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TESTING A GROUND-BASED CANOPY MODEL USING THE WIND RIVER CANOPY CRANE

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ABSTRACT. A ground-based canopy model that estimates the volume of occupied space in forest canopies was tested using the Wind River Canopy Crane. A total of 126 trees in a 0.25 ha area were measured from the ground and directly from a gondola suspended from the crane. The trees were located in a low elevation, old-growth forest in the southern Washington Cascades. The ground-based model was based on six measurements and assumptions about the individual crown shape (e.g., conic, parabolic), the crane-based measurements required up to 377 measurements per tree. The two models were then compared, both by species and by crown position, to see where major discrepancies occurred. At the stand scale, ground-based and crane-based models of canopy structure were similar. At the scale of individual trees, however, ground-based estimates of crown volume differed significantly from the more detailed models of crown shape afforded by direct canopy access with the crane. Douglas-fir crowns were overestimated by 10.6%, Pacific yews were overestimated by 0.8% and western hemlocks were underestimated by 1.9%. While errors for yew and hemlock were smaller than for Douglas-fir, their standard deviations are much higher: 0.09 for Douglas-fir and 0.13 and 0.12 for Pacific yew and western hemlock, respectively. Most of the error resulted from model estimates of the lower crown, as epicormic branching and uneven shading caused highly irregular lower crowns in Douglas-fir. Over 85% of the differences between the two models among all the Douglas-fir trees were in the lower halves of the crowns. Similarly, 74% of the hemlock error and 58% of the Pacific yew error resulted from differences in their lower crowns. At the stand-level, the ground-based model of crown volume and the vertical distribution of foliage provided estimates consistent with more the detailed measurements made using the canopy crane.

Key words: canopy model, ground-based measurements, crane-based measurements, canopy model comparisons, old-growth canopy, Douglas-fir canopy, Douglas-fir, *Pseudotsuga menziesii*, western hemlock, *Tsuga heterophylla*

INTRODUCTION

The canopy is the location of many critical ecological processes in forests and a source of much of the forest's biological diversity (Schowalter et al. 1981, Erwin 1983, Terborgh 1985, Parker et al. 1992). Canopy structure—the spatial arrangement of tree stems, branches, and foliage—directly influences the form and function of canopy processes (Sillett 1995, Van Pelt 1995, Lyons 1998). In particular, canopy structure can exert influences on habitat quality for arboreal mammals, insects, and birds, including the spotted owl. Studies of the northern spotted owl (*Strix occidentalis caurina*) suggest that certain canopy structures may improve owl foraging success (Carey et al. 1992, North 1993, Rosenburg et al. 1994), and is one reason for the owl's association with old-growth forests (Carey 1985). Despite its importance, the stand-level structure of the canopy has had little quantitative study because limited access makes quantification difficult and integration of detailed measures for many tree crowns is necessary. With the installation of a canopy crane in an old-growth Douglas-fir (*Pseudotsuga menziesii*) forest, ecological research is poised to investigate the environment above the forest floor. Before the species and processes of the canopy environment can be better understood, a fundamental analysis of canopy architecture is needed.

Previous studies of canopy structure can be broadly grouped into analyses at three different scales: the fine scale found within a tree crown; the medium or stand scale; and the coarser scale of regional canopy cover. Most canopy studies have been done at the fine or coarse scales because of access and analysis problems. Using fixed platforms and climbing ropes, studies of fine-scale structure have assessed branching patterns and foliage distribution by climbing into and directly measuring components of tree crowns (Perry 1977, Pike et al. 1977, Massman 1982). These studies have documented that each

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tree crown is unique and highly irregular, making it difficult to scale up from the few accessible trees to an analysis of stand-level canopy structure. Large-scale analysis has measured canopy structure using aerial photographs or satellite imagery over sections of landscapes (e.g., Cohen and Spies 1992, Wu and Strahler 1994). These remote methods can assess the upper surface of the canopy, but provide little information about the interior structure of the canopy environment.

An accurate measure of stand-level canopy structure is needed because most monitoring, planning, and management of forests occurs at this spatial scale. A practical method of measuring structure should eventually be ground-based, because few forest managers have direct access to the canopy environment. A ground-based measure should provide foresters and ecologists with a consistent, quantitative means of comparing canopy structure between stands. Models of tree crowns developed from ground-based measures have been proposed for measuring canopy structure (Van Pelt and North, 1996). The accuracy of such models, however, must be tested against actual measurements of foliage distribution for an aggregate of adjacent trees.

