**Tree Allometry: Quantifying Variation in Northern Hardwood Forests**

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**Background and Significance**

The complex, three-dimensional structure of forest vegetation has long been a subject of interest in the fields of ecology, forestry and plant physiology. This structure, and the development of it through time, has many important implications for understanding biomass structure, competition, and nutrient cycling in forest systems. Furthermore, the ability to accurately and inexpensively assess carbon stores has recently become desirable following increased interest in and monetization of carbon sequestration. Therefore, the goal of extrapolating important three-dimensional measurements (i.e aboveground biomass, volume, and carbon) from more easily obtainable two-dimensional measurements (i.e. diameter and height) has been the goal of many field studies and manipulative experiments.

In order to make these predictions, it is important to first understand the growth trajectory of trees. This is often conceptualized as a series of resource allocation “decisions” made by the individual tree (Weiner 2004). According to the classical view, at each point in time a tree has a given amount of resources and allocates them to various structures proportionally. According the allometric view, a tree has a resource allocation trajectory along a size, rather than time, gradient. This trajectory can also change as a result of variation in environmental conditions. This is referred to as allometric plasticity (Weiner 2004). The relationships between the environment, tree size and and resource allocation can then be used to inform models of the relationship between two-dimensional measurements and the three-dimensional parameters of interest.

Another concept central to this question is the universality of scaling in plants. This refers to the observation that most physical attributes of plants adhere to very simple relationships when viewed as a function of size (West et al. 2005). This fundamental principle of biology suggests, in contradiction to ideas regarding allometric plasticity, that the allometric relationships of trees would remain constant regardless of age or species. If the universal scaling laws apply to trees, it would follow that the resource allocation trajectory of trees must follow similarly simple functions (i.e. of the form ). Furthermore, the universal scaling laws imply that resource allocation trajectories are deterministic, and are not affected by changes in environmental variables.

The ability to address these questions has been hampered in the past by the high cost and effort associated with obtaining good data. In order to explore allometric relationships in trees, detailed measurements of mass and volume must be taken for the entire tree. This typically involves destructive sampling, and is therefore inhibitive in many cases. The data for this project are a synthesis of data from a multitude of smaller samples taken at the Hubbard Brook Experimental Forest in New Hampshire. The data thus represent an unusually comprehensive sample across different stand ages. This provides the unique opportunity to look more robustly at allometric relationships than is usually possible given the constraints of designing such a study.

**Objectives**

This paper will aim to establish whether the allometric relationships of trees vary with differences in stand age and species. Embedded in this central question are several opportunities for detailed analysis. For example, we will examine the differences in allometric relationships when predicting stem biomass, leaf biomass, or total biomass. Because leaves are not subject to the same biomechanical constraints as the stem, the two measures could yield different results when parsed apart. A further interesting question involves which predictor (diameter, height, or volume) is the most important. The results of this analysis will then be used to develop a modelling framework for application to similar forest systems. Finally, this paper will address the issue of propagating error from individual to stand level estimates.

**Research Design and Methods**

The data for this study come from a series of four previous studies conducted over a period of 50 years in various areas of Northern Hardwood Forest in the Northeast United States. The first of these studies, Whittaker et al. (1968) measured the biomass of trees from Brookhaven Forest, New York. The species sampled include *Pinus rigida*, *Quercus alba* and *Quercus coccinea*. 15 individuals of each species were destructively sampled. Stem weight, root weight, leaf weight, stem volume, and 5-year growth were measured. These measurements were then used to calculate component biomass and total volumes.

The second study, Whittaker et al. (1974), measured 93 trees from three species in 57 year old, even-aged stands representative of the Northern Hardwood forest found in this region of New Hampshire. The species sampled were: *Acer saccharum, Betula alleghaniensis,* and *Fagus grandiflora*. An additional 15 trees of the species *Picea rubens* and *Acer spicatum* were sampled from high elevation plots. Similar measurements as taken in Whittaker et al. 1968 were conducted and compiled.

Third, Fahey et al. (1998), measured biomass, diameter and height for 51 trees in the Hubbard Brook Experimental Forest. Here attention was focused on early successional forest types, which are mainly composed of pin cherry (*Prunus pennsylvanicus*). Biomass measurements were separated into stem biomass vs leaf biomass.

Finally, Fatemi et al. (2011), sampled trees in four, young even-aged stands in Bartlett Experimental Forest and White Mountain National Forest. Both of these forests are near Hubbard Brook and exhibit the same forest type and structure. The purpose of the study was to determine whether young stands exhibited different allometric relationships than the ones observed by Whittaker et al. (1974). Similar species were measured, with the addition of *Betula papyrifera*.

This study synthesizes the data collected from all of these studies, which represent a wide range of stand ages, species compositions, and locations within the Northern Hardwood forest type. The main point of interest is determining what factors are important in predicting stem biomass and leaf biomass from diameter and height. Therefore, a model will be developed using a GLMM (Generalized Linear Mixed Modeling) approach at first. The modelling framework used may change as meaningful results are accrued. For example, a Bayesian framework may need to be adopted if individual tree age is seen to be an important factor in determining biomass, because this was only measured in Whittaker’s studies. Initially, a power-function of the form will be assumed and used as the link function. Model selection will be used in order to determine which explanatory variables are significant.

The results of these analyses will be used first to make a statement on whether the allometric relationships of trees vary with differences in stand age and species. If they do vary, an attempt will be made to develop a predictive model which can be applied to similar forest systems.

**References**

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