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IAWA Journal 46 (4), 2025: 433-435

iawa

Introduction

Quantitative Wood Anatomy: research applications, opportunities and challenges

In memory of Professor Pieter Baas

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Published online: 3 November 2025

Wood anatomy, as a branch of plant anatomy, dates back to the 1600s, and is generally well known for investigating the morphological characteristics, spatial arrangement, tissue proportion, structure, and function of various cells in the secondary xylem.

Since these early days, Quantitative Wood Anatomy (QWA) has emerged as a distinctive approach within the field of wood anatomy research over the past two decades. It aims to realise the quantitative extraction, mining, integration, and application of information on wood anatomical traits. In 2007, at the 2nd Workshop on QWA (WSL, Birmensdorf, Switzerland), QWA was defined for the first time as a "methodological approach based on the measurement of wood cell anatomical characteristics, analysed through time and used to characterise the relationships between tree growth and various environmental factors". Since then, the community of scientists working with QWA has grown considerably, and the research approach of QWA has been increasingly widespread across different disciplines.

QWA is a truly integrative research approach, applied at different tissue scales (e.g. from cell ultrastructure up to macro-anatomical level) and life forms (e.g. from herbaceous plants to dwarf shrubs up to giant trees). It uses traditional light microscopy techniques while benefiting from modern tools such as micro-computed tomography (micro-CT) and dedicated AI-based image analysis software. Moreover, it brings together scientists from various fields to address questions related to dendrosciences, ecophysiology, ecology, evolution, forest management and protection, geosciences, paleobotany, species identification, tree biology, wood dynamics and formation, wood quality, wood utilisation, and many more.

In the last decade, notable advances in QWA, including sample preparation, data collection, and analysis, have been made through the emergence of advanced detection equipment and rapid advancements in big data and digital technologies. This progress has strengthened fundamental research in the field and facilitated interdisciplinary collaboration. By quantitatively extracting, analysing, integrating, and applying wood anatomical information, scientists have established connections between anatomical characteristics, tree physiology, climate conditions, wood properties, and wood processing techniques.

This special issue includes major studies ranging from QWA support for phylogenetic studies, to new methodologies and tools, up to functional considerations. The proposal for a special issue of the IAWA Journal on QWA was made on February 19th, 2024. It aimed to emphasise recent advances in QWA research and related multidisciplinary fields, and to strengthen connections with relevant research groups, such as Q-NET (Von Arx *et al.* 2021), a QWA network established in 2020 for various contexts, currently supported by the Association for Tree-Ring Research (ATR), the International Association of Wood Anatomists (IAWA) and the Tree-Ring Society (TRS).

Published by Koninklijke Brill BV, Leiden

DOI 10.1163/22941932-00002330

On May 17th, 2024, the IAWA decided to dedicate this QWA special issue to the memory of Professor Dr. Pieter Baas (1944–2024). With Professor Baas's passing on April 29th, 2024, the IAWA lost a remarkable leader. Professor Baas was one of the most distinguished scientists in plant anatomy and wood anatomy, and the greatest advocate for worldwide cooperation of wood anatomists in our times. The announcement of the special edition was formally launched during the IAWA Symposium titled "The contribution of wood in forest: from wood dynamics to trait diversity and carbon gains" — an event originally organised by Professor Baas together with Professor Yafang Yin and Professor Veronica De Micco at the XXth International Botanical Congress (IBC), which took place in Madrid from July 21st to 27th, 2024.

This special issue contains three papers showing how QWA can be useful in phylogenetic studies. The paper by Sanches *et al.* is a valuable example of how the quantification of wood anatomical traits and the evaluation of morpho-functional features related to adaptations to different environments can contribute to the understanding of evolutionary processes in specific clades (i.e. Galphimioid in the Malpighiaceae). Rajput *et al.* described and quantified wood anatomy of young and fully grown mature stems of 13 species of the family Menispermaceae, including species with successive cambia and regular secondary growth, finally building a phylogenetic mapping. Beckers *et al.* presented the first wood anatomical overview of Sapotaceae based on about 450 species, summarising earlier works combined with over 150 new descriptions. The authors revealed several striking evolutionary patterns that will likely aid taxonomic and evolutionary studies, crucial for the conservation of this Family, which is threatened with extinction due to ongoing (illegal) logging practices.