The objective of this paper is to compare a proposed ground-based estimation of crown volume (Van Pelt and North 1996) with a more detailed model developed from measurements using the canopy crane in a structurally complex forest at the Wind River Experimental Forest.

Study Site

The 4380 ha Wind River Experimental Forest lies within the Gifford Pinchot National Forest near Carson, Washington. The Thorton T. Munger Research Natural Area (RNA) is located within the Experimental Forest at the east end of Trout Creek Hill, an extinct Quaternary volcano. The old-growth forests at Wind River are dominated by Douglas-fir and western hemlock (*Tsuga heterophylla*), with western redcedar (*Thuja plicata*) abundant in places. Pacific yew (*Taxus brevifolia*) is abundant as a small understory tree. There is no evidence of major fire at the site in at least 300 years, and stumps in an adjacent area indicate some trees were more than 500 years old when cut in the 1970s (Franklin and Waring 1980). Dominant disturbance now is one of small-scale gap disturbance from windthrow, insects, and pathogens (Franklin and DeBell 1988).

In the fall of 1994, an 80 m tall construction crane was placed at the east end of the Thorton T. Munger RNA along an old railroad bed. The jib of the crane is 85 m long and allows access, via a small gondola, to a 2.5 ha circle of forest. A four ha square plot is centered on the crane, completely enclosing the circle. All trees in this larger plot are permanently tagged and mapped as part of a long-term study of old-growth population dynamics.

Field Procedures

A 0.25 ha square within the crane circle was randomly chosen as the study plot. This plot size was large enough to encompass a large number of trees of several species, but small enough to sample in a reasonable amount of time.

Ground-based Measurements

Each tree > 5 cm diameter at-breast-height within the 50 × 50 m plot was measured for height, crown base height, and four cardinal crown radii. A compass was used to determine the direction for the crown radii measurements. Crown radii were determined by marking the ground location under the edge of the crown (i.e., the dripline), by sighting the outer edge of the crown foliage along a clinometer held at a 90° angle. Each crown was visually assigned one of four shapes; cone, cylinder, truncated ellipse, or umbrella. The four shapes had been determined from previous comparisons of Pacific Northwest crown shapes that different field technicians could repeatedly identify in common. All measurements were made from the ground, using tapes and clinometers.

Crane-based Measurements

For each canopy tree within the plot, the gondola of the crane was lowered parallel to the crown for as far as was possible. Because the trees cannot be touched by the gondola or by the supporting cables, all portions of all trees were not accessible. The cab of the crane contains a positioning device that gives the gondola's location (x, y, z coordinates). To minimize slack variation in the height value (z), we collected measurements only while being lowered. Each tree was assessed from above and vertical drops were made down each shaft affording gondola access. Gondola access varied with each tree, but all trees were measured with three to five drops from different angles. Measurements were collected at 2 m intervals along each drop.

From the gondola, the distance from the trunk of the tree to the outermost foliage was measured using a graduated 5 m fiberglass telescoping pole. The pole was extended to the trunk and the distance to the outermost foliage intersected was recorded. Once all the possible drops for all of the trees in the plot were finished, we completed the few missing measurements and the measurements on the smaller trees by doing the same measurements from the ground. These were made with the telescoping pole, a clinometer, and tape.

Analysis

Each crane-based measurement was first converted into x, y, z coordinates. Crown volumes for the ground-based measurements were calculated based on the appropriate conic shape (Van Pelt and North 1996) and 'sliced' into 1 m disks, each with its own volume. Crown shape was modeled by connecting the coordinates so that each crown was a solid constructed from up to 377 measurements of the crown envelope. (FIGURE 1). The modeled solids were used to calculate crown volume by summing the volume of disks up the length of the crown. The differences between the two methods were compared on a tree-by-tree, meter-by-meter basis.

RESULTS

At the stand scale (summing all trees), the two methods produced similar values. The ground-based model calculated a total crown volume that was 3.7% greater than the value produced by the more detailed crane-based measurements (TABLE 1). When separated by species, the two methods still were consistent. The largest difference was for Douglas-fir, which the ground-based model estimated as having a total crown volume 10.4% greater than the crane-based model.

