury in precipitation is measured with a single-sample bulk sampler on a 14-day basis. Precipitation measurements are made with the same frequency at all stations. Heavy metals are also measured with filter samplers (PM10) monthly with 50%-time coverage. The results can provide actual measurement information on monthly, seasonal and annual basis.

Results of the moss surveys are important for evaluation of long-term trends of heavy metals and it has been carried out in Sweden since 1975. Over the past 45 years, between 1975 and 2020, the metal concentrations in moss for Sweden decreased most for lead (-112%Pb), followed by chromium (-98%Cr), vanadium (-96%V), nickel (-88%Ni), cadmium (-77%Cd), arsenic (-63 %As), copper (-52%Cu) and zinc (-44%Zn). The analysis also showed significantly decreasing levels of all metals in all regional areas of Sweden. For example, the addition of lead in petrol was banned in the mid-1990s, with is one explanation for the reduction being so large. Arsenic content in moss has decreased in line with the European emission reduction until 2010. The reduction of cadmium occurred since 1975 is mainly due to better purification equipment at metal smelters and steelworks, but also to the fact that in Sweden in the mid-1990s a tax on cadmium was introduced. However, this tax was abolished in 2010. The reduction of cadmium in certain fertilizers may also have contributed.

For arsenic, lead, copper and chromium, the reduction of levels in moss has been in good agreement with the emission reductions presented for Sweden and for the EU27 + UK from 1990. The levels of cadmium, zinc and mercury in moss, on the other hand, decreased in percentage less compared to the emission reductions.

A general in Sweden a south-north gradient could be seen for most of the analyzed metals in moss, with the highest concentrations in southern and southwestern Sweden and the lowest in northern Sweden and the mountain areas. The same pattern has been observed in the background stations in air particle PM10 and deposition. The metal concentrations in the air have generally been lowest at the more northern stations Bredkälen and Pallas. The highest annual average values of metals in air have been measured at Råö, Norunda, Hallahus.

Temporal and geographic patterns in metal concentration will be presented both in moss and background deposition at EMEP stations.

Bibliography:

Danielsson, H., Nerentorp, M., Pihl Karlsson, G. (2021). Metaller och kväve i mossa, 2020: Nationell undersökning i bakgrundsmiljö. IVL Rapport C614. IVL Svenska Miljöinstitutet.

FILLING GAPS IN DATA TIME SERIES WITH MACHINE LEARNING

Stefan Wallek

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In accordance with the introductory remarks in Chapter 12 of the scientific background document B (June 2020 version), the utilisation of the DO_3SE model or flux models necessitates a comprehensive dataset comprising hourly meteorological and ozone inputs. Addressing gaps in data time series poses challenges, particularly when extended interruptions due to malfunctions or maintenance result in substantial temporal voids spanning several hours or days. Linear interpolation applied to values from the day before and after such gaps may yield inappropriate results. Leveraging data from a reference station can be beneficial, assuming one is available. However, caution is imperative, particularly in mountainous and coastal regions where the topology can significantly influence measured values. The relationship between the reference monitoring station and the study site must be well-understood and subject to changes itself. In the absence of suitable reference monitoring stations, alternative methods for extensive gap-filling are viable, either based on analyses of the time series at the study site or utilising other data sources.

For ozone and air temperature, collective models were developed for each parameter using extreme gradient boosting, incorporating hourly measurements spanning 2009—2021. During this period, ozone was measured at 89 stations, and air temperature data was available for 77 stations. To enhance model independence from external data sources, only metadata of the stations (latitude, longitude, altitude) and time variables (daylight, year, month, week, day of the year, hour) were employed as predictor variables. The datasets were randomly partitioned into training (70%) and test (30%) sets to assess model performance. For ozone, the R^2 is 0.92, with a mean absolute error of 4.12 ppb and a root mean square error of 5.97 ppb, against a standard deviation of 14.62 ppb. For air temperature, the R^2 is 0.98, with a mean absolute error of 1.15 K and a root mean square error of 1.72 K, against a standard deviation of 8.14 K. Slight variations in these values occur when considering only data during daylight hours between April and June.

The study underscores the substantial potential of machine learning methods in filling gaps within data time series, offering an easily applicable solution. The exclusive reliance on metadata and time variables ensures that relatively few resources are required for model creation, making this approach highly accessible and cost-effective. By incorporating geographical longitude, latitude, and altitude information, spatial patterns and variations can be partially captured.

MICROPLASTIC ATMOSPHERIC DEPOSITION ASSESSMENT USING MOSS IN EUROPE: MADAME

Mehriban Jafarova[1,2], Stefano Loppi[2], Julian Aherne[1], and participants of the ICP Vegetation

[1] Trent University, Canada; [2] University of Siena, Italy

It is now well established that mosses and lichens, which are well known for their ability to accumulate airborne pollutants such as potentially toxic elements, can be effectively used for assessing the atmospheric deposition of microplastics.

Under the MADAME (Microplastic Atmospheric Deposition Assessment using Moss in Europe) pilot project, during 2022 moss samples were gathered voluntarily from ca. 100 sites spanning 33 European countries, using a standardised collection protocol. All samples were subsequently sent to Trent University for microplastics analysis. The primary objectives of this study are to assess the abundance and characteristic (shape, size, colour, and polymer type) of MPs throughout Europe, and to evaluate the drivers of atmospheric MP contamination. Here we present, for the first time, the results for all countries.

BIOMONITORING WITH MOSS AND LICHEN: ISSUES FOR CONSIDERATION

Stefano Loppi

University of Siena, Italy

Although biomonitoring with moss and lichen has been widely used for a long time, there are still unclear aspects that deserve careful consideration. The first concerns the object of biomonitoring: what do we measure, concentrations or deposition? This makes a big difference when biomonitoring surveys are correlated with epidemiological studies. There is evidence that our estimates refer to atmospheric deposition, so the way we express the data is of paramount importance. A more realistic estimate can be obtained by expressing the data not by weight but by surface area, which also allows deposition rates to be estimated. The level of variability and uncertainty is rarely considered in biomonitoring studies: even in remote areas, where perturbations are stochastic, there is a great deal of variability that often prevents accurate estimates and predictions, particularly in dry areas (e.g. the Mediterranean) due to dust and particle deposition. In the case of microplastics, since they are fully xenobiotic, the situation is different than for chemical elements: this is important in the use of blanks and in the definition of LOD values, as well as in the interpretation of the data, particularly when using active biomonitoring by transplantation, e.g. moss or lichen bags.

IN SEARCH OF AN OPTIMAL MOSS TRANSPLANT BIOMONITOR FOR AIRBORNE MICROPLASTICS

Mehriban Jafarova and Julian Aherne

Active biomonitoring with moss transplants or bags (i.e., a mesh screen that encases a moss sample) has been widely used to assess atmospheric pollution. Several studies have systematically evaluated the effects of sampler shape and screen mesh size on the uptake of trace elements by moss transplants, but this has not been investigated for microplastics. The objective of this study was to evaluate the influence of sampler shape and size, mass of moss within the sampler, and screen mesh size on the accumulation of atmospheric microplastics. Specifically, we evaluated three different samplers, two bag samplers (5 cm × 8 cm) each containing 1 g of moss, but with different mesh sizes (1 mm versus 6 mm), and a 6 cm cube containing 3 g of moss with a 6 mm mesh size. The three sampler designs (containing *Pleurozium schreberi* (Brid.) Mitt. (red-stemmed feathermoss) obtained from a rural background site) were deployed in triplicate within two urbans areas in southern Ontario, Canada. We predicted that the cubes would be the optimal sampler for atmospheric microplastics given their larger surface area (~3×bag), greater mass of moss (3 g), and larger mesh size (6 mm).

COMPARATIVE STUDY ON THE USE OF LICHEN AND MOSS TRANSPLANTS AS BIOINDICATORS OF ATMOSPHERIC MICROFIBER DEPOSITION

Lisa Grifoni[1], Mehriban Jafarova[2], Julian Aherne[2], Stefano Loppi[1]
[1]University of Siena, Italy; [2]Trent University, Canada

There is growing interest in the use of moss and lichen to monitor airborne microplastics, yet few studies have compared the effectiveness of each biomonitor. In this study we have assessed the ability of moss (*Pseudoscleropodium purum*) and lichen (*Evernia prunastri*) transplants collected from a remote area to accumulate microfibers (MFs) under the same deployment conditions, across a range of urban exposure sites in the city of Siena, Italy. The results showed that both biomonitors accumulated similar amounts of MFs, both in terms of counts and on a mass basis, but when the data were expressed on a surface area basis, lichens showed significantly higher values. Irrespective of the metric used, moss and lichen data were strongly correlated.

ACTIVE MOSS BIOMONITORING IN TIRANA CITY, ALBANIA DURING SUMMER AND WINTER OF 2023

Sonila Shehu (Kane)[1*], Biljana Balabanova[2], Pranvera Lazo[1], Alketa Lame[1]

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[2] Goce Delcev University, Faculty of Agriculture, Stip, North Macedonia
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Transplants of *Hypnum cupressiforme* moss species, packed as "moss bags", were used for investigation of airborne potentially toxic element pollution in urban areas of Tirana, capital city of Albania. The moss bags were exposed at seven sites in two different seasons, summer and winter, of 2023 with respect of different land use classes (typical urban, residential, urban background). The concentrations of seven major elements (Ca, K, Al, Fe, Mg, Na, and Mn) and twelve potentially toxic elements (As, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Tl, V, and Zn) were determined in moss bag samples by inductively coupled plasma mass spectrometry (ICP-MS) performed at Goce Delcev University, Faculty of Agriculture, Stip, North Macedonia. A comparison between summer and winter elements and the order of elemental concentrations were performed. This is the first active biomonitoring study of major and potentially toxic elements performed in two different seasons in Tirana city.

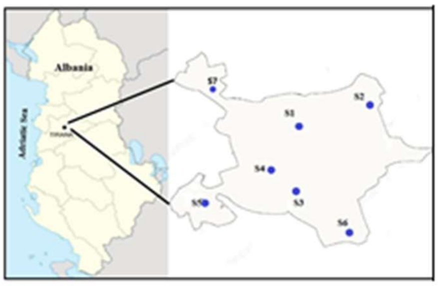

Fig. 1 The sketch map of monitoring sites

The concentrations of Sb, Mn, and Ni in moss bags exposed on summer, as well as the concentration of Sb in moss bags exposed on winter showed high variation among sites (CV % > 75 %), indicating the data are affected by several factors. The rest of elements were more stable and revealed low to moderate variation between sites. The sequences of major elements in two seasons were Ca > Ca_1 > K > K_1 > Al > Al_1 > Fe > Fe_1 > Mg > Mg_1 > Na > Na_1 > Mn > Mn_1. These are typical elements of soil dust particles. In general, they showed higher contents in moss bags exposed for two months on summer (signed as Me for May – June elements) than in bags exposed for two months on winter ((signed as Me_1 for December – January elements). Albania is a south-eastern Mediterranean country, which is highly affected by Saharian dust storm (1- Copernicus 2024 data) with higher intensity in summer (March-June) than in winter (December – January) (2- Querol et al. 2019). Trace elements Ni, Cr, Pb, Co, V, As, and Mo showed the same sequence order as major element (Ni > Ni_1 > Cr > Cr_1 > Pb > Pb_1 > Co > Co_1 > V > V_1 > As > As_1 > Mo > Mo_1) by indicating dual effects of local and Saharian dust origin. The rest of elements showed higher content in winter samples than in summer samples (Cd_1 > Cd > Sb_1 > Sb > Tl_1 > Tl) by indicating higher local emission sources. High relative accumulation factors (RAF) were found for elements Cr, Cu, Fe, Ni, Sb, V, and Zn in moss bags indicating these elements are the most abundant in most sampling sites. High average values of contamination factors (CF) in summer season (CF > 2) were found for the same elements (Cr, Cu, Fe, Ni, Sb, V, and Zn), indicating the exposure sites showed slight to moderate contamination status (C2 to C3 scales). Low RAF and CF values were found for elements linked with soil dust emission (Al, Fe, Mg, Na, K, and Mn) indicating a slight pollution in most sampling sites. Similar results were reported by Aničić et al. 2022 for 2021 winter exposed moss bags.