Regarding new methodologies, also useful to fight illegal logging, the MultiWoodID is presented by Zeng *et al.* The authors developed this "intelligent system" for rapidly processing wood samples and identification from the cross-section. The proposed tool is a portable system containing a wood polisher, a portable image acquisition device, a wood identification model, a mobile application, and a web platform. It is targeted to help Customs inspectors who can quickly and accurately verify wood species on-site simply through a smartphone. Pokhrel *et al.* reported the development and application of an automated radial scanning microscopy-based imaging system for rapidly identifying, quantifying, and positioning, within earlywood or latewood, the resin canals in *Pinus taeda* L. wood. Resin canals are essential for tree defense in the Pinaceae family, and such a tool for rapid measurement and characterisation of resin canal characteristics is valuable in studies exploring their anatomical variability due to genetic and environmental effects. Renström *et al.* reported the development and application of Near-Infrared (NIR) imaging spectroscopy to map the physical (i.e. density, microfibril angle) and chemical (i.e. lignin, carbohydrates) properties of *Populus* wood sections. Calibrated using Pyrolysis-GC/MS and SilviScan data, the high-resolution NIR models showed strong performance in both greenhouse-grown and field-grown trees.

From a functional viewpoint, the dualism in the importance of hydraulic and mechanical functions in shaping wood traits is also considered in the SI. Jagels & Watson tackled the dispute of hydraulic and mechanical constraints to tree height growth. More specifically, they focused on tracheid length, as a proxy for microfibril angle, to test its relation to potential maximum tree height in North American conifers. The authors demonstrated that, in addition to well-studied hydraulic relations, biomechanical factors also contribute to establishing the limits of maximum tree height. They also underlined the importance of environmental factors and the possible impact of current climate change. Awano *et al.* studied the cell wall ultrastructure of the ultra-light wood of a swamp forest tree *Alstonia spatulata* Blume (Apocynaceae), using transmission electron microscopy. This study complemented a previous one by Pieter Baas to gain a better understanding of the fiber wall architecture and the overall ultrastructure of the driftwood. However, the gained information still has not solved the mystery of how small- to medium-sized trees can be supported by such a mechanically weak base.

With regard to the "variability issue" in wood anatomical structures, the paper by da Silva *et al.* explored the anatomical variation of wood anatomical traits in trunks and branches of four tropical deciduous and evergreen species of the Brazilian Atlantic Forest. They highlighted the importance of also considering parenchyma cells and fibers in analyses of the ecological anatomy and physiology of secondary xylem, for their contribution to hydraulic safety and efficiency. The importance of understanding wood variability was also highlighted by Liu *et al.* who analysed the radial anatomical variation with a focus on the transition between juvenile and mature wood in *Pinus elliottii* half-sib families. They outlined how systematic anatomical characteristics and determination of juvenile and mature wood can be helpful in guiding family selection in silviculture and optimising processing parameters in wood industries.

Lastly, from a more integrated view of plant hydraulics, Amitrano & De Micco performed a bibliometric analysis of 12 669 articles published in the last 25 years, aiming to compare thematic structures and integration across "leaf anatomy", "wood anatomy", and their intersection. The analysis revealed a significant asymmetry between consolidated wood studies and leaf research that appeared under-integrated, especially concerning whole-plant coordination. Very few studies address both organs concurrently, although integrating anatomical traits across wood and leaves is essential for refining whole-plant hydraulic models and predicting climate adaptation.

In brief, the diverse themes presented in this special issue mirror the breadth and depth of Professor Baas's versatility and are a tribute to his fervent curiosity and remarkable ability to inspire and bridge generations of scientists. These studies will enhance multi-disciplinary integration and update knowledge in wood anatomy.

Finally, we thank the authors and referees of this special issue for their great contributions.

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