On an individual tree basis, however, there were large differences. Some trees were underestimated from the ground by over 50%, while others were overestimated by nearly 50% of the crane-based model (range 44–141% error). The largest errors, however, originated from the smaller understory hemlocks and yews.

Some of the variability between the ground-based model and the crane-based measurements is depicted in the cross-sections (FIGURE 2). The Douglas-fir cross-sections (FIGURE 2A) show the poor fit of the model at the crown base but the fairly good fit for the top of the crown. In the larger hemlocks (FIGURE 2B), the ground-based model closely resembles the full crown shape. The smaller, understory hemlocks, however, do not resemble the simple geometric shapes of the ground-based model. Pacific yew was the most variable species and crown dimensions often did not conform to the ground-based model (FIGURE 2C).

There were different amounts of error in the different vertical strata (FIGURE 3). The largest error for ground-based Douglas-fir measurements was an overestimation of crown volume in the middle and lower sections of the stand (FIGURE 3A). The ground-based model, however, missed the epicormic 'fans' below the main crown that are included in the volume calculation for the crane-based model, resulting in an underestimation of Douglas-fir crown volume beneath the continuous crown.

The lower crowns of the hemlocks were generally overestimated by the ground-based model (FIGURE 3B). This section was predicted to be the widest in the tree, but many of the hemlocks

FIGURE 1. A small section of the mapped stand as modeled in the computer based on measurements collected using the canopy crane. The trees were simulated using 3-D software (Metacreations 1998).

TABLE 1. A comparison of ground-based and crane-based estimation of canopy volume for all trees in a 50 × 50 m plot. The standard deviations (SD) for western red cedar, Pacific silver fir, and grand fir are not included due to their small sample sizes. The three other trees were small Pacific dogwood trees which did not significantly contribute to canopy structure.

Species	N	Canopy Volume (m^3)		% Difference	SD
		Crane-based	Ground-based		
Douglas-fir	21	14,043	15,680	+10.4	0.09
Western hemlock	56	17,823	17,481	−1.9	0.12
Pacific yew	40	735	758	+0.8	0.13
Western red cedar	3	1591	1542	−0.3	—
Pacific silver fir	2	33	30	−0.9	—
Grand fir	1	54	59	+0.9	—
other	3				
Totals	126	34,279	35,550	+3.7	0.17

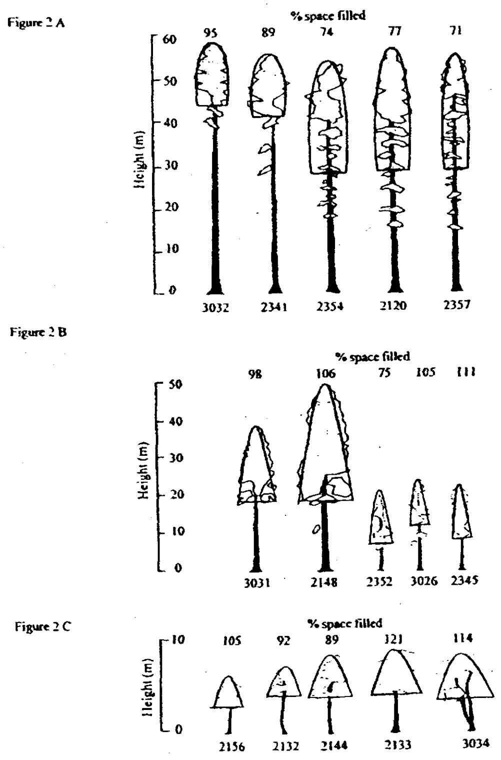

FIGURE 2. The crane based model is shown in gray, and the ground-based model is shown as an outline. The percent difference between the two is shown at the top of each tree profile. Numbers below each tree are the tag numbers assigned by the Wind River Canopy Crane project. *A.* Cross-sections of five Douglas-fir trees showing profiles modeled using both methods. *B.* Cross-sections of five western hemlock trees. *C.* Cross-sections of five Pacific yew trees.

actually had sparse or irregular crown bases. Conversely, the upper crowns were underestimated because the ground-based model predicted narrower crowns than were actually present. For hemlock, the overall differences between the two methods were surprisingly small—the ground-based estimates were only 1.9% below those of the models developed from the data collected from the canopy crane. The fairly large errors on individual trees may cancel each other out when the values are summed for the whole stand.

