

BIOINFORMATIC AND BIOMETRIC METHODS IN PLANT MORPHOLOGY¹

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Recent advances in microscopy, imaging, and data analyses have permitted both the greater application of quantitative methods and the collection of large data sets that can be used to investigate plant morphology. This special issue, the first for *Applications in Plant Sciences*, presents a collection of papers highlighting recent methods in the quantitative study of plant form. These emerging biometric and bioinformatic approaches to plant sciences are critical for better understanding how morphology relates to ecology, physiology, genotype, and evolutionary and phylogenetic history. From microscopic pollen grains and charcoal particles, to macroscopic leaves and whole root systems, the methods presented include automated classification and identification, geometric morphometrics, and skeleton networks, as well as tests of the limits of human assessment. All demonstrate a clear need for these computational and morphometric approaches in order to increase the consistency, objectivity, and throughput of plant morphological studies.

Key words: automation; charcoal shape; leaf shape; leaf venation; morphometrics; plant morphology; pollen classification; root networks.

Increasingly, quantitative approaches to plant morphology are changing the landscape of research for plant ecology, physiology, and evolution. Advances in microscopy, imaging, and computational analyses potentially allow more detailed investigations than have previously been possible. This has increased the variety and quantity of data available for phenotypic analysis, and is stimulating new directions and applications in the study of plant morphology. The increased speed and detail that can be captured by these new technologies also means that the information represented by shape and form can potentially be as rich a bioinformatic data source as genetic data.

As plant scientists, we are only beginning to discover the potential power of these quantitative approaches. On July 29, 2013, we chaired a special session of the annual Botanical Society of America meeting in New Orleans, Louisiana. The session sought to bring together plant morphologists, systematists, and paleobotanists, alongside computer scientists, applied mathematicians, and informaticians, who were united in their interest in developing or applying novel biometric or bioinformatic methods to the form and function of plants. Our aim was to provide a forum for a cross-disciplinary exchange of ideas and methods, addressing a wide range of applications and research goals, with the shared theme of the quantitative analysis

of plant morphology. This special issue is a result of that session.

The strong representation of paleoscientists in this issue reflects both our own backgrounds (palynology and paleobotany) and the field's general focus on morphological data. Outside of some exceptional circumstances (e.g., the Miocene *Clarkia* locality with organelles [Niklas et al., 1985] and DNA [e.g., Kim et al., 2004], 250-million-year-old sperm of *Glossopteris* [Nishida et al., 2003], and chromosomes in 180-million-year-old Osmundaceae [Bomfleur et al., 2014]), morphology is the key type of data we rely on. However, many other segments of the plant sciences use morphologic data and rely on comparative studies of the plant phenotype, including taxonomy, systematics, evolution, developmental biology, and horticulture. The methods presented in this issue will have relevance to these fields as well.

This issue includes both work presented in New Orleans (Green et al., 2014; Han et al., 2014; Bucksch, 2014; Mander et al., 2014) and invited work (Crawford and Belcher, 2014; Holt and Bebbington, 2014; Krieger, 2014). Research such as the early pioneering work on plant allometry (e.g., Niklas, 1994), the quantification of leaf shape for paleoclimatic analyses (CLAMP [e.g., Wolfe, 1993; Wolfe and Spicer, 1999; Spicer, 2007], leaf margin analysis [Wilf, 1997], and digital leaf physiognomy [Royer et al., 2005; Peppe et al., 2011]), and several advances in automated plant species identifications (reviewed in Cope et al., 2012) inspired this topic. There is a wide application and use of biometric and bioinformatic methods, more than a single issue can address. This collection highlights some recent and emerging methods in the study and application of plant form by many younger and early-career scientists.

Several papers in this collection discuss the application of biometric and bioinformatic methods in palynology by developing a Miocene pollen database with semantic image search capabilities (Han et al., 2014), testing applications of an automated

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pollen classifier (Holt and Bebbington, 2014), and analyzing differences in human and automated classification of grass pollen based on surface textures (Mander et al., 2014). Other papers highlight how biometric and bioinformatic methods apply to plants more broadly, including using skeleton networks to examine plant morphology such as roots (Bucksch, 2014), improving the quantification of geometric leaf shape metrics with a new protocol to measure leaf circularity (Krieger, 2014), comparing human and automated methods of quantifying aspects of leaf venation (Green et al., 2014), and applying morphometrics to charcoaled plant remains (Crawford and Belcher, 2014).

All of the papers included in this special issue present a compelling argument for the need for computational or morphometric approaches. Improved consistency of analyses, increased throughput, and increased objectivity are the primary reasons provided. Two papers go further and demonstrate some of the limitations of human assessment (Green et al., 2014; Mander et al., 2014), which emphasizes the importance of continuing to develop these types of methods. As more and more morphological and image-based data are gathered, our ability to analyze and interpret that data is of the utmost importance. In an age when it is possible to rapidly sequence whole genomes, objective, reproducible, and accurate assessments of morphology are a critical missing link to supporting phenomics and providing a broader context of how plant morphology relates to ecology, physiology, genotype, and evolutionary and phylogenetic history.

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