frontiers | Frontiers in Forests and Global Change

TYPE Editorial
PUBLISHED 18 July 2022
DOI 10.3389/ffgc.2022.952232

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to
Forests and the Atmosphere,
a section of the journal
Frontiers in Forests and Global Change

RECEIVED 24 May 2022
ACCEPTED 21 June 2022
PUBLISHED 18 July 2022

CITATION
Gessler A, Ferretti M and Schaub M
(2022) Editorial: Forest monitoring to
assess forest functioning under air
pollution and climate change.
Front. For. Glob. Change 5:952232.
doi: 10.3389/ffgc.2022.952232

Editorial: Forest monitoring to assess forest functioning under air pollution and climate change

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KEYWORDS

forest monitoring, global change, forest ecosystems, monitoring techniques, UNECE ICP Forests

Editorial on the Research Topic
Forest Monitoring to Assess Forest Functioning Under Air Pollution and Climate Change

Climate change and air pollution are globally threatening ecosystems and the services they provide to humanity. Forest ecosystems cover ca. thirty percent of the global land area and provide a vast array of ecosystem services, from global to local scales. Firstly, they store large amounts of carbon and—by continued sequestration—forests strongly contribute to the terrestrial carbon sink, thus holding considerable potential for climate mitigation as well as the substitution of fossil energy (Pan et al., 2011; Cowie et al., 2021). Secondly, they directly modulate local to global climate *via* their albedo, surface roughness, and their influence on the water cycle (Bonan, 2008). Thirdly, forests provide timber as construction material and fibers for bioenergy that mitigate greenhouse gas emissions, as well as for paper production and the chemical industry (cf. Richardson et al., 2006). Moreover, and prominently, forests are globally crucial for biodiversity conservation (Foley et al., 2005; Pilotto et al., 2020): temperate forest ecosystems are biodiversity hotspots and are thus partially balancing the biodiversity loss induced in agricultural systems (e.g., Donald et al., 2001). In addition, forests are of key importance for landscape aesthetics, recreation and tourism, especially in highly urbanized regions (Bell et al., 2009). They play an essential role in protecting human populations from natural hazards (Forest Europe., 2020) such as floods, snow avalanches, rockfall, erosion, and landslides, especially in mountain regions.

Numerous vital forest ecosystem functions and services are jeopardized by global change and by air pollution in its different form. For example, the projected increase in temperature together with a higher frequency and intensity of drought events constitute a large threat for European temperate forests, which already show signs of vulnerability

(Allen et al., 2010, 2015). In addition, air pollution by e.g., nitrogen deposition and ground-level ozone is—despite all abatement strategies in the past—globally still an important agent affecting tree and forest health (Braun et al., 2010; Fenn et al., 2010; Paoletti et al., 2010; Cailleret et al., 2018; Schmitz et al., 2019). Moreover, interaction between e.g., nitrogen deposition and climate change induced drought periods might aggravate negative effects on forest ecosystems (Gessler et al., 2016).

Often the effects of environmental stressors (be it increased temperature and water vapor pressure deficit, reduced soil water supply, increased ozone concentration, or nitrogen deposition above the critical loads) are chronic and the negative impacts on tree vitality and forest function emerge slowly. Sometimes, e.g., during hot droughts, trees are also affected quickly within a growing season or with a year lag (e.g., Rohner et al., 2021; Hunziker et al., 2022). To be able to (1) observe trajectories of forest functioning over long time scales and at the same time to (2) identify predisposing factors that might lead to a fast reaction of trees and forests to environmental drivers, long-term forest monitoring is crucial.

Over the last 30 years, the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) has developed into one of the world's largest forest monitoring networks. Its results provide information on forest health, growth, diversity, and effects of air pollution, and climate change. The objectives of the programme are (i) to provide a periodic overview on the spatial and temporal variation of forest condition in relation to anthropogenic and natural stress factors (in particular air pollution) by means of European-wide and national large-scale representative monitoring on a systematic network (Level I), and (ii) to gain a better understanding of the cause-effect relationships between the condition of forest ecosystems and anthropogenic as well as natural stress factors (in particular air pollution) by means of intensive monitoring on a number of selected permanent observation plots spread over Europe and to study the development of important forest ecosystems in Europe (Level II).

Under the Research Topic "*Forest Monitoring to Assess Forest Functioning Under Air Pollution and Climate Change*" updates on current topics related to forest monitoring are given, including new methodological developments and new results for a better understanding of growth and vitality of European forests.

Braun et al. reports on 37 years of monitoring of European beech in Switzerland on forest plots that cover gradients of drought, nitrogen deposition, ozone, age, altitude, and soil chemistry. They observed, that in already dry regions of Switzerland, the dry and hot summer of 2018 caused a serious branch dieback together with leaf yellowing and also increased mortality in beech (*Fagus sylvatica*). They could also show that drought periods in subsequent years were predictors for tree mortality and increased crown transparency and that three main factors i.e., hydraulic failure, energy starvation, pests and diseases could explain most of the variation in tree damage.

Ferretti et al. related stem radial growth to crown defoliation and damage in conifers. Their main finding was that there was a clear and significant negative correlation between defoliation and annual (or every 5–10 years periodically measured) stem diameter growth. This relationship became stronger when data were aggregated over longer time series in order to smooth out short-term fluctuations. The results generally support the widespread use of defoliation in many forest monitoring schemes as a rapid indicator of forest health and vitality.

Radial growth together with tree water dynamics is also in the focus of a methodological paper (Zweifel et al.). These authors describe the key features of the biological drought- and growth-indicator network TreeNet (https://treenet.info/) and thus highlight the steps from the installation of the point-dendrometer and soil and atmosphere related sensors in the field to data acquisition, data transmission, data processing, and online visualization. They also describe how the raw data obtained from the point-dendrometers are converted into information on tree water deficit and growth. The TreeNet network, allows tracking of the diurnal and seasonal cycles of tree physiology in near real-time, covering a wide range of temperate forest species and their respective environmental conditions across Switzerland.

Another methodological paper (Zolles et al.) assesses how temperature measurements inside and outside of a forest can provide information on leaf area index (LAI) and forest phenology. While the assessment of the annual dynamics of LAI and of the phenological phases is time consuming especially in deciduous forests, temperature information can be gained highly automated. The difference between the daily maximum temperature between the open land and the forest station was highly correlated with LAI for the years 2011–2017 but inclusion of additional years weakened the relationship. Moreover, within the growing season, different phenological events could be identified. There, is thus potential to use the temperature differences to characterize phenology and LAI dynamics, but the method cannot replace the conventional measurements.

A detailed analysis of leaf morphological traits was performed by Zhu et al. They analyzed leaf mass, leaf area (or needle length) and leaf mass per area (or needle mass per length) in a time series from 1995 to 2019 with leaves that were harvested every other year on 11 ICP Forests long-term monitoring plots comprising pure European beech and Norway spruce stands and one mixed stand. The stands covered gradients of elevation, precipitation, and temperature. Even though there were no long-term trends in leaf traits in beech, they were impacted by masting, crown defoliation, temperature, and water vapor pressure. In spruce, needle length decreased over time and needle traits were generally affected by spring conditions. The partially different temporal trajectories and environmental drivers for leaf traits in the two species might indicate differences in their adaptation and acclimation potential.

Nussbaumer et al. characterized the resource dynamics in mast years for European beech and oak species all over Europe. They therefore investigated the influence of mast years on stem growth, leaf production, and leaf carbon, nitrogen, and phosphorus in *Fagus sylvatica*, *Quercus petraea*, and *Q. robur* using long-term data from ICP Forests. In beech, before mast years, resources were accumulated, while during mast years resources switched from vegetative to generative tissues with reduced stem and leaf growth supporting, both, the resource storage and the resource switching strategy. In oak species, stem growth was reduced after mast years, suggesting that they solely rely on the resource storage strategy for masting. Different resource dynamics strategies in the two species might indicate differences in their adaptive capacity to a changing climate.

Dynamics of soil CO_2 efflux and vertical CO_2 production in a European beech and a Scots pine forest are in the focus of a study by Jochheim et al. The authors applied a combination of the flux-gradient method and closed chamber measurements to study the CO_2 efflux and the vertical distribution of soil CO_2 production. Soil CO_2 production at the beech site ranged over a greater soil depth than at the pine site, attributed to different fine root distribution. Even though, there was on average no difference in CO_2 efflux between the two sites, the flux of the beech site was higher in wet but lower in dry years. It was assumed that drought reduced heterotrophic respiration at both sites, but additionally decreased autotrophic respiration strongly at the beech stand.

The contributions in this Research Topic show that many "classical" monitoring techniques such as the assessment of growth, defoliation, or nutrient contents in leaves are still important and helpful to understand the trajectories of forest functioning under changing environmental conditions as well as the underlying mechanisms. New methods (such as point dendrometers or soil CO_2 measurements) provide particularly high temporal information that allows in some cases (Zweifel et al.) close to real-time analysis of the interaction between environmental drivers and their impact on ecosystem functioning. With the increased probability of extreme events, now-casting of the forest stress and health status will become more and more important and needs to be complemented by remote sensing approaches that allow high spatial coverage (Sturm et al., 2022) and the detection of early warning signals (D'Odorico et al., 2021) enabling us to detect stress response in the canopy before any visual signs of defoliation or leaf discoloration can be observed. These are, however, additional, complementary methods that cannot replace the methods used since long to generate long-term time series, but make them even more valuable.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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