DISCUSSION

Using this approach we do not know the actual shape of the tree crowns being measured. We have assumed the crane-based model is more accurate because it is calculated from numerous direct measurements of crown width. However, these measurements do not account for many small-scale irregularities in individual crown architecture. Furthermore, both models treat tree crowns as solid foliage volumes, which ignores space between branches and the area close to the tree bole which usually does not have foliage. The crane-based model cannot provide a true measure of crown architecture, but it should be a closer approximation of these complex, irregular, three-dimensional shapes.

Douglas-fir crowns can grow very tall in the canopy of old-growth forests. While the tops of these trees may conform to a simple model, the mid to lower crowns can be quite irregular and unpredictable. Model estimate errors for Douglas-fir were the highest of the species examined and were largely due to the unpredictable nature of the lower crowns of these old trees. Revising the simple model would not necessarily improve its accuracy, as each tree's lower crown is unique.

Figure 3 A

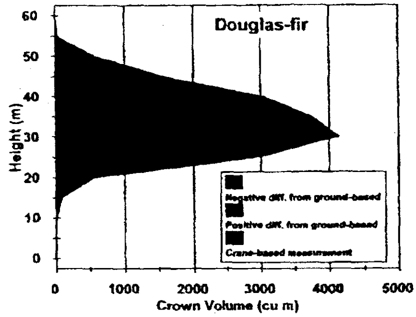

Figure 3 B

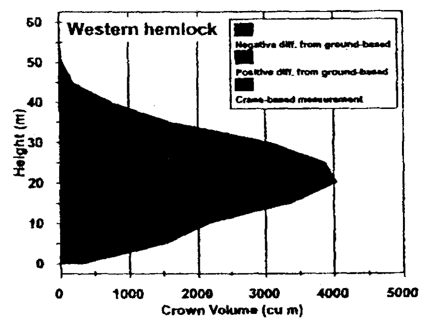

FIGURE 3. Canopy volume profiles calculated from one meter thick discs using ground-based and crane-based models. *A.* For Douglas-fir, the ground-based model underestimates volumes at both the top and bottom of the crowns, and overestimates the mid to lower crowns. The ground-based model filled in too much in the sparse lower crown, but did not include branches below the base of the continuous crown. *B.* For hemlock, the individual tree differences between the two models tended to balance out when foliage volume was summed at the stand level, the differences although largely negating each other for the stand as a whole. The ground-based model filled in too much in the lower crowns but slightly underestimated the upper crown.

For hemlock, the small difference (1.9%) between the two methods can be partially explained by two conditions: 1) the larger hemlocks, which make up the majority of the foliage volume, were fairly regular in shape, and conformed well to the predicted shape. The wildly eccentric intermediate and suppressed trees (which account for the high variance) were a small contribution to overall crown volume; 2) The errors from ground-based estimates included both under- and overestimates of the measurements obtained from the canopy crane, which canceled each other out. The intermediate trees, whose crown volumes were significant but were still irregularly shaped, were the largest source of difference between the two models. For suppressed trees, the crowns were small enough that the average volume differences between the two models were low, even though the ground-based model of crown shape did not match the more detailed crane-based model.

Ground-based measurements were weakest at modeling individual crown profiles in low-light conditions. Both understory trees and tall tree foliage below the crown base were poorly estimated by the ground-based model. This may result from crowns becoming more irregular in low-light conditions as branches die and epinastic control weakens. Even in conifers with strong apical dominance, crown profiles may not approximate simple geometric solids when sunlight is patchy or diffuse. The multi-layer canopy and small gaps of old-growth forests create highly heterogeneous light conditions. Ground-based model estimates of crown shape would probably be most accurate in young stands which often have a dense, uniform crown layer and low understory light levels.

The ground-based model provides a good approximation of the vertical distribution of foliage and total foliage volume of a stand. The foliage volume of crown areas poorly estimated by the model were a small part of the stand's total foliage volume. Although individual crown irregularities and foliage below crown base were not effectively modeled, over- and under-estimations in the ground-based model averaged out. For assessing different stands, a ground-based model may provide repeatable, comparable measures of stand-level canopy structure. However, ground-based canopy modeling would not provