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Editorial

Biomonitoring with Lichens and Mosses in Forests

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Currently, forest ecosystems are often located in remote areas, far from direct sources of air pollution. Nonetheless, they may be affected by different types of atmospheric deposition, which can compromise their health and inner balance. It is therefore important to identify sensitive and reactive forest components able to provide indications of the interactions between air pollution, deposition, and climate change [1].

Lichens and bryophytes play an important role in forest ecosystem functioning. They have a role in the water cycle and forest food webs, and they increase the canopy interception of precipitations and nutrients [2,3]. Being quite sensitive to environmental changes, they can represent suitable early-warning indicators of impacts better than other forest components [4]. Several species can be considered as indicators, as they are sensitive to air pollutants and climate change and show the ability to accumulate trace elements [5–7].

In general terms, we can identify three main purposes for performing lichen and mosses monitoring in forest ecosystems: (i) to monitor the effects of atmospheric pollution and climate change, (ii) for conservation studies related to forest management and threatened species, (iii) to obtain information on ecosystem functioning.

The hundreds of scientific research studies conducted in this field in recent decades confirm the current interest in using these organisms as biomonitors and the continuous demand for updates on the topic. This Special Issue includes five research articles and one review paper, where these topics are deepened based on the results of current and emerging research projects carried out around the world.

Air pollution in remote areas, mostly represented by forest sites, is receiving more and more attention, with three articles focusing on this topic [8–10]. In fact, despite a general improvement in air quality standards over recent decades (see, e.g., the decrease in sulfur oxide levels), nitrogen depositions (both oxidized and reduced) and Potentially Toxic Elements (PTEs; including heavy metals) still represent the main pollutants also affecting forest remote sites.

In the context of the European Moss Survey, Nickel et al. [8] explore the canopy effect on the accumulation of atmospheric deposition (12 metals and nitrogen) in mosses in eight sites (26 plots) in northwest Germany. In each site, they consider the relationship between neighboring canopy drip and open land plots, both in the concentrations of accumulated pollutants and in the leaf area index, which confirms it as a suitable measure of vegetation structure. Interestingly, the higher variability of the values measured in the open plots compared to the canopy sites suggests several influencing factors significantly affecting the results. The authors suggest taking care when selecting future sampling sites to ensure that the vegetation structures are as similar as possible throughout the entire monitoring network.

With a study performed in two natural parks in Thailand, Boonpeng et al. [9] focused on the seasonal concentrations of 15 airborne PTEs in the foliose lichen *Parmotrema tinctorum* (Despr. ex Nyl.) Hale. By exposing samples of this lichen during the rainy and dry seasons, they observed higher pollution loads during the latter, possibly due to road traffic and tourism activities. This methodological study also confirms the ability of the transplanted

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lichen *P. tinctorum* to be an effective biomonitoring tool for airborne PTEs in natural environments and for decision makers and park managers.

A third study carried out in urban and forest areas of Ecuador [10] shows the effectiveness of the monitoring tools using lichens and bromeliads for air monitoring and bryophytes for water quality. In particular, the lichen *Parmotrema arnoldii* and the bromeliads *Tillandsia usneoides* showed similar heavy metal accumulation capacity. For water quality, the moss *Platyhypnidium aquaticum* was more effective in accumulating metals and metalloids than *Marchantia polymorpha*. These biomonitors are therefore confirmed as reliable tools for assessing environmental quality in tropical areas.

Other contributions in this Special Issue focused on forest heterogeneity in terms of tree species diversity and substrate affecting the diversity of epiphytic lichens and mosses. An interesting study carried out in natural forests of the Tibetan Plateau [11] contributes to deepening epiphyte bryophytes' ecological role in forest ecosystems, especially concerning the effect of the elevation gradient, which in turn affects tree species diversity.

In a different context, in the North-Western Italian Alps, Ongaro et al. [12] showed that common ash (*Fraxinus excelsior* L.) can represent an important tree substrate for the conservation of locally and nationally red-listed species of epiphytic lichens.

Still considering lichens, the review article focuses on the recent trends and future challenges for lichen biomonitoring in forests [1]. It provides a critical analysis of the topic from the point of view of the main methods adopted in various contexts, mainly focusing on lower-trunk epiphytic lichens, as they are the most studied in forest ecosystems. Lichen biomonitoring studies have been classified in four main categories based on (i) lichen diversity indices, (ii) lichen functional groups, (iii) the viability of single indicator species (see also the recent review paper by Ravera et al. [13]), and (iv) the bioaccumulation approach. The close interconnection between the aspects explored in this review provides a complex and multifaceted picture of the topic.

To conclude, we are aware that the topic addressed in this Special Issue is far from exhaustive. However, we hope readers will be inspired by the articles included here and find interesting food for thought for their research.

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