Keywords: Air pollution; Active moss biomonitoring; *Hypnum cupressiforme*; ICP-MS; Tirana, Albania

References:

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2- X. Querol, A. Tobías, N. Pérez, A. Karanasiou, F. Amato, M. Stafoggia, C. Pérez García-Pando, P. Ginoux, F. Forastiere, S. Gumy, P. Mudu, A. Alastuey (2019) Monitoring the impact of desert dust outbreaks for air quality for health studies. Environment International. 130. 104867. https://doi.org/10.1016/j.envint.2019.05.061

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Abstracts
Ozone

LATEST DEVELOPMENTS AND APPLICATIONS OF THE DO_3SE MODEL

Lisa Emberson

PHYTOTOXIC OZONE DOSE RISK ASSESSMENT FOR AIR POLLUTION EFFECTS MONITORING IN SPAIN IN THE FRAMEWORK OF THE EU NATIONAL EMISSION CEILINGS DIRECTIVE

González-Fernández, I.[1], Campos-Saelices, S., Carrasco-Molina, T.[1], Martín, F.[2], Vivanco, M.G.[2], de la Maza, E.[1], Alonso, R.[1], García-Gómez, H.[1], Rábago, I.[1]

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Article 9 of the EU Directive on the reduction of national emissions of certain atmospheric pollutants (Directive 2016/2284) establishes the requirement for Member States of monitoring the negative effects of air pollution on ecosystems, coordinately with other EU and Air Convention monitoring programmes, and suggests a list of optional indicators including leaf visible injury, vegetation growth or exceedance of flux-based ozone critical levels.

In the last reporting period (year 2023), some countries including Spain, reported exceedances of flux-based ozone critical levels. However, no common methodologies were agreed for calculating ozone fluxes, making comparisons among countries difficult. Harmonization of methods, or intercomparison exercises, of ozone flux estimates would be advisable for facilitating Europe wide data analysis. In this context, we present the methodology followed by Spain for calculating exceedances of ozone dose critical levels and the results for the period 2018-2021.

Funding provided by DGPC-CIEMAT working programme on atmospheric pollution and persistent organic pollutants (ACTUA-MITERD, Spanish Ministry of Ecological Transition); project TRANSAIRE: Transición hacia un aire más limpio en España (TED2021-132431B-I00) funded by MCIN/AEI/10.13039/501100011033 and NextGenerationEU/PRTR; and MITERD-SEMA-OAPN-CIEMAT working programme on air pollution monitoring and effects at the Spanish Network of National Parks (RECAEPN, Organismo Autónomo Parques Nacionales, Spanish Ministry of Ecological Transition) – funded by NextGenerationEU/PRTR.

PROGRESS IN UNDERSTANDING THE PROTECTIVE EFFECT OF WOOD DISTILLATE AGAINST OZONE PHYTOTOXICITY IN OZONE-SENSITIVE PLANTS

Andrea Vannini[1], Nicolò Tonini[1], Andrea Viviano[2,3], Barbara Moura[2], Elena Marra[2], Jacopo Manzini[2,3], Lorenzo Cotrozzi[4], Claudia Pisuttu[4], Gemma Bianchi[4], Cristina Nali[4], Alessandro Petraglia[1], Elena Paoletti[2], Yasutomo Hoshika[2]

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Wood distillate (WD), a by-product of plant biomass pyrolysis, has gained prominence as a cost-effective and environmentally friendly strategy to mitigate ozone (O_3)-induced phytotoxicity. Its protective effect in plants is mainly based on two mechanisms: (i) direct supplementation of antioxidants in leaf tissues, and (ii) stimulation of the plant's endogenous antioxidant response (Vannini et al., 2022; Bianchi et al., 2024). In a recent study, Vannini and Petraglia (2024) showed that the application of an Italian WD formulation to the O_3-sensitive tobacco cultivar *Nicotiana tabacum* L. cv. BelW3 reduced leaf senescence and increased photosynthetic performance. However, only one WD product was tested, leaving open the question of whether other distillate formulations might provide different levels of protection. In addition, seed yield - a critical factor for many economically important crops, including legumes - remains largely unexplored in existing research, so the wider agricultural relevance of WD has not been fully explored.

To fill these gaps, we investigated two commercially available WDs (WD1 and WD2) in Italy and evaluated their protective effects on two O_3-sensitive species: *N. tabacum* (cv. BelW3) and *Phaseolus vulgaris* (cv. S156). The former served as a model to assess senescence and photosynthetic responses, while the latter provided insights into effects on seed production.

The experiments were carried out in the summer of 2024. Tobacco plants (cv. BelW3), both treated (with WD1 and WD2 as 0.2% spray applications) and untreated, and the O_3-tolerant cultivar BelB were grown in pots under natural conditions in Parma (Emilia-Romagna, Italy). After four weeks of growth (May-June), weekly sprays of WD1 and WD2 were applied for nine weeks (June-August). During this period, visible leaf injury (Plant Injury Index, PII), chlorophyll content, and chlorophyll fluorescence parameters (F_V/F_M, PI_{abs}, PI_{TOT}) were measured after one, two, three, six, and nine weeks.

In parallel, *P. vulgaris* (cv. S156) plants were grown in Florence (Tuscany, Italy) in a free-air controlled exposure (FACE) facility. Plants, both treated and untreated with WD1, were exposed to ambient (AA), 1.5× ambient (AA×1.5) or 2.0× ambient (AA×2.0) O_3 concentrations for four weeks (May-June). Due to space limitations, only WD1 was applied by weekly spraying. During the experiment, PII, light-saturated net photosynthetic rate (Asat), and stomatal conductance (Gs) were monitored after two, three, and four weeks. Seed number and weight were also assessed.

Our results show that WD application significantly alleviated O_3-induced damage in both species. In *N. tabacum*, WD1 and WD2 reduced visible leaf injury and restored photosynthetic efficiency to levels comparable to BelB plants, as evidenced by photosynthetic improvements. In *P. vulgaris*, WD1 reduced leaf injury, improved Asat, and significantly increased seed weight under elevated O_3 concentrations. Overall, WD treatments not only protect plants from O_3 stress but also support crop productivity.

In conclusion, these results highlight the potential of WDs as an effective, sustainable solution to mitigate O_3 damage in sensitive crops.

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OZONE IMPACTS ON SOYBEAN PRODUCTION, AGROECOSYSTEMS— AND A SOLUTION, A NEWLY DEVELOPED CLIMATE-SMART SOYBEAN

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Abstract

The impact of ozone (O_3) on intricate plant-microbe-soil interactions remains overlooked. To fill this knowledge gap, our research team employed an "omic" approach to investigate O_3 impacts on root metabolism and soil microbial communities from two soybean genotypes with contrasting sensitivity to elevated O_3: Fiskeby 840-7-3 (O_3-sensitive) and Fiskeby III (O_3-tolerant) in a field-based climate simulation system with elevated O_3 concentrations. The root proteomes showed that Fiskeby 840-7-3 increases metabolite biosynthesis, promoting interactions with soil microbes to cope with O_3 stress in the early growth stage, while promotes root growth by consuming energy in the pod-filling stage, leading to yield decreases by 50%. In contrast, Fiskeby III reduces energy consumption by decreasing carbon metabolism in the vegetative stage and metabolite biosynthesis in the pod-filling stage, resulting in less O_3 damage to yield, about 29%. Interestingly, the effect of elevated O_3 on below-ground soil microbiomes and soil health surpasses damage in above-ground plant. Elevated O_3 significantly disrupts below-ground bacteria-fungi interactions, including increasing fungal saprotroph proliferation to accelerate soil organic matter decomposition and soil carbon pool depletion. The abundance and diversity of arbuscular mycorrhizal fungi are decreased by elevated O_3, which affects plant performance. However, free-living diazotrophs exhibited remarkable acclimation under elevated O_3, improving plant performance by enhancing nitrogen fixation. The overall impact of long-term elevated O_3 poses a crisis for agroecosystems, leading to profound risk to food security. To combat future challenges of O_3 pollution and co-occurring climate crisis on crop productivity, our research team developed a strategic screening pipeline to identify climate-smart soybeans. The genetic characteristic of O_3 and other abiotic stress resilience in Fiskeby III was introgressed to a high-yield cultivar, Holladay. Throughout heat and O_3 stress screening, a progeny, N16-7526, showed tolerance to both heat and O_3— without reducing yield, whereas the Holladay parent reduced yield by 24% under both warming and elevated O_3 stress. Long-term climate crisis threatens agroecosystems and food sustainability. N16-7526 demonstrates an excellent adaptation to climate challenges, increasing agricultural productivity while preserving agroecosystems.

FO$_3$X: CHALLENGES OF OZONE FACE EXPERIMENTS IN THE MEDITERRANEAN EUROPE

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Tropospheric ozone (O_3) is an oxidative air pollutant with causing a significant negative effect on forest tree species. Free-air controlled exposure (FACE) facilities are considered an ideal tool that can provide realistic estimates of tree response to O_3 under real world conditions. Since 2015, a last generation of O_3 FACE facility has been available at the CNR experimental garden at Sesto Fiorentino in central Italy (FO$_3$X), which is a unique facility in Mediterranean Europe within an AnaEE (Analysis and Experimentation on Ecosystems) European research platform (see https://isia.cnrs.fr/catalog/1/installations/61). FO$_3$X consists of nine 5×5×2 m blocks (n = 3 replicated blocks) in which the concentrations of O_3 and other stress factors (e.g., drought, nitrogen, heavy metal, salt stress) can be controlled. This facility permits the exposure of plants to three levels of O_3 concentrations (ambient, 1.5- and 2.0-times ambient concentration, denoted as AA, 1.5×AA and 2.0×AA, respectively), with main environmental variables continuously monitored. During 10-year activities, many national and international collaborations have been achieved (hosted 44 visiting researchers from 13 countries such as Italy, Slovenia, France, Portugal, Romania, China, Thailand, Brazil, UK, USA, Japan, Switzerland, Croatia) with 22 joint scientific papers published in peer-reviewed ISI journals. This presentation will introduce our FACE facility with a future perspective.

PERFORMANCE OF PROCESS-BASED AND EMPIRICAL MODELS IN PREDICTING STOMATAL CONDUCTANCE (AND OZONE DOSE): A PRELIMINARY COMPARATIVE ANALYSIS ON A MATURE FOREST STAND

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Stomatal conductance is crucial for the determination of the phytotoxic ozone dose, and the consequent risk assessment. This parameter is predicted form standard meteorological measurements by means of i) empirical models for stomatal conductance like the Jarvis' one, or ii) semiempirical models -like the Ball-Berry's one- coupled with a biochemical model for photosynthesis, like the Farquhar's one.

A comparative analysis of the performance of these two methodologies in predicting the stomatal conductance was performed on the data gathered at Bosco Fontana (Italy), a mature oak-hornbeams forest in Northern Italy. The simulated conductances were compared with those obtained from eddy covariance measurements of water fluxes making use of the inversion of the Penman-Monteith equation, which assumes a simple big-leaf approach and the energy balance closure.

The Jarvis model was parameterized according to the Mapping Manual of ICP Vegetation (MM), eventually adjusting gmax to better fit with the observations.

The process-based model was set to the standard parameterization of the Farquhar's and Ball-Berry's schemes for photosynthesis and stomatal conductance in C3 plants. The photosynthesis and stomatal submodels were piped with two additional submodules, a CO2 diffusion one and a leaf energy balance submodule, all iterated until the convergence of Ci, An, Gstom and Tleaf was reached to equilibrium values.

Preliminary results show a satisfactory performance of both methodologies, with a slightly better behavior of the Jarvis' model. However, this better performance was reached by reducing to 1/3 the gmax value indicated in the MM for continental broadleaves (and to 1/5 that for mediterranean oaks) and by increasing Topt and VPDmin respectively by 1°C and 1.7 Kpa.

On the contrary, the process-based model did not require to scale gmax, and the best fit was reached by adopting the appropriate specie-specific g1 parameter for the Ball-Berry submodel and by slightly increasing the thermal breakdown parameter (ΔHd) for photosynthesis.

While Jarvis's parameterization of stomatal conductance can be tailor-made to fit perfectly site-specific measurements, process-based models appear to be more robust and can be considered for general application.

