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COMMENTARY

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A new perspective on tree growing season determination

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Abstract

Defining plant development timing through seasonal growth and dormancy phases is a valuable proxy for studying climate change and serves as an annual bioindicator. However, current methods for determining the growing season vary due to species-specific interpretations and differing understandings of its main drivers. Körner et al. (2023) introduced four *non-interchangeable* definitions of growing seasons to clarify this complex issue. While some studies have paired different methods, none have simultaneously applied a full set of methods at the individual tree or species level. Here, I aim to present a new perspective to understanding growing season timing by focusing on all facets of above-ground tree growth and measurable biological and phenological markers. This approach calls for simultaneous, continuous monitoring during active and dormancy periods on the same trees and across different species at a large spatial scale. The goal is to comprehensively understand each method's errors, temporal lags, and the factors determining each growing season, as defined by Körner et al. (2023, Ecology Letters, 26, 1277). Accurate estimation of growing season timing can reshape our understanding of its environmental drivers, improve terrestrial ecosystem models, assess the impact of climate change on tree growth, determine the biological zero for various species, verify remote sensing indices and forecast species distribution.

KEYWORDS
interdisciplinarity, long-term monitoring, phenology, plant ecology, temporal lag, timing

1 | ONSET, CESSATION AND LENGTH OF THE TREE GROWING SEASON

For centuries, it has been recognised that plants have a seasonal cycle and, thus, a growing season highly related to climatic seasonal patterns (e.g. *De causis plantarum of Theophrastus*, Einarson & Link, 1976). The growing season of trees occurs when local environmental conditions permit established growth and development. It has an onset, a cessation and thus a length. Its onset can be defined as when primary growth (e.g. budburst, foliage and shoot) and secondary growth (e.g. cambium differentiation and xylem formation) start. Cessation occurs when growth stops or when leaves become brown and fall. Between the cessation of growth and its commencement is the dormant period. Deciduous trees do not photosynthesise during dormancy, and evergreens do at a slow rate and for restricted periods. Despite this general, although vague, concept of the growing season, species- and methods-specific definitions of its onset and cessation, thus its length, vary substantially. To conceptualize and sort out the theory behind this complex issue, Körner et al. (2023) introduced four *non-interchangeable* ways to define the growing season. Each definition implies various methods to estimate the onset and cessation of the growing season, resulting in different dates and lengths. The growing season sensu stricto is when a plant or part of it grows and produces new tissue, irrespective of net carbon gain (Körner et al., 2023). The phenological season is defined by developmental phenological markers (Körner et al., 2023). However, plants may become photosynthetically active long before a visible development advance, such as budburst (Fry & Phillips, 1977; Havranek & Tranquillini, 1995; Lempereur et al., 2015) and after invisible developmental states and processes (metabolism activation and hormones production), which complicates the definition of the onset and cessation of a phenological season. The productive season is the first and last passing across a minimum biomass production rate or net carbon gain (Körner et al., 2023). The meteorological season is when plants can grow based on experience, using meteorological criteria (Körner et al., 2023). As Körner and Hiltbrunner (2018) stated, two aspects are essential while working with meteorological data: the location of the action, meaning air, plant or soil data and the time scale: hour, day, month, season or year.

Knowing the complexity of the topic and acknowledging the ecological value of Körner et al. (2023) work, which certainly clarifies the interpretation of the growing season, I propose a simplification concerning tree species and above-ground visible and measurable phenological markers. The timing of the growing season also involves roots, hormones and gene expression, which are fundamental but challenging to measure at large scales and for long periods of time. Körner et al. (2023) strategically described the four growing seasons, including the meteorological one, which is widely used in the ecology community but often gives contrasting results on the timing and lengthening of the growing season due to arbitrary temperature thresholds. While I concur with Körner et al. (2023) regarding the four distinct and non-interchangeable approaches, I propose to the ecology, climatology and dendrology community a joint effort on combining each of these seasons to have a holistic view of tree growth and development from soil to air and from stem to crown. Recent studies have paired leaf phenology with cambium activity and xylem growth (e.g. Gričar et al., 2022), gross primary productivity estimated from eddy covariance data with cambium activity and sapwood area (e.g. Puchi et al., 2024) and remote sensing data with dendrometer data (e.g. Purdy et al., 2023). However, no study has simultaneously combined multiple approaches on the same trees over extended periods, including dormancy monitoring.

