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A parsimonious and interpretable model of plant dimensional scaling

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Accurate dimensional scaling is essential for translating forest inventory measurements of stem diameter and height into estimates of tree volume, biomass, and carbon stocks, which underpin ecosystem function. Most existing scaling approaches fall into three broad classes: empirical allometries, metabolic scaling theory, and physiologically inspired models such as the pipe model. While widely used, these frameworks typically operate at coarse spatial or taxonomic scales, rely on poorly interpretable parameters, and offer limited insight into how scaling relationships vary across species and environments.

A recent parsimonious model of plant dimensional scaling is the T model, which describes tree height and crown area as a function of basal diameter. It uses just three parameters, all of which are physiologically interpretable and directly measurable functional traits. These are: (1) the initial ratio of height to diameter, or stem slenderness, which affects initial height growth rate as diameter increases, (2) maximum tree height, which affects the later saturating part of the height-diameter scaling, and (3) initial ratio of crown area to sapwood area, which is similar to the pipe model and determines the scaling of crown area with height and diameter.

Here, we combine measurements from Tallo, a large global dataset of individual tree measurements (spanning over 3000 species-site pairs) with high-resolution environmental data, to test and parameterize the T model for each species within each site. We show that: (1) The T model fits the data well, providing a parsimonious and interpretable model of plant dimensional scaling, (2) the estimated dimensional traits (i.e., the model parameters) show systematic variation across climatic gradients, suggesting an overall macroclimatic adaptation, (3) the traits exhibit substantial phenotypic plasticity, in that site-specific species-mean traits covary with environmental gradients in the same direction and magnitude as community-wide site-mean traits, (4) among coexisting species, especially in the tropics, the traits coordinate systematically with maximum height, reflecting adaptation to the light environment among different canopy strata. This systematic variation likely allows multiple trait combinations to achieve similar levels of species performance (or evolutionary fitness). Such 'functional equifinality' may provide a parsimonious explanation of biodiversity and species coexistence, complementing other known

mechanisms such as niche partitioning and neutrality.