OZONE IMPACTS ON CARBON SEQUESTRATION IN MANGROVES

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GLOBAL EFFORTS TO ADDRESS METHANE EMISSIONS COULD REDUCE OZONE-INDUCED YIELD LOSSES OF CROPS

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This study has shown that there is a large potential to avoid wheat production losses through global efforts to reduce emissions of non-methane ozone precursors. In addition, global efforts to reduce methane concentrations could avoid additional wheat production losses due to the role of methane as an ozone precursor. Ex-post analysis on scenarios used within the EMEP-MSC-West model revealed that within the UNECE region (excluding North America and Israel) in 2050 using the LOW future emission scenario, the reduction in ozone as a consequence of reducing global non-methane precursor emissions showed avoided wheat production losses of 6.4 million tonnes compared to that with current legislation. For the EU27 countries this was 3.1 million tonnes of wheat, equating to a value of approximately €675 million. Reducing both non-methane and methane ozone precursors globally gave avoided wheat production losses in the UNECE region in 2050 totalling 9.0 million tonnes, compared to that calculated from emissions in current legislation. Within EU27 this was 4.4 million tonnes of wheat, equating to a value of approximately €976 million.

Within the UNECE region (excluding North America and Israel) the relative benefits of additional reductions in non-methane emissions within the region, non-methane emissions in the rest of the world, and global efforts to reduce methane emissions, were approximately equal. This demonstrates the benefits from reducing regional non-methane emissions, global non-methane emissions and global methane as contributing factors to avoid crop yield losses due to their role in ozone formation.

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GLOBAL FLUX-BASED ANALYSIS OF CHANGES TO O_3 RISK FOR WHEAT DURING THE 21ST CENTURY UNDER DIFFERENT CLIMATE AND EMISSION SCENARIOS

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Tropospheric ozone (O_3) poses significant threats to vegetation and ecosystems, particularly staple crops like wheat, accelerating leaf senescence, and lowering yields. This study evaluates the future risk of O_3 damage to bread wheat (Triticum aestivum) using CMIP6 Earth System Model simulations, and a dual-sink big-leaf dry deposition model. Incorporating three Shared Socioeconomic Pathways (SSPs), this assessment quantifies the phytotoxic ozone dose (POD) across the 21st century under varying climate and emission scenarios.

Results reveal that strong pollution control scenarios (SSP1-2.6) significantly reduce ozone exposure and associated yield losses worldwide. On the other hand, key hotspots under weak O_3 precursor emissions control scenarios (SSP3-7.0) include East Asia, the southern and eastern edges of the Tibetan Plateau, and Northern Europe. Intermediate O_3 precursor emission control pathways (SSP5-8.5) show mixed outcomes, with initial POD increases in the first half of the century, followed by reductions due to pollution control measures. Furthermore, under SSP3-7.0 and SSP5-8.5, South Asia and Sub-Saharan Africa emerge as potentially high-risk regions under conditions of adequate water supply.

Analysis of radiative forcing and emission policies contributions to O_3 risk indicates regional differences, with some changes in POD being driven more by climate variables and their interaction with O_3, rather than by O_3 concentrations alone. Therefore, this evaluation may inform policymakers on strategies to mitigate O_3 impacts on wheat and address future global food security threats.

A PLANT-INSECT-ATMOSPHERE INTERACTION CASE STUDY: DIFFERENTIAL HERBIVORY BETWEEN CYANOGENIC AND NON-CYANOGENIC WHITE CLOVER UNDER INCREASING OZONE LEVELS

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Tropospheric ozone (O_3) is a secondary air pollutant whose background levels have been increasing since the industrial revolution due to the emission of its precursors (NO_x, CH_4, NMVOC) from fossil fuel combustion. High O_3 levels pose a significant environmental challenge, particularly in the natural systems of the Northern hemisphere, with the Mediterranean basin being especially vulnerable. As a critical stressor in the context of global change, high O_3 levels are known to induce oxidative stress in O_3-sensitive species. This stress disrupts metabolism and physiological processes, ultimately impairing plant growth and reproduction. Plant-insect interactions are affected by global change factors such as climate change, yet the potential of other factors such as air pollution, particularly O_3, to alter these interactions remains poorly understood. White clover (*Trifolium repens*), an O_3-sensitive perennial legume, occurs in natural populations with varying proportions of cyanotypes (cyanogenic and non-cyanogenic plants). The cyanogenic cyanotype can produce hydrogen cyanide (HCN), a trait typically associated as a chemical defense against herbivores. However, it is unclear whether the two cyanotypes differ in their tolerance to ozone pollution or whether air quality can influence the balance between cyanotypes and the intensity of herbivory they experience.

The present study complements the work by Menéndez et al. (see Poster session), which examined the differential sensitivity to O_3 between cyanogenic and non-cyanogenic plants. In this study, we investigated whether O_3 differentially impacts plant-insect interactions based on the O_3-tolerance of the clover cyanotypes. White clover plants from both cyanotypes, cyanogenic and non-cyanogenic, were grown under four O_3 levels 3 times-replicated for 48 days: filtered air (FA, reproducing pre-industrial levels), non-filtered air (NFA, reproducing current ambient levels in central Iberian Peninsula), NFA supplemented with 20 ppb of ozone (NFA+20) and NFA supplemented with 40 ppb of ozone (NFA+40). The assay was carried out in the CIEMAT Open Top Chamber (OTC) facility (La Higueruela Research Farm MNCN/CSIC, Toledo, Spain). Ozone symptoms, leaf senescence (leaf pigment content) and herbivory symptoms were measured weekly during the O_3 exposure period.

In general, cyanogenic plants exhibited greater O_3-tolerance, as evidenced by the lower intensity of O_3 symptoms and a more stable foliar pigment response. After the first half of the experiment, herbivory symptoms were higher in cyanogenic plants and intensified under the highest O_3 levels (NFA+40). However, this pattern became less clear by the end of the exposure period, as O_3-induced senescence was widespread across both cyanotypes. The observed greater herbivory in cyanogenic plants was associated with their higher O_3 tolerance and better biomass condition (i.e., higher chlorophylls contents were linked to reduced herbivory, while higher anthocyanin contents were associated with increased herbivory). Our results demonstrate that hydrogen cyanide-based resistance to herbivores in white clover is influenced by ozone levels, highlighting its context-dependent nature. Future studies are needed to further explore the dynamics of plant-herbivore interactions in ozone-polluted environments.

HYPERSPECTRAL DETECTION OF OZONE DAMAGE IN BROADLEAF TREES

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At the near-surface, ozone (O3) is a toxic pollutant which has reached dangerously high concentrations across the world and is predicted to continue to rise. O3 reduces the growth, productivity and resilience of trees but the extent of O3 damage to forests is uncertain. To develop a high throughput method of monitoring O3 damage to forests, we have developed hyperspectral monitoring of O3 damage in broadleaf trees across a range of naturally occurring O3 concentrations, via controlled experiments and field studies. Using a machine learning approach, we demonstrate accurate prediction of O3 exposure of trees under natural conditions from hyperspectral leaf reflectance alone. This method could be used for forest level assessments of O3 damage. Vegetation indices characterising green reflectance and red-edge track O3 induced changes in leaf reflectance. Vegetation indices have the potential to scale up O3 damage monitoring across spatial scales. As O3 concentrations continue to rise globally, understanding the extent of O3 damage to forests is crucial to effectively harness the carbon sequestration potential of forests. We demonstrate the exciting potential of spectral monitoring of O3 damage in mature trees under natural conditions.

OZONE IMPACTS ON CROPS

Hayes, F., Sharps, K.

There is a need for additional dose-response functions for a wider range of crops to allow more effective assessment of ozone impacts. It is particularly important to consider potential impacts on tropical crops.

Crop loss functions derived using data from published ozone experiments have shown that many staple crops from around the globe are sensitive to ozone. Ozone-sensitive crops include the pulses soya, peanut, beans, cowpea and chickpea. Other ozone-sensitive staple crops include wheat, potato and sweet potato.

Overall, the most sensitive crop types were those based on beans and seeds, with leafy vegetables, tubers and fruit crops also showing high sensitivity. Tropical crops were overall slightly more sensitive to ozone than temperate crops.

Large knowledge gaps about ozone sensitivity remain for several important crops, particularly from topical regions, including banana/cooking banana, cassava, cashew and coconut.
Importantly, this study indicates that the understudied crops of tropical regions may be at least as sensitive to ozone as those generally better-studied crops of temperate regions.

Abstracts
Moss

LEAD ISOTOPES IN URBAN MOSSES HELP IDENTIFYING SOURCES OF ATMOSPHERIC METAL CONTAMINATION

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Heavy metals in the atmosphere come from a variety of human sources, from road traffic to current or past industrial legacies. Lead (Pb) is a (neuro)toxic metal that has adverse effects on human health, particularly when absorption rates are high. Although atmospheric contamination by Pb has fallen considerably since the gradual elimination of one of its main sources of emission, Pb can be retained in soil and dust for decades, with the possibility of it becoming airborne again. Taking the Paris region as an example, we used a moss species, *Grimmia pulvinata* (Hedw.) Sm., to characterise and identify the main sources of Pb. To do this, we coupled metal concentrations and Pb isotope ratios from samples taken from 77 cemeteries in the Ile-de-France region within a 50 km radius of the centre of Paris. Metal enrichment factors indicated a dominant anthropogenic origin. Principal component analysis showed that three main components explained 89% of the variations in metals: i) the European atmospheric background, ii) regional urban sources and iii) the resuspension of regional soils. This was corroborated by the Pb isotope ratios, whose variations were modelled by a ternary mixture taking into account the same 3 emission sources. Using a MixSIAR isotopic model, we show that the European atmospheric background contributes slightly and that bioindicators within 20 km of the city centre are mainly impacted by urban sources (contributions: 50-80%). Samples taken more than 20 km away are evenly split between urban and agricultural sources. The use of elemental isotopes, including Pb, makes it possible to better characterise the origin of contamination and more effectively guide public policies to reduce contaminants in the atmosphere.

INTEGRATING MOSS BIOMONITORING AND GLEMOS MODELLING TO INVESTIGATE THE SPATIAL DISTRIBUTION AND SOURCE ATTRIBUTION OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN EUROPE

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Air pollution poses significant risks to crops and (semi-)natural vegetation, with polycyclic aromatic hydrocarbons (PAHs) representing a critical group of pollutants due to their persistence and ecological impacts. This study explores the integration of moss biomonitoring data and the Global EMEP Multi-media Modelling System (GLEMOS) to validate model-based source attribution and improve our understanding of PAH distribution in Europe.

The investigation incorporates diverse datasets to provide a comprehensive analysis. It utilizes moss biomonitoring data from Norway, including measurements of PAH uptake, diagnostic ratios for identifying potential emission sources, and critical load exceedances for ecosystem-specific PAH deposition. These findings are contrasted with GLEMOS model outputs, which offer high-resolution spatial patterns of PAH air concentrations and deposition across Europe, along with insights into source attribution and transboundary pollution dynamics.

The analysis demonstrates spatial correlations between PAH concentrations in mosses and GLEMOS-simulated deposition, providing new insights into pollution patterns around industrial sites. Notably, air sampling near industrial areas revealed low PAH concentrations, often comparable to background levels, indicating that industry is not the sole source of observed PAH levels. This underscores the importance of incorporating multiple datasets for a comprehensive understanding of pollutant behaviour.

Our findings suggest that moss biomonitoring, when combined with GLEMOS model outputs, enhances the ability to characterize PAH spatial distribution and source contributions. The approach highlights the value of integrating biological and modelling techniques for validating pollutant source attributions and addressing transboundary pollution challenges.

This study provides a proof-of-concept for validating source attribution in air quality models and emphasizes the role of integrated approaches in supporting policy decisions to protect vegetation and ecosystems from the adverse effects of air pollutants.

MOSS MONITORING IN SWITERLAND
PILOT ANALYSES ON PFAS

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Switzerland has been participating in the moss monitoring program of the ICP vegetation since 1990, using consecutive sampling sites distributed over the entire country. Even though the survey started by analysing the moss samples for heavy metals only, other pollutants have become a focus of interest throughout the years.

Currently, PFAS (Per- and polyfluoroalkyl substances) – commonly known as forever-chemicals – have gained increasing public interest in Switzerland because they have recently been detected not only in groundwater but also in foods and in human blood. PFAS have globally also been found in precipitation samples in urban as well as in remote areas, leading to the assumption that PFAS are transported over a longer distance and reaching the environment also via atmospheric deposition. As mosses have shown to be good biomonitors for a large range of pollutants originating from atmospheric deposition, we were interested if PFAS could also be detected in moss samples.

For these preliminary analyses in Switzerland, six mixed samples from the 2015 study were used in order to have enough moss material for the analyses. Five samples consisted of already ground moss material where all sampling sites of each geographical region were group together. One sample consisted of dried sprouts from different sites across Switzerland. The samples were analysed for 16 different PFAS including two forms of FTOHs (see Table 1). None of the analysed PFAS nor any of the two FTOHs was detected in the samples. This finding is in accordance with earlier studies from Sweden, Norway and Germany. However, in more recent studies, PFAS have been found in mosses close to detection limit at some sites in Germany and in Canada, suggesting that mosses can at least to some extent take up PFAS. Therefore, more research is planned for the 2025 survey to investigate i) if mosses in general are suitable biomonitors for at least some PFAS and ii) if so, is there indeed no systematic atmospheric deposition of PFAS in Switzerland that can be detected by (mixed) moss samples or are some more polluted sampling sites "diluted" by the use of mixed samples.

Table 1 Summary of analysed PFAS and FTOHs including the limits of quantification (LOQ) or limit of detection (LOD)

Substance abbreviation	**LOQ / LOD**			**Substance abbreviation**	**LOQ / LOD**		
PFBA	LOQ	0.1	µg/kg	PFBS	LOQ	0.1	µg/kg
PFPeA	LOQ	0.1	µg/kg	PFHxS	LOQ	0.1	µg/kg
PFHxA	LOQ	0.1	µg/kg	PFOS	LOQ	0.1	µg/kg
PFHpA	LOQ	0.1	µg/kg	PFTeDA	LOQ	0.1	µg/kg
PFOA	LOQ	0.1	µg/kg	Et-FOSAA	LOQ	0.1	µg/kg
PFNA	LOQ	0.1	µg/kg	Me-FOSAA	LOQ	0.1	µg/kg
PFDA	LOQ	0.1	µg/kg	6:2 FTOH	LOD	5.0	µg/kg
PFUnDA	LOQ	0.1	µg/kg	10:2 FTOH	LOD	10	µg/kg

SHOULD DIFFERENT MOSS SPECIES BE INCLUDED IN A SINGLE SURVEY?

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Moss and lichen biomonitors are ubiquitous organisms in almost all ecosystems. However, the distribution of particular species is specific for different latitudes, altitudes, habitats, substrates, shade and water availability. The selection of the appropriate species is a crucial criterion for biomonitoring on a broad spatial scale. Still, no one species is universally spread across a wide area (e.g., a continent) to be uniformly collected within the sampling campaigns. Accordingly, in this study, mosses *Hypnum cupressiforme* and *Brachythecium* spp., were sampled at 22 remote sites over Serbia aiming for interspecies comparison of their bioaccumulative capacities in different concentration ranges to test the possibility of their interchangeable use within the same survey. In addition, lichen *Evernia prunastri* were collected in parallel to the mosses. The concentration of 16 potentially toxic elements (PTEs), Al, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, P, Pb, S, Sr, V, and Zn, was measured in all the samples. Between the collocated mosses, linear regression analysis (type II), showed significant determination coefficients only for a couple of the elements (Cd and S), while for *H. cupressiforme* vs. lichen, significant regression lines were obtained for a broader set of elements (Ba, Cd, Fe, Hg, Mn, Ni, Sr). The obtained slope of the regression line is close to 1.0 and the significant determination coefficient suggests possible interchangeable use of the species only for Ni in the moss-lichen pair. The ratio of the PTEs in the mosses discovered higher concentrations in *H. cupressiforme* than in another moss at some sites and vice versa at other sites. According to the PTE ratios, *H. cupressiforme* accumulated much more element content than the lichen but followed a similar spatial pattern. In addition, principal component analysis (PCA) pointed out a different grouping of the PTEs depending on the species tested. The poor correlation of the moss-moss data is perhaps because several species of the genus *Brachythecium* were sampled, which possibly influenced the average genus accumulation capacity. In addition, morphological features of the mosses (concave vs. flat leaflets, creeping vs. cushiony life form) presumably delegate differences in PTE accumulation. To conclude, it should be careful with using more biomonitor species, even of the same genus, within the same study.

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LICHENS, CHITIN, NITROGEN EFFECTS, CHITIN-MODIFIED HM ELECTROCHEMISTRY AND SENSOR DEVELOPMENT

Stefan Fränzel

Lichens are often used besides or instead of mosses in environmental monitoring. Lichens, like arthropods, are covered by chitin which even can be dissolved without destroying the algal cells. This author previously showed that *grafted* chitin (on glass or plastics) can be used for environmental monitoring purposes representing samples of both (moist) sediments and water. Conditions of M adsorption can be (and were) optimized for achieving high reproducibility while spiking experiments revealed that some 70% of added metal ions are actually retrieved; 10 min exposition will do while effects of added ligands on metal (several REEs, Mn, Ni) adsorption apparently depend on the ligand/metal ratio (usually >> 1 for the said metals in freshwater). REEs, Bi, V, and Cu were found to adsorb particularly strongly to chitin, being retained already at pMol/l levels. However, there are indications for both diffusion of sorbates into the bulk chitin layer (pertinent to long-term expositions in the open field) and existence of unlike sites representing different adsorption kinetics and -thermodynamics including ligand effects. Given there is redox activity of the metal ions/complexes and these can be studied in water (i.e., the bulk metals do not dissolve or get covered by thick oxide layers), depletion of dissolved ions in between chitin flakes surrounding some electrode (but not the otherwise identical counter-electrode) causes a concentration gradient potential of some 40 – 100 mV.

ASSESSING THE POTENTIAL OF X-RAY FLUORESCENCE IN BIOMONITORING SURVEYS

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In recent years, there has been growing interest in finding alternatives to inductively coupled plasma mass spectrometry (ICP-MS) for multi-elemental composition analysis. Biomonitoring, which involves the use of biological samples such as higher plants, mosses and lichens to assess environmental pollution and ecosystem health, requires frequent and cost-effective multi-elemental analyses. While ICP-MS is highly accurate, its application is often limited by the operational costs and the need for extensive sample preparation. Portable X-ray fluorescence (XRF) analyzers have emerged as a promising, cost-effective, and less labor-intensive alternative for routine applications in biomonitoring.

This study investigated the suitability of XRF analysis for routine multi-elemental composition analysis, assessing its analytical potential by measuring a wide array of certified reference materials of soil and plant origin.

A portable XRF analyzer was used to evaluate 32 soil and 12 plant standard materials in both the Soil and Geochem modes, utilizing sequential beams to detect a wide range of elements. Recovery rates were calculated by comparing XRF measurements with certified values, and correlations were verified through the Spearman coefficient. The results demonstrated the reliability of XRF measurements for soil samples, with many elements showing good or very good recovery rates and strong correlations with certified values. For plant samples, XRF tended to overestimate certified values, but the strong, statistically significant correlations for almost all tested elements allowed for correction of this systematic bias by dividing the XRF-obtained values by the reported median value. The Geochem mode proved to be more reliable for a broader range of elements.

It was concluded that XRF can serve as a suitable alternative to ICP-MS in routine multi-elemental composition analysis, particularly in biomonitoring applications where cost-effectiveness and simplicity are key issues. Additionally, comparative data on field lichen samples analyzed via both ICP-MS and XRF, which are currently under evaluation, will also be presented.

ACCUMULATION OF ELEMENTS IN MOSSES: PASSIVE VERSUS ACTIVE BIOMONITORING

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The research raises the question about temporal trends in elements accumulation in mosses: passive *versus* active biomonitoring. In June 2024, samples of *Pleurosium shreberi* and *Hylocomium splendens* were collected at four sites in Dubna, Moscow region in accordance with the sampling strategy of the European moss survey protocol. At the same places moss bags were exposed for 3 months to examine accumulation of potentially toxic element . In September 2024, together with exposed moss bags again were collected moss samples. The content of 15 elements: Al, Cu, Cd, Co, Pb, Zn, Ba, Cr, Mn, Fe, Sr, V, Ni, S and P in samples was determined using ICP-OES. At all sites decrease of element content in moss samples was observed: up to 50% for *Pleurosium shreberi* and approximately by 15% for *Hylocomium splendens*. Results of active biomonitoring showed accumulation of Sr, Zn and Mn in mosses during expose period, the content of other elements decreased or was on the level of unexposed samples. According to relative accumulation factors accumulation of elements was insignificant. The data of passive and active biomonitoring showed the same pattern.

THE MOSS SURVEY 2020-23 IN SLOVAKIA

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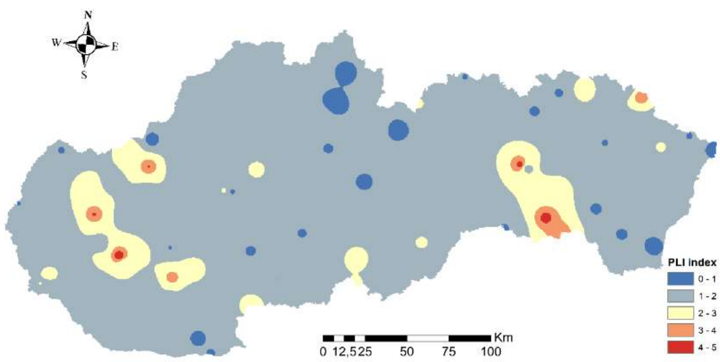
Environmental studies using bryophytes for biomonitoring of changes in atmospheric deposition of heavy metals in Slovakia started in 1990. In the 7th moss survey in 2020-23 new sampling sites were added. For the first time open and background sites, as well as localities with high potential of heavy metal exposure. Totally were collected and analysed mosses from 201 sites: 59 original ICP Forest sites and 142 open sites from which 3 were background.

Collected mosses 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, Slovakia.

Forest sites: Since 1990, the metal concentration in mosses in the ICP Forest sites has declined the most for Pb (89.87%), Cd (86.32%), Zn (80.81%), Al (78.59%), Hg (70.80%), Fe (63.45%), Cu (60.10%), As (38.17%), Cr (27.61%) and Ni (17.82%). The nitrogen concentration in mosses are stable (1.74 - 1.79 %), but too high above its natural background concentration in mosses (approx. 0.50%).

Open and background sites: Comparing the median values of the open sites versus background localities revealed that the highest difference is for Cr (79.41 %), following with Fe (64.93 %), Ni (63.29 %), Al (59.56 %), Zn (41.78 %), Hg (37.50 %), As (33.61 %), Cd (32.74 %), Cu (32.61 %) and Pb (17.83 %).

Pollution load index (PLI): Slovakia generally experiences moderate to no pollution (PLI = 1.45). Several hotspots with moderate to high PLI exist (Map 1). In the eastern part of the country: Košice region - a centre of metallurgy and steel production, Spiš – Gemer region - area where mining activities started in the 14th century. In the western part of the country: the highest PLI cover the area of a large fertilizer producer and Trnava region with dominant glass fibre production and automotive industry.



Map 1: Spatial distribution map of the Pollution Load Index (PLI) in Slovakia.

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ATMOSPHERIC DEPOSITION OF RADIONUCLIDES:

ASSESSMENT BASED ON PASSIVE MOSS BIOMONITORING

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Terrestrial moss has been used for the monitoring of atmospheric deposition of radionuclides since the late 50es of the last century, mostly for tracing deposition patterns of radionuclides due to technological accidents [1-3]. However, until recent time this aspect of investigations was absent in the UNECE ICP Vegetation (http://icpvegetation.ceh.ac.uk/) in spite of the great importance of knowledge on global mixing of long-lived radionuclides in the atmosphere and their deposition after the Chernobyl and Fukushima disasters. In the moss survey 2015/2016, an optional assessment of long-lived radionuclides such as ^{137}Cs and ^{210}Pb was suggested [4]. Low background gamma ray spectrometry is provided by several interested laboratories in Slovakia [3], Greece [5] and Serbia [6]. The feasibility of moss sampling to assess the atmospheric deposition of radionuclides is discussed and examples from the literature are reviewed.

Keywords: Moss, biomonitor, atmospheric deposition, radionuclides, nuclear accidents.

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TRACKING ENVIRONMENTAL CHANGES IN MOSCOW REGION WITH MOSSES: FROM PRE-PANDEMIC TO POST-RESTRICTION PERIODS

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The COVID-19 pandemic had a profound negative impact on human health and economies globally. To mitigate the spread of infection, many countries, including the Russian Federation, implemented strict public health measures. Lockdown and isolation significantly reduced industrial production, economic activity, transportation, and human movement, while only essential industries and services were permitted to operate during this period. These restrictions led to significant improvements in air quality in Moscow and other large Russian cities during the lockdown period, particularly for nitrogen dioxide emissions [1]. Our study in Moscow region of moss samples of *Pleurozium schreberi*, collected in June 2020 at 19 sites previously identified as polluted, revealed that while COVID-19 restrictions improved air quality by reducing traffic emissions, industrial sources continued to contribute significantly to heavy metal pollution during this period [2].

To assess whether moss biomonitoring can effectively detect short-term changes in air pollution levels, it was decided to compare pre-pandemic (2019) moss survey results to those obtained during pandemic restrictions (2020) and post-pandemic (2021). The content of heavy metals (Cd, Cr, Cu, Fe, Ni, Pb) in the moss samples was analyzed using atomic absorption spectroscopy (AAS) in 2019-2020, while inductively coupled plasma atomic emission spectroscopy (ICP-AES) was employed in 2021. The Kruskal-Wallis test revealed significant differences at $p = 0.05$ for Cd, Cu, and Pb levels. Cadmium showed the lowest median value in 2020 and the highest in 2021. Copper exhibited a notable decline over the years, while Pb demonstrated an upward trend. Over time, Cr and Fe median values exhibited non-significant changes. Specifically, Cr median values declined modestly, while iron median levels increased. Nickel showed its highest median during the COVID-19 period and lowest in 2019. These trends highlight variations in metal concentrations across different periods, potentially influenced by environmental factors and industrial activities.

This study demonstrates the feasibility of using moss as a biological indicator of short-term changes in environmental metal pollution due to human activity. Further study of the specific factors influencing these changes is needed.

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BIOMONITORING OF ATMOSPHERIC DEPOSITION OF POTENTIALLY TOXIC ELEMENTS IN KOSOVO IN 2020

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Air pollution is an increasing challenge for modern society globally, and it is a very common problem in Kosovo. In this work, the atmospheric deposition of 25 chemical elements: Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sr, Ti, Tl, V and Zn, were determined in 45 moss samples as natural samplers [1]. Moss samples (*Homalothecium sericeum, Hypnum cupressiforme,* and *Pseudoscleropodium purum*) were collected, cleaned, digested and then analyzed by inductively coupled plasma–atomic emission/mass spectrometry (ICP–AES and ICP-MS). Statistical analysis (Basic statistics, Pearson correlation and Principal component analysis), Pollution indices (Contamination factor and Pollution load index) and spatial distribution maps were performed to explain the obtained results for 8 potentially toxic elements (Al, Cd, Cr, Cu, Fe, Ni, Pb, and Zn). The contamination factor (*CF*) showed that only Cu and Zn had no or almost no contamination levels over the range of moss samples with $CF < 1$, while Cd and Pb gave extremely high values, $CF > 27$. Pollution load index (*PLI*) also showed that only a few samples are moderately polluted $2 < PLI < 3$, while most of the samples appeared to be highly polluted $4 < PLI < 5$, and very highly polluted $PLI > 5$. There were no unpolluted categories in the samples for PLI_{site} values when 8 of potentially toxic elements are taken into calculation, and its values increase even more when Cd, Cr, Ni, and Pb are included in calculation [2]. 38 sites of the sampling area fall in the highest category of pollution for these four heavy metals. Trepça mines and its facilities, Ferro-Nickel mines in Drenas, cement factory in Hani i Elezit, and coal thermopower plant in Obiliq were identified as the main pollution sources.

Keywords: Kosovo; air pollution; mosses; ICP-MS; pollution indices, factor analysis.

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ACTIVE MOSS BIOMONITORING IN AREAS AFFECTED BY ASHFALLS OF SHIVELUCH VOLCANO (KAMCHATKA)

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The moss bag technique was applied on Kamchatka to assess the effect of Shiveluch volcano on the air quality. Moss bags were exposed in settlements located at different distances from the volcano and affected by ashfall to varying degrees. The inductively coupled plasma optical emission spectrometry was used for the determination of the content of Al, Ba, Co, Cd, Cr, Cu, Fe, Mn, P, Pb, Sr, S, V, and Zn in both exposed and unexposed moss samples. Relative accumulation factor revealed enrichment of mosses exposed in the area affected by ashfall with Al, Cr, V, and Zn. Correlation and principal component analysis allowed to identify elements of volcanogenic, geogenic, and anthropogenic origin. Ecological risk values less than 150 indicate low potential ecological risk in the region. Active moss biomonitoring can be considered a cheap and efficient tool for in-depth study of the influence of volcanic activity on air quality on the peninsula.

MOSS BIOMONITORING AN IMPORTANT TOOL FOR AIR QUALITY ASSESSMENT – A NATIONAL STUDY IN ALBANIA

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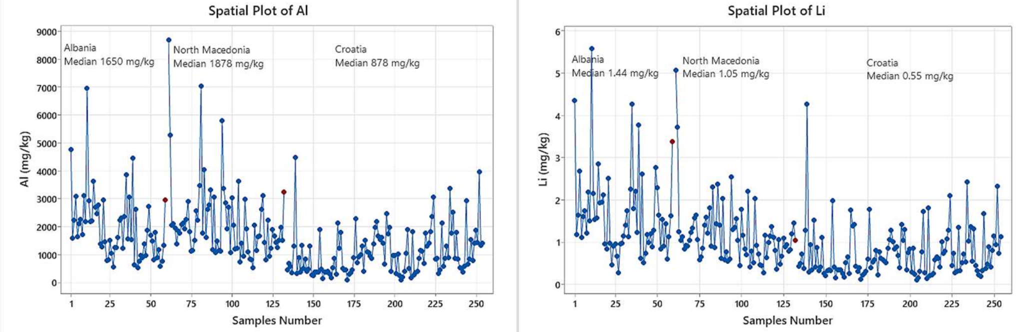
Atmospheric deposition of trace metals (TM) was assessed in the entire territory of Albania by using *Hypnum cupressiforme* moss as a biomonitor. The goal of this study is to study how trace metals move around and change over time, find out how they get released, and figure out how they affect the amount of trace elements in the air around Albania. Moss samples were collected from 75 locations. Data from moss surveys conducted in 2010, 2015, and 2021 were analyzed using descriptive statistics and multivariate analysis to assess the temporal trend of elements. The results of the statistical analysis pointed to geogenic factors, mining, and metal processing as primary local emission sources for TM atmospheric deposition in Albania. An enhancement in elements derived from anthropogenic and soil dust emission sources was observed in the spatial distribution of trace metals. Due to the high background levels of most elements, enrichment factors revealed no to slight enrichment in more than 80 percent of the territory. Albania East is exposed to high levels of Co, Cr, Ni, and Fe, higher than the neighboring and EU countries. The data of the 2010 moss survey and the content of lithophile elements in mosses from Albania, Croatia, and North Macedonia revealed better air quality in Croatia. It is supported by the data published from the global air quality statistics, which show that Croatia had a clean air quality index (AQI = 29–50), while Albania and North Macedonia had a moderate air quality index (AQI = 50–100). Croatia has significantly strengthened its environmental legislation and policy framework for environmental protection and sustainable development since 1999, which is reflected in its air quality.

The good relationship between the concentration data of lithophile elements (Al, Fe, and V) and AQI data is an important finding that confirms that moss species have a high capacity to retain atmospheric deposition particles. Moss data provides a complementary measure of elemental deposition from the atmosphere to the terrestrial ecosystems, which makes it possible to achieve a relative comparison of the deposition data achieved at a high sampling density in national/and or continental monitoring. A continuous monitory program is necessary to control the pollution level and the effects of pollutants in Albania.



Spatial plot of Al, and Li in moss samples of Albania, Croatia and Macedonia

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Abstracts Posters and Others

BRYOPHYTE MOSS – SUBSTRATE SOIL INTERACTION IN ATMOSPHERIC TRACE METAL DEPOSITION: A NATIONAL STUDY IN ALBANIA

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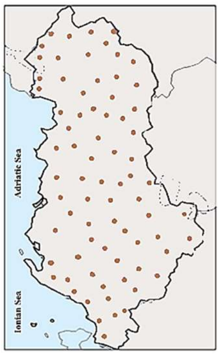
The present study looked at the level and distribution of cobalt, chromium, and nickel in soil and moss (*Hypnum cupressiforme* (*Hedv.)*), the latter used as a biomonitor of Co, Cr, and Ni in atmospheric deposition. These elements were identified in high concentrations compared to values reported by European moss surveys of 2010 and 2015. The possibility of moss element uptake from substrate soils was assessed by analyzing moss and topsoils from the same areas.



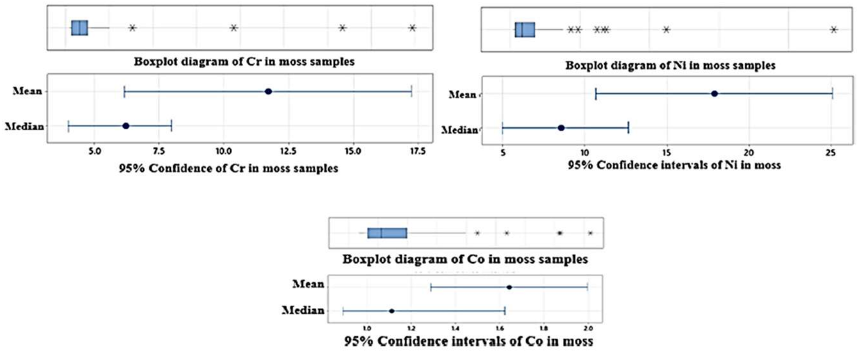


Fig. 1 Map of Albania samples (in mg/kg)

with 75 sampling sites

Fig. 2 Boxplot and 95% confidence interval of Cr, Ni, and Coin moss

Higher concentrations of elements in moss were found in areas of very high element content in soil characterized by no/or thin humus layer and sparse vegetation that stimulates soil dust generation.

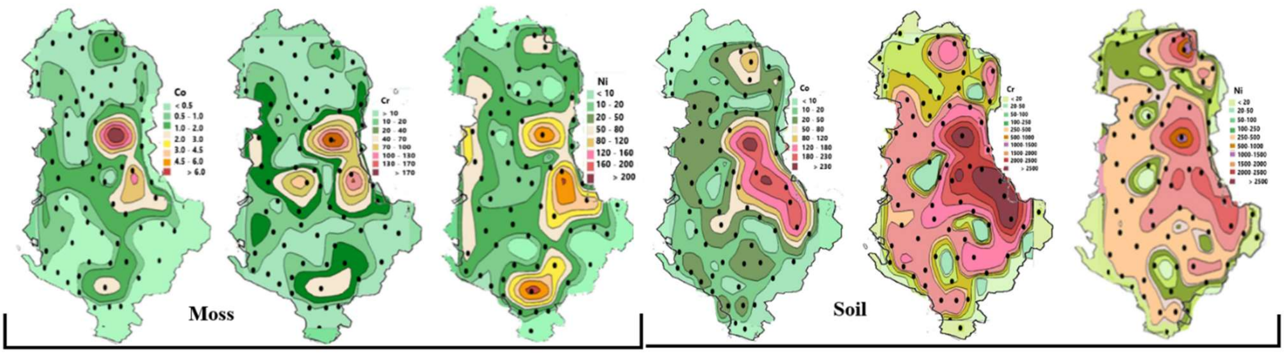


Fig. 5 Akima's distribution maps of Co, Cr, and Ni spatial distribution in moss substrate soils (in mg/kg)

Associations between elements in moss and soil samples, investigated by Spearman-Rho correlation analysis, indicated strong and significant correlations ($r > 0.81$, $p = 0.000$) between elements' data in moss or soil, and weak or no correlations ($r < 0.4$, $p > 0.05$) between the same data of moss and soil.

Conclusions

The study showed a minor effect of substrate soil constituents on concentration of moss elements in mosses within the studied area, with the exception of areas with high Cr, Ni contents. This conclusion is supported from differences observed in the positions of the outlier sites and spatial distribution of elements in moss and soil samples, and the weak correlations between elements in moss and soil samples. It is a compelling test for mosses as a suitable biomonitor of the atmospheric deposition of metals, even in areas dominated by high minerals in soils, such as Albania.

This survey showed that moss biomonitoring provides a low-cost method for identifying areas at risk from metal deposition fluxes and may track contamination trends over time. The high concentration of these elements in moss—higher than European concentration levels—imposes continuous monitoring on a national scale.

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MOSS BIOMONITORING FOR AIR QUALITY ASSESSMENT AROUND A METALLURGICAL COMPLEX IN ELBASAN, ALBANIA

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This research focused on the assessment of the air quality of the Elbasan region, Albania, by using moss biomonitoring and trace metals atmospheric deposition. Elbasan is an industrial area located in central Albania. It is vulnerable to environmental pollution, particularly soil and air pollution. In this research, we analyzed the concentrations of 13 toxic metals in the atmospheric deposition by using moss as biomonitor. Moss samples, *Hypnium cupressiforme*, were collected during the dry season of June 2021 from 12 sampling sites. The concentrations of 14 metals (Al, As, Cd, Co, Cu, Cr, Fe, Hg, Li, Ni, Pb, Sb, V, and Zn) were determined in mosses by the ICP-MS method. Descriptive statistical analysis was used to assess the level and variance in spatial distribution of the studied metals.

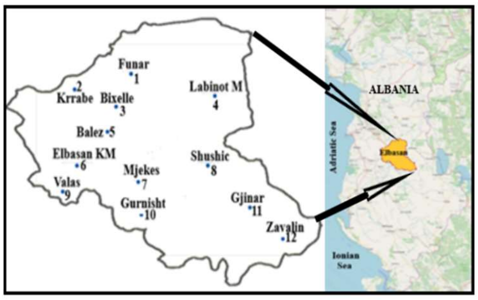


Fig. 1 The map of Elbasan area and the

position of sampling sites

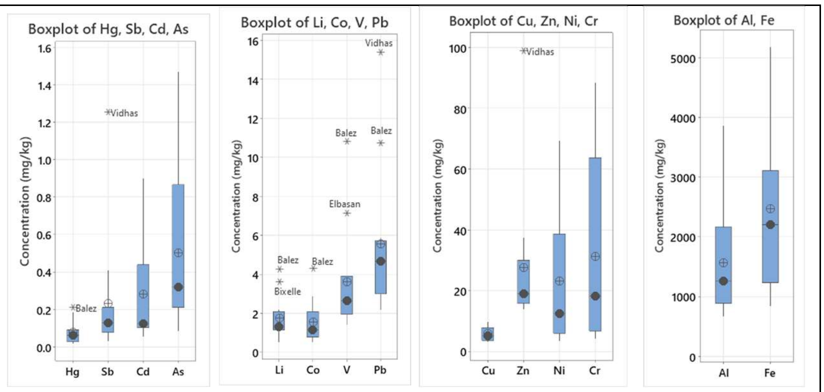
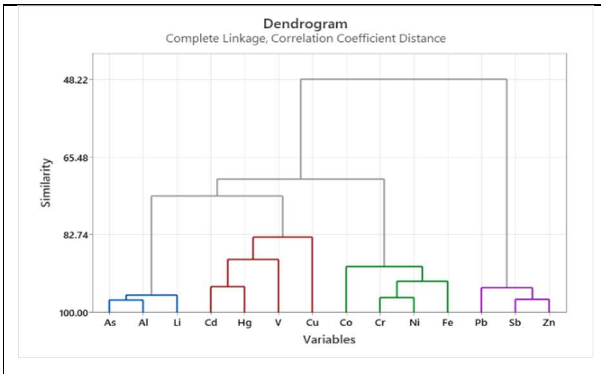


Fig. 2 Boxplot diagrams of elements present in current moss

Pearson correlation, and cluster analysis were used to investigate the associations of elements and discuss the most probable sources of these elements in the study area.



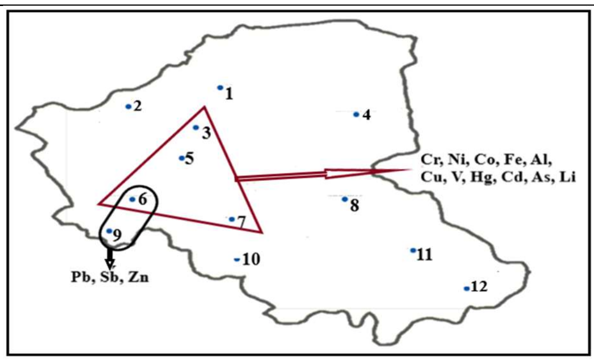


Fig. 4 The final partition of elements-in 4 clusters	**Fig. 6** The anomalies of elements along sampling sites

Cr, Ni, Co, and Fe showed strong and significant correlations ($r > 0.8$, $p = 0.000$) - representing anthropogenic association mostly of air particles from ferro-chrome and iron smelter plants. It revealed substantial impacts from local industry and man-made activity, as well as from soil dust emissions. Ferro-chrome, iron smelter plants, and cement factories are the biggest emitters of trace metals in the Elbasan area. The historical deposit of metals and the current emissions from the metal processing industry, cement production, and steam production in the Elbasan area pose crucial problems that require strong actions to improve technology for reducing emissions into the atmosphere and industrial waste.

Keywords: Moss biomonitoring, air quality, toxic metals, ICP/MS analysis, statistical analysis, Elbasan Region, Albania

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PRELIMINARY ANALYSIS OF TOTAL KJELDAHL NITROGEN CONTENT IN MOSS SAMPLES FROM ALBANIA DURING EMS 2021 AND PREPARATIONS FOR EMS 2025

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As part of Albania's participation in the European Moss Survey (EMS) 2021, the focus was on reporting the heavy metal (HM) content in mosses. However, for EMS 2025, efforts are being made to also analyze and report Total Kjeldahl Nitrogen (TKN) content, expressed as a percentage, using the Kjeldahl method. For this purpose, three samples were randomly selected from the 75 samples collected during EMS 2021, specifically from the sites Mjekës, Bujan, and Hani i Hotit, to test this method. This process was conducted in the laboratories of the Department of Chemistry, Faculty of Natural Sciences, University of Tirana, using the classical Kjeldahl method with traditional glassware. Meanwhile, in 2023, these three samples were also analyzed at **TENUIS Laboratory** (TL, formerly NOVAL Laboratory), using automatic Kjeldahl apparatus, as part of a master's thesis.

To test the functionality of the apparatus and standardize the distillation process, ammonium sulfate [$(NH_4)_2SO_4$] was used as a salt with a known nitrogen content. The recovery rate was 94.5%, demonstrating the satisfactory efficiency of the method used. All samples were analyzed in triplicate, and the reported values represent the averages of these three measurements. Additionally, a blank sample was prepared following the same procedure as the samples, but without adding moss material, to ensure accuracy.

The results indicate TKN percentages in the analyzed samples as follows: **0.82% (Mjekës, Elbasan; 0.84% TL), 1.18% (Bujan, Tropojë; 1.28% TL),** and **0.85% (Hani i Hotit, Malësi e Madhe; 0.95% TL),** with a mean TKN percentage of **0.96% (1.02% TL).** Comparable analyses performed by **TL** using automatic Kjeldahl apparatus reported TKN percentages closely aligned with the results obtained using the classical Kjeldahl method.

Compared to data from previous studies in Southeastern European countries (North Macedonia, Croatia, and Bulgaria), TKN percentages in Albania are approximately similar, reflecting the impact of local activities such as agriculture, industry, and traffic. In contrast, nitrogen percentages in samples from Finland, a cleaner area, are significantly lower (<0.7%), highlighting the effects of atmospheric nitrogen deposition in our region.

These analyses demonstrated that the classical Kjeldahl method can be used to accurately report TKN content in mosses in Albania for EMS 2025 as part of **ICP Vegetation.** Overall, these data are essential for supporting the development of strategies to reduce pollution and preserve sensitive ecosystems in Albania and the region.

ASSESSMENT OF AIR POLLUTION IN SOME LOCATIONS OF KOSOVO USING MOSSES AS A BIOINDICATOR

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Air pollution is a crucial threat to the environment and human health. The purpose of this study is to assess air pollution with heavy metals via atmospheric deposition by utilizing mosses as biomonitors near a traffic axis in Kosovo. Mosses were used as biomonitors because they obtain nutrients mostly from atmospheric deposition. Moss samples (Hypnum cupressiforme sps.) were collected at ten sampling sites along the Pristina-Prizren axis (86 km) in Kosovo. Heavy Pb, Cd, Zn, Cu, Ni, Cr, Mn, and Fe, which are linked with traffic emissions and anthropogenic pollution, were analyzed using the furnace and flame atomic absorption spectroscopy (AAS). Statistical analysis was applied to process the experimental data. The concentration of some metals in sample M6 for lead (1.62 mg/kg), cadmium (12.90 mg/kg) and zinc (12.90 mg/kg), while in sample M4 for chromium (4.43 mg/kg), manganese (379.41 mg/kg), nickel (21.09 mg/kg) and iron (2196.55 mg/kg) in some sampling locations are higher. Emissions from the "Balkan" Rubber Factory in Suhareka, long-range transport from the mining industry, coal-fired energy sources, and areas with heavy vehicle traffic are the main emitters of these elements. The outcomes of this investigation provide information regarding potential sources of metal pollution in contaminated areas, thereby serving as a basis for future research endeavors and enabling relevant institutions to implement strategies for reducing this form of pollution. Keywords: Kosovo; Heavy metals; mosses; pollution; atmospheric deposition

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HOW TO OVERCOME THE LACK OF MOSSES IN AGRICULTURAL AND URBAN AREAS? MOSS BAG BIOMONITORING FOR THE ICP VEGETATION MOSS SURVEYS

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Moss biomonitors are a ubiquitous organism, present in all ecosystems, except marine ones. Specific morpho-physiological adaptations of mosses recommend them for the application in biomonitoring of air pollution. They are particularly suitable for long-term biomonitoring across large areas, and, thus, applied in the European(-Asian) international Moss survey program. However, in anthropocene, mosses have vanished from some ecosystems, such as urban with predominantly paved and landscaped surfaces, and agricultural where dominate tillage and melioration. These areas make approximately one-quarter of the terrestrial surface, belongs to highly contaminated areas. Moreover, in some countries, the agricultural areas can be predominant scenery in some countries. The moss bag technique can be a valuable alternative for the biomonitoring of air pollution in the absence of naturally growing mosses in agricultural and urban areas. The technique has been developed and well-defined for the urban conditions while in agricultural areas just a few studies were performed (Aničić Urošević and Milićević, 2019; Milićević et al., 2017; Capozzi et al., 2016a). The results of these studies suggest that the moss bag technique can be successfully used for air pollution assessment in both areas. Agricultural areas represent diffuse pollution sources with more spatial homogeneity of air pollution than in urban areas. Still, in the agricultural areas, there are temporal fluctuations of air pollution, which coincide with the agrochemical treatments. Thus, in an agricultural area, the minimum recommended period of the moss bag exposure − six weeks (Capozzi et al., 2016b), does not guarantee a measurable moss load with pollutants if the exposure period of the bags does not involve the time of agrochemical applications (Milićević et al., 2017). To conclude, the goal of a survey implies a definition of the moss bag exposure time in a particular ambient.

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COMPARISON OF RADIONUCLIDES ACTIVITY IN LIVE AND DEVITALIZED TRANSPLANTED MOSSES *HYLOCOMIUM SPLENDENS* (HEDW.) SCHIMP. FROM FORMER URANIUM MINES IN LOWER SILESIA (SW POLAND).