My new perspective develops by integrating the four growing seasons conceptualized by Körner et al. (2023), simultaneously on the same trees and analysing a wide range of tree species at larger spatial scales for a long time. Doing that makes it possible to comprehensively understand the error and the temporal lag between each method and the factors determining each growing season at the tree species level without interpretation but at the cost of an interdisciplinary and long-term monitoring analysis.

2 | THE IMPORTANCE OF INTERDISCIPLINARY AND LONG-TERM MONITORING RESEARCH

Recent advancements in recording multiple physical and biological parameters in semi-real time and installing devices recording high-temporal scale data at a relatively low cost have facilitated the creation of several ecological networks. Noteworthy examples include DendroGlobal and TreeNet for dendrometer data, SAPFLUXNET for sap flow data (Poyatos et al., 2020) and GloboXylo (Rathgeber, 2019) for xylogenesis data. Networks like the European Phenology Network (van Vliet et al., 2003) and the International Phenological Garden (Renner & Chmielewski, 2022) contribute to phenological and long-term monitoring efforts. Fluxnet and ICOS, which use flux towers with eddy covariance measurements of carbon dioxide and water vapour fluxes since the late 1990s, have significantly advanced the study of long-term global change biology (Baldocchi, 2020). Moreover, phenological monitoring using near-surface sensors, such as Unmanned Aerial Vehicles (UAVs), PhenoCams and Spectral Reflectance Sensors, and satellite sensors, particularly multispectral Sentinel-2 imagery, has proven effective for forest leaf phenology studies and land surface phenology assessments for specific species (Misra et al., 2020; Thapa et al., 2021). However, despite many disciplines dealing with changes in the timing of life-cycle events in response to climate change, the efficiency of monitoring, using and integrating multiple biological and phenological data from existing networks is surprisingly low.

Therefore, there is an urgent need to consider the growing season in all its facets, bridging different fields from leaf, fruits and flowering phenology to dendrochronology, wood anatomy, climatology, ecophysiology, remote sensing and climate and species distribution modelling.

Considering Körner et al.'s (2023) classification of the four growing seasons, I advocate for a comprehensive approach at both the tree and species levels. This approach aims to combine the growing season sensu stricto quantified through dendrometer, sap flow and xylogenesis methods; the phenological season observed through in situ observations and remote sensing data; the productive season measured through eddy covariance and the meteorological season based on soil humidity, stem and air temperature. Each method is subject to various sources of error and bias, such as survey timing (e.g. weekly or biweekly) and data fitting function, resulting in different timings of onset and cessation. So far, the extent of these potential errors has yet to be precisely discovered. However, combining them in long-monitoring research makes it possible to estimate the errors and the timing of each method's growing season temporal lag and, thus, to accurately determine the onset, cessation and length of the growing season (Figure 1). Once the timing of the growing season and the temporal lag are known for each method and each species growing in different climate conditions, the length of the growing season can be temporal and spatially upscaled and modelled. Additionally, to understand the tree growing season at tree and species levels in terms of drivers, timing and length, biological and phenological events must be analysed in a continuum, including trees' active and dormancy periods and factors such as individual genetic variation, plant age, light availability and microclimate and environmental conditions. In this respect, the International Phenological Garden network's use of homozygous trees propagated vegetatively allows for disentangling genetic effects from climate and environmental factors.

This new perspective based on an integrated approach aims to reveal the endogenous and exogenous factors affecting the growing

