Application of the pipe model theory to predict canopy leaf area

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The pipe model theory presents the idea that a unit weight of tree foliage is serviced by a specific cross-sectional area of conducting sapwood in the crown. Below the crown, a large fraction of the tree bole may be nonconducting tissue, so the sapwood area would have to be known to estimate foliage. We applied the pipe model theory to the analysis of several western coniferous species to learn whether the distribution of canopy leaf area could be accurately estimated from knowledge of the sapwood cross-sectional area at various heights. including breast height (1.37 m). Results are excellent, but taper in the conducting area must be considered when sapwood area is measured below the crown.

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La théorie du modèle tubulaire introduit l'idée qu'une unité de poids du feuillage de la couronne d'un arbre est alimentée par une surface transversale spécifique d'aubier conducteur. Sous la couronne, une grande partie du tronc peut ne pas avoir de tissu conducteur, si bien que la zone d'aubier devrait être connue pour estimer le feuillage. Nous avons appliqué la théorie du modèle tubulaire à l'analyse de plusieurs espèces de conifères de l'Ouest pour savoir si la distribution de la surface de recouvrement foliaire pourrait être estimée avec précision en connaissant la surface transversale d'aubier à différentes hauteurs, y compris à hauteur de poitrine (1,37 m). Les résultats sont excellents, mais la conicité dans la zone conductrice doit être prise en considération lorsque la surface d'aubier est mesurée sous la couronne.

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Introduction

From an analysis of various vascular plants, Shinozaki *et al.* (1964*a*, 1964*b*) found that a linear proportionality exists between the weight of foliage and the weight of nonphotosynthetic tissue from the base of the live canopy upwards. They concluded that a given unit of leaves was serviced by a continuation of conducting tissue of constant cross-sectional area, analogous to a pipe system.

The original work by Shinozaki *et al.* (1964*a*) also clearly demonstrated that below the live crown no fixed ratio existed between total cross-sectional area and the supported foliage. They concluded that an increasing proportion of the vascular system in the stem below canopy height was nonconducting but did not quantify the relationship.

These ideas have been used to estimate the canopy leaf area from knowledge of the sapwood area at breast height (1.37 m), where diameter measurements are normally taken by foresters (Dixon 1971; Grier and Waring 1974; Waring *et al.* 1977; Whitehead 1978; Rogers and Hinckley 1979; Kaufmann and Troendle 1981). Initially, the analyses were expressed in foliage weight per unit of conducting area (Grier and Waring 1974). Leaves of more shade-tolerant species, however, were known to vary in weight in proportion to light (Larcher 1980), so for general application of the pipe model, area was substituted for leaf weight.

Detailed studies of large trees, sectioned and delineated by conducting area at intervals below the crown (Huber 1928; Morikawa 1974), show that while the proportion of wood conducting water decreases toward the base, the area continues to increase. The absolute amount increases, particularly below the zone of butt swell. This would suggest that the pipe model should apply rigorously only when the conducting area is determined from the base of the crown upward. In the recent paper by Kaufmann and Troendle (1981), no differences were reported in the amount of leaf area supported by a unit of conducting sapwood tissue from breast height upward. In this paper we demonstrate that such differences do exist when trees are sampled that have an extensive part of their bole length free of branches. We further indicate that the cross-sectional area of sapwood tapers linearly between breast height and the base of the crown so that accurate estimates of canopy leaf area are possible from measurements of sapwood taken at breast height. Finally, we summarize for conifers all published accounts for the relationships between conducting sapwood area and leaf area.

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