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The aim of this work was to compare two active biomonitoring methods, live and devitalized samples of terrestrial mosses were used in studies of environmental pollution with radionuclides. Activities of radioisotopes were measured in samples of transplanted live and devitalized moss *H. splendens* and soil samples. The samples were collected from test areas near former uranium mines in Radoniów and Kowary (both SW Poland) and control site placed far from sources of pollution, located near the Roztocze National Park (SE Poland). Activities of the following radioisotopes were determined by gamma-ray spectrometry: Bi-214, Cs-137, K-40, Pb-214 and U-235 in mosses. On the other hand Ac-228, Cs-137, K-40, Bi-212, Bi-214, Pb-210, Pb-212, Pb-214 and U-235 were measured in soil. The highest radionuclide activities were recorded in the case of devitalized mosses. However, the t-test showed that devitalized and living mosses share the same deposition pattern, which allows us to conclude that both types of active biomonitoring are equally suitable for use. Results from this scientific study, contributing to the development of a standardized protocol for moss-based radionuclide biomonitoring.

Keywords: active biomonitoring, radioisotopes, mosses, *Hylocomium splendens,* uranium mines

ASSESSMENT OF AIR QUALITY IN ALBANIA USING MOSSES AS BIOMONITORING INDICATORS FOR TRACE METALS AND MICROPLASTICS

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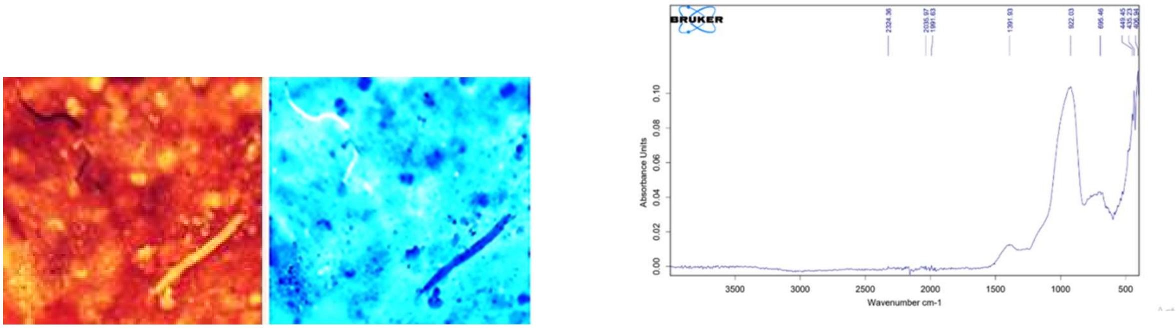
This study aims to evaluate air quality in various regions of Albania (Tirana, Kanina, and Prrenjas) by analyzing trace metals and microplastics using mosses as bioindicators. Samples of Hypnum cupressiforme moss were collected and analyzed using atomic absorption spectrometry to determine concentrations of five trace metals (Cd, Cu, Ni, Pb, Zn). The study employed a statistical approach, including descriptive statistics, correlation analysis, linear regression, factor analysis, principal component analysis (PCA), and cluster analysis.

The results showed high zinc concentrations in the Tirana stations, attributed to traffic emissions and corrosion of galvanized vehicle parts. Lead concentrations were relatively low across all stations due to the elimination of leaded gasoline. Prrenjas was identified as one of the most polluted cities in Albania, with elevated levels of cadmium linked to historical industrial activities, particularly mining. Nickel was prevalent in industrial zones, especially in areas associated with steel and cement production.

Cluster analysis identified three groups of trace metals: Cluster 1 (Zn, Cu, Cd), Group 2 (Pb), and Cluster 2 (Ni). Cluster 1 elements are strongly associated with traffic-related emissions, while Cluster 2 is linked to industrial activities. Additionally, microplastics were found in significant quantities on the moss samples, indicating high concentrations of airborne microplastics in the sampled regions.



a b c

Figure 1 a,b Photo from the stereomicroscopic observation (400x magnification) of the Kanina sample on the filter. **c** FTIR analysis

The study reveals the impact of anthropogenic activities, such as traffic and industrial processes, and environmental pollutants, including heavy metals and microplastics, on air quality. These findings show the importance of continued monitoring and developing strategies to reduce pollution in Albania.

CHEMICAL ELEMENTS AND MICROPLASTICS IN AIR OF THE PRISHTINA REGION USING MOSSES AS BIOMONITORS

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The objective of this study was investigation of chemical elements and microplastics in air of the industrial zone of the Prishtina region in Kosovo. Moss samples were collected during August 2024, from 8 locations in Drenas and Obiliq municipalities. Moss samples were digestion in Teflon tubes by using HNO_3 and H_2O_2, and then 18 chemical elements (Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Se and Zn) analyzed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPE-9800). The median values for toxic elements: cobalt (3.30 mg/kg), chromium (12.75 mg/kg), copper (9.31 mg/kg), nickel (15.51 mg/kg) and lead (15.99 mg/kg) were higher than in previous investigation [1], because in this region there are located the ferronickel smelter in Drenas and the lignite power plants Kosova A and Kosova B in Obiliq.

For the first time in Kosovo, we have some preliminary results for the presence of microplastics in moss samples. The moss samples (1 gram per each sample) were digested by using Fenton reagent (ferrous iron sulfate solution 0.05 M) in the catalytic wet peroxide oxidation method [2]. Samples were vacuum-filtered onto cellulose filter papers and placed into glass petri dishes for storage, and then analyzed for presence of microplastics using stereo-microscope [3]. In some moss samples we identified the fragments of fibres from 1500-2200 µm.

Keywords: Kosovo; air pollution; mosses; heavy metals, microplastics.

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TEMPORAL ANALYSIS OF ATMOSPHERIC METAL PRECIPITATION USING MOSS AS A BIOINDICATOR.

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Temporal analysis examines changes, trends, and patterns in atmospheric metal deposition over time. Mosses, known for their high metal uptake capacity, sensitivity to air pollution, and ability to survive extreme weather, serve as effective bioindicators.

This study investigates the temporal trends of atmospheric metals (Pb, Zn, Ni, Cd, Cu, Fe, and Al) in four Indian states—Punjab, Uttar Pradesh, Uttarakhand, and Himachal Pradesh—between 2012 and 2022. Variations in metal deposition are attributed to differences in industrialization, traffic, urbanization, and environmental regulations. Notably, metal precipitation levels dropped significantly during 2019–2021 due to pandemic-induced lockdowns, which halted industrial and transportation activities. Moss samples were collected systematically over the decade, categorizing the study period into pre-pandemic (2012–2019), pandemic (2020–2021), and post-pandemic (2022). Analysis was conducted using Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

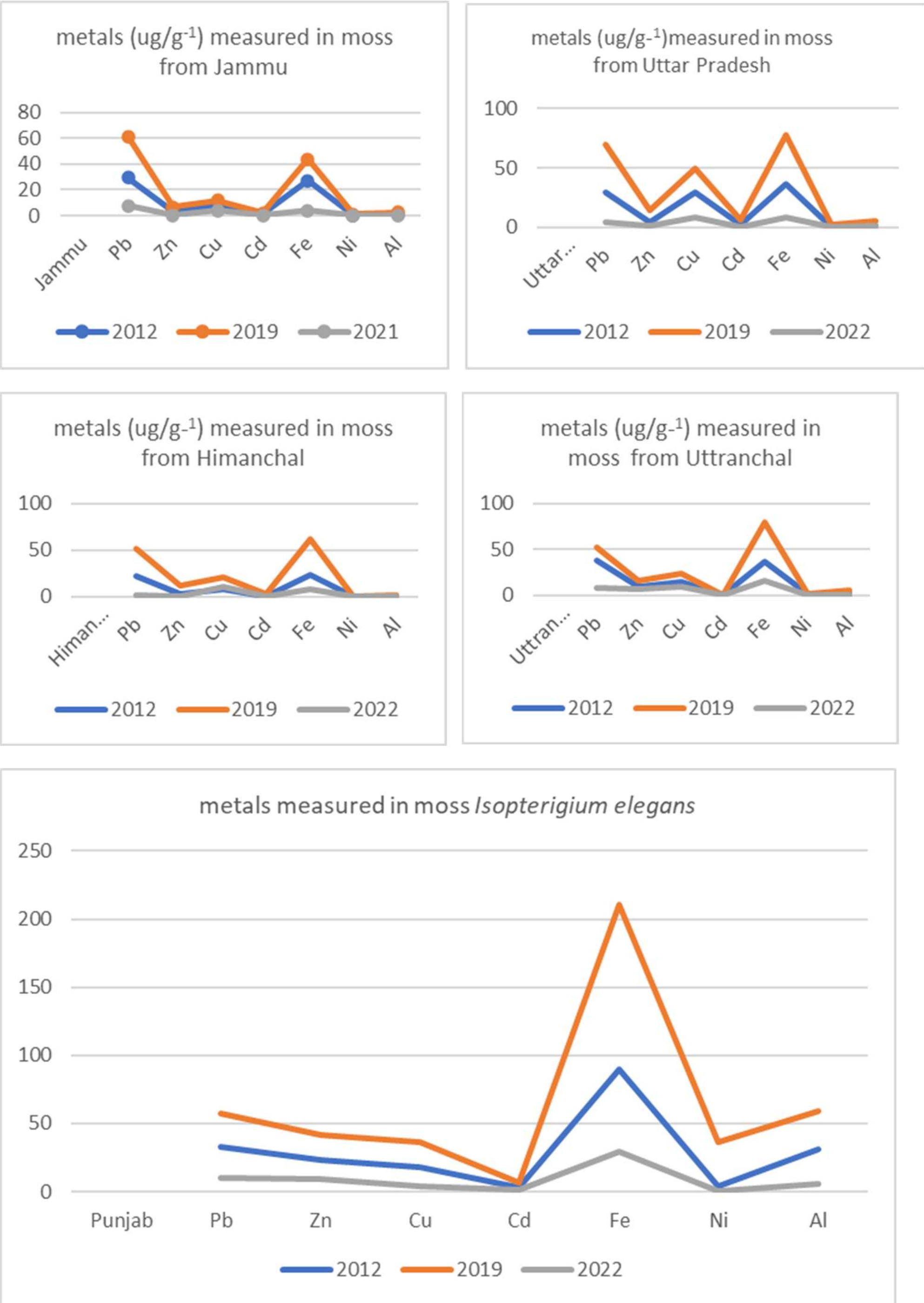
Key Findings: Pre-Pandemic (2012–2019):

- **Punjab:** Rising metal deposition, particularly Fe and Ni, linked to industrial activities (e.g., cycle manufacturing) and Zn from agricultural sources.
- **Uttar Pradesh:** Increased Cu, Fe, and Cd concentrations in Moradabad, attributed to the brass and electronic waste industries.
- **Jammu:** Elevated Pb, Ni, and Cu levels due to tourism, trade, and pilgrimage activities.
- **Uttarakhand:** High concentrations of Pb, Zn, Cu, and Cd in road dust, mainly from vehicular emissions, brake pad wear, and agricultural practices.

Pandemic (2020–2021):A significant decline in all metal concentrations due to the slowdown in industrial activities and transportation.

Post-Pandemic (2022): A rebound in metal deposition as industries and transportation resumed, though not immediately reaching pre-pandemic levels.

Conclusion: The pandemic-induced lockdown (2019–2021) led to a significant reduction in atmospheric metal concentrations, highlighting the impact of industrial and vehicular activities. The study underscores the effectiveness of moss as a biomonitoring tool for air quality trends. Higher Cu, Zn, and Cd deposition was observed in industrial and high-traffic areas, with seasonal variations—Cu, Zn, and Cd levels peaking in summer and winter, while Pb was highest during the rainy and summer seasons. Urbanization and industrialization significantly elevate atmospheric heavy metal levels, potentially contaminating the food chain and posing health risks. Combustion processes, including power generation, smelting, incineration, and vehicular emissions, remain the primary sources of heavy metal pollution.



Metals (µg/g-1) measured in moss *Isopterigium elegans*

DOES OZONE DIFFERENTIALLY INFLUENCE THE PERFORMANCE OF *TRIFOLIUM REPENS* CYANOTYPES?

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Tropospheric ozone (O_3) is a secondary pollutant that impacts ecosystems by inducing oxidative stress in plants and altering their interactions with herbivores, neighbouring plants, and microorganisms. White clover (*Trifolium repens)*, a perennial legume highly sensitive to O_3, has the capacity to produce hydrogen cyanide (HCN), a chemical defence against herbivory. Cyanogenic plants are generally more common in rural areas, where herbivory pressure is higher, compared to urban areas. However, the influence of O_3 on the distribution and performance of cyanogenic *versus* non-cyanogenic plants remains unclear. This study evaluated whether O_3 exposure influences the performance of C and NC white clover to evaluate differential O_3-sensitivity of the cyanotypes to the pollutant.