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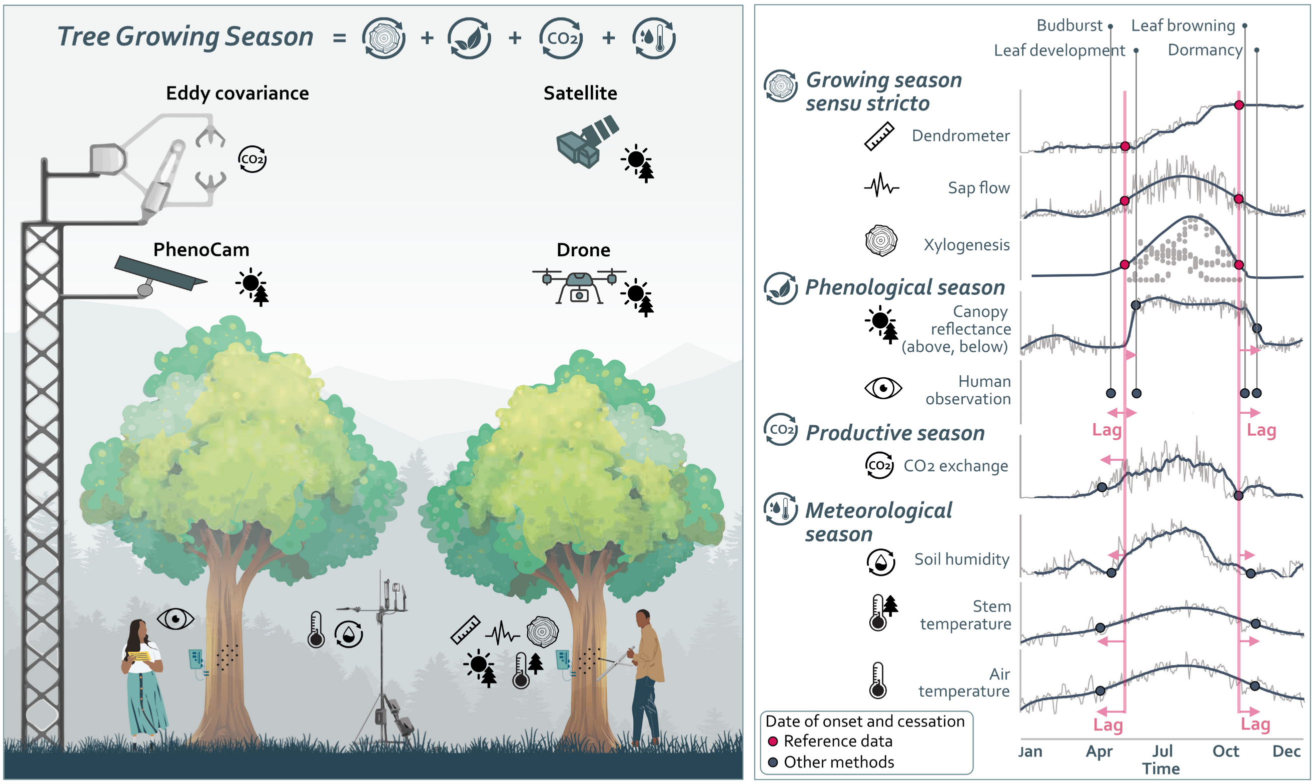

FIGURE 1 Schematic representation of the interdisciplinary sampling design and the methods used to estimate the timing of the four growing seasons (Körner et al., 2023) such as the growing season sensu stricto, the phenological season, the productive season and the meteorological season. Mock data show the trend of each method; the black circles represent the onset and cessation estimates from each method within the annual window for the North Hemisphere, and the red circles show the onset and cessation of the dendrometer, sap flow and xylogenesis method considered a reference. The red lines represent the onset and cessation of the growing season and the related lag (red arrows) produced by each method.

season's timing and length, enhancing our understanding of trees' responses to climate change and improving forecasts.

I, therefore, call for new research integrating multiple methods, considering xylogenesis, dendrometer, and sap flow as reference measurements, estimating the temporal lag of all the other methods, and combining results from different networks. Dendrometer and sap flow methods should be incorporated into sites where xylogenesis studies are already in progress with the goal of forecasting and backcasting the timing of the growing season without the labour and time-demanding xylogenesis method.

This interdisciplinary approach aims to unravel one of the simplest, long-lasting but complex mechanisms regulating the seasonality of the trees with a strong implication in the context of climate change. Nonetheless, long-term monitoring will allow understanding and ranking of the main growing season determinants. It will also facilitate the integration of phenological models, which use the timing of phenophases (e.g., leafing, flowering, fruiting, and senescence) with forest productivity and carbon cycle models that depend on primary and secondary growth metrics (e.g., branch and root biomass, ring width, and aboveground biomass). This integration will help to predict tree species distribution under future climate scenarios. Moreover, this approach will validate and verify remote sensing indices like the Normalized Difference Vegetation Index (NDVI) and determine the temperature thresholds—the meteorological season—for different species in different biomes.

In conclusion, understanding the growing season timing and length changes has potential implications for human life and various biological phenomena, such as ecosystem productivity, species-specific interactions, evolutionary responses, biodiversity losses and the establishment of non-native species.

AUTHOR CONTRIBUTION

AP developed the idea and wrote the manuscript.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable—no new data are generated, and the article describes entirely theoretical research.

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BIOSKETCH

Alma Piermattei is a dendrochronologist who studies plant and forest ecology, focusing on tree growth responses to climate change and the interaction with biotic and abiotic factors.

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