Cyanotypes with differing capacity for HCN production were exposed for 48 days to four chronic O_3 treatments: filtered air (FA) reproducing pre-industrial levels, non filtered air (NFA) reproducing current ambient levels in Southern Europe, and non filtered air supplemented with 20 ppb (NFA+20) or 40 ppb (NFA+40) of added O_3. Plant performance (vegetative and reproductive biomass) was evaluated at the end of the 48-days O_3-exposure period and after a 30-days recovery period.

After O_3-exposure, the pollutant had a marginal but negative effect on total aboveground biomass, which was independent of the cyanotype. After the first half of the O_3-exposure O_3-induced foliar symptoms and senescence were greater in non cyanogenic, although this pattern disappears at the end of the exposure period when a more generalized senescence was observed in both cyanotypes. Regardless of O_3 exposure, C plants had lower biomass than non-cyanogenic plants. In fact, the biomass of O_3-exposed C plants was significantly lower than NC plants grown with low O_3.

Although reproductive biomass was similar between cyanotypes, C plants exhibited a higher reproductive effort. These differences persisted after the recovery period, during which O_3 had no effect on either the total plant biomass or the reproductive biomass, showing the recovery capacity of both cyanotypes after the O_3-exposure period. Interestingly, the number of flowers per unit of biomass was higher in cyanogenic plants. Our preliminary results indicate some productive and reproductive capacity differences between cyanotypes under O_3, showing that the pollutant can be a pressure to consider for cyanotype selection in chronic O_3 affected areas. Future studies should analyse more deeply the consistency of this preliminary finding.

TRACING THE CONCERTED MODULATIONS IN THE METABOLOME AND CARBON SEQUESTRATION EFFICACY OF TROPICAL TREE SPECIES UNDER SIMULATED PARTICULATE MATTER STRESS

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Land restoration activities are highly promoted under the United Nation's-Sustainable Development Goals which can alone contribute to all 17 of them. This is being achieved by enhancing plantations in urban areas with a scientific approach. Trees being sessile have to cope with the exposed environmental adversities. Along with the added benefit of evolving O_2, trees are the major sequesters of atmospheric CO_2. Therefore, changes in their ambient conditions will alter the metabolic pathways of the trees and will in turn interfere with their sequestration capacities ultimately dismantling the global carbon dynamics. The present study targets changes in the metabolites of dominant tree species of the Indo-Gangetic Plains, commonly employed in urban greening under the influence of an ascendant air pollutant -particulate matter (PM). Tree species (*Psidium guajava*, *Ficus religiosa*, *Dalbergia sissoo*) belonging to different functional types (evergreen, semi-evergreen, and deciduous) and leaf forms (simple and compound) were exposed to a gradient of particulate matter (ambient and elevated) for two years. Ultimately, the alteration in the carbon sequestration efficacy and allocation dynamics of trees was targeted under the applied stress. The study employed high-resolution NMR for the identification and quantification of the major metabolites and has further demarcated the changes in relative metabolic pathways under applied stress. The results ensconced major alterations in the anaplerotic routes and redox metabolites that varied with tree functional types, delineating an adverse effect on the carbon metabolism of all the tree species under the applied stress. Further, the study inferred that PM induced negative carbon balance in the simple leaf species while compound leaf species were carbon neutral. The simple leaf species were more sensitive to increasing PM load as the soluble sugar content was higher in them indicating a higher demand for stress tolerance. Conversely, the compound leaf species tried to maintain the balance between various facets of development which can be inferred by its low soluble sugar content and higher growth under stress compared to simple leaf species. It has been established that under negative carbon balance simple leaf trees sustained and mitigated stress by switching the carbon allocation priorities towards the maintenance of low but functional levels of non-structural carbohydrates by downregulating the growth activities.

Keywords- trees, particulate matter, metabolites, carbon balance, carbon sequestration

CROP QUALITY AND QUANTITY AS INFLUENCED BY IMPORTANT AIR POLLUTANTS IN PAKISTAN

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In the agricultural sector, a variety of air pollutants have been found to be harmful to crops, resulting in negative impacts on both crop yield and the economy. These pollutants are primarily emitted during the incineration or combustion of coal and gas. Agricultural crops exposed to high concentrations of air pollutants can experience acute and chronic injuries, as well as visible markings on their foliage, reduced growth, and decreased yield, ultimately leading to premature death. Since the industrial revolution, emissions of nitrous oxide, carbon dioxide, and methane have increased sharply from sources such as vehicles and factories. Some of these pollutants are regulated globally due to their severe impact on plant structure and metabolism. Developed countries have implemented sustainable mitigation strategies against air pollution, but developing countries face challenges in implementing a comprehensive framework for air pollution control due to limited resources. Pakistan is one such country where staple crops are affected by air pollution from various sources, and reducing the use of agrochemicals while maintaining crop productivity is a challenge. In this chapter, we present an overview of the effects of common air pollutants on crops, their pathways of exposure, and the resulting biochemical disturbances in plant metabolism. We also discuss the need for robust mitigation strategies and policies to address the disastrous effects of air pollution on staple crops in Pakistan, along with the laws that have been implemented to control air pollution.

EFFECTS OF AIR POLLUTION ON MORPHOLOGICAL, BIOCHEMICAL, DNA, AND TOLERANCE ABILITY OF ROADSIDE PLANT SPECIES

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Air pollution is a severe problem in the modern world. Urbanization, industrialization, and traffic emit air pollutants such as carbon monoxide (CO), nitrous oxides (NOx), hydrocarbons (HCs), and particulate matter into the environment. Plants can absorb air pollutants through stomata. They adversely affect the various metabolic and physiological processes of plant species. This review describes the impact of air pollution on plant health, morphologically, physiologically, and genetically, and the tolerance ability of plants located along roadside areas. Many morphological effects, like chlorosis, necrosis, leaf area, stomatal clogging, plant productivity, leaf falling, and reduction in flower yield, are observed due to the influence of air pollution. Air pollutants also damage the DNA and affect the biochemicals of the plants, as well as pH, relative water content (RWC), simple sugar, ascorbic acid (AA), total chlorophyll content (TCH), proline, and polyamines. Some plants located under pollution stress can mitigate air pollution. Plants with higher APTI values are more tolerant of air pollution, while those with the lowest APTI values can be used as an indicator of the rate of air pollution. There is much morphological, biochemical, and DNA damage noted in this review. Different strategies can be used to diagnose the effects of air pollution in the future and develop green belts to mitigate air pollution in pollution-stressed areas. Keywords: air pollution tolerance index; antagonistic; chlorosis; DNA damages; industrialization; stomatal clogging; urbanization

AIR POLLUTION MITIGATION POTENTIAL OF DOMINANT LANDSCAPE PLANTS OF AN URBAN ECOSYSTEM (LAHORE CITY) OF PAKISTAN: AN AIR POLLUTION TOLERANCE INDEX (APTI) ASSESSMENT

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Lahore, the second largest city of Pakistan with higher population and large industrial zones, is under tremendous environmental stress of increasing air pollution. Roadside plants can mitigate increasing pollution rate by serving as a natural sink. This research work was designed to evaluate the role of roadside plantation in pollution mitigation in an urban ecosystem of Lahore. In this urban ecosystem, three busiest roadsides i.e., Zafar Ali Road, Canal Road and Jail Road with heavy traffic flow and commonness of plants were selected as sampling sites.

Air Pollution Tolerance Index (APTI) of the selected plants was calculated through chlorophyll content (mg/g), ascorbic acid content (mg/g), relative water content (%) and pH. At control sites, ascorbic acid ranges from 3.11±0.21 (Cosmos sulphureus) to 1.18±0.08 (Tabarnaemontana divaricata) while at polluted sites, it was found to range from 2.95±0.09 (Cosmos sulphureus) to 1.03±0.08 (Tabarnaemontana divaricata). Chlorophyll content ranged from 37.00 ±1.11 (Ficus religiosa) to 5.28±1.22 (Hibiscus rosa sinensis) at control sites, while at polluted sites, it ranged from 29.09±1.15 (Ficus reliogiosa) to 5.56±0.95 (Tabarnaemontana divaricata). At control sites, relative water content ranged from 198.76 ±2.45 (Catharanthus roseus) to 10.02±1.95 (Tabarnaemontana divaricata) while at polluted sites, it was found to range from 192.40±2.11 (Catharanthus roseus) to 9.50 ±1.18 (Tabarnaemontana divaricata). At control sites pH value ranged from 6.69±0.21 (Catharanthus roseus) to 5.04 ± 0.45 (Alstonia scholaris). At polluted sites, it ranged from 6.69±0.21 (Catharanthus roseus) to 5.42±0.48 (Alstonia scholaris). At control sites, APTI value varies from 28.45±0.21 (Catharanthus roseus) to 2.59±0.11 (Tabarnaemontana divaricata). While at polluted sites, APTI value ranges from 27.5711,45 (Catharanthus roseus) to 2.18‡1.33 (Tabarnaemontana divaricata). Calculated APTI values were correlated with ascorbic acid, chlorophyll, %relative water content and pH. Highly positive correlation was found between APTI and ascorbic acid with R2 = 0.9183. While slightly positive correlation of APTI with chlorophyll and relative water content (R2 = 0.3779 and 0.336 respectively) was found. This indicates towards their participation in strengthening plants' defense mechanism.

This research work followed by statistical analyses evaluates the tolerance level of plants towards air pollution. This evaluation paves the way in screening out the tolerant plants for pollution abatement. In this research work, Catharanthus roseus and Cosmos sulphureus were found tolerant to air pollution having high APTI values while Helianthus annuus, Ficus benjamina, Ficus religiosa, Hibiscus rosa-sinensis, Robinia pseudoacacia, Alstonia scholaris and Tabarnaemontana divaricata was found sensitive to the air pollution. Keywords: APTI (air pollution tolerance index), ascorbic acid content, chlorophyll content, relative water content, urban landscape ecosystem.

QUANTIFICATION AND CHARACTERIZATION OF MICROPLASTICS (MPS) POLLUTION IN PERIUBURBAN AGRICULTURAL LANDS OF LAHORE, PAKISTAN

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Microplastics (MPs) contaminate every conceivable terrestrial and aquatic environment including high peaks and deep marine trenches. Agricultural lands alone are expected to receive plastic up to 23 times more than ocean basins. In this study, soil samples were collected from peri-urban agricultural lands of Lahore on four sides including Kala Shah Kaku (KSK), Punjab University (PU), Dera Gujran (DG), and Sagian (SG). National Oceanic and Atmospheric Administration (NOAA) protocol was used for MPs extraction and analysis. Extracted MPs were analyzed under microscope at 40X magnification and their composition was analyzed using Fourier Transform Infrared (FTIR) spectroscopy. A considerable concentration of MPs was recorded at all sites. The highest contamination was found at SG with 876 ±194 MPs/kg of soil, and the lowest contamination was recorded at PU with 672 ±235 MPs/kg of soil. However, these differences among the sites were not statistically significant ($p = 0.29$). The overall predominant shape of MPs was fibers (613±71, 79.73%) followed by sheets (125±55, 16.28%), fragments (30±5, 3.9%) and foam particles (1±2, .09%). The differences in the distribution of MPs in various types were statistically significant ($p = 0$), while differences between sites were insignificant ($p = 0.13$). About 95% of MPs were less than 2 mm and 85% were less than 1 mm size. The distribution of MPs in various sizes ($p = 0$) and differences of this distribution between sites ($p = 0.037$) were both statistically significant. A good diversity of nine colored MPs was recorded, however majority of the MPs were transparent (89.57%). Six polymer including Polyethylene (PE), Polyethylene terephthalate (PET), Polypropylene (PP), Polystyrene (PS), Polycarbonate (PC), and Polyvinyl Chloride (PVC) were identified by FTIR. The current levels of MPs pollution are higher than in many other parts of the world. Composition of MPs (types, colors, sizes, and polymer types) indicates the diversity of their sources and their possible implications on agricultural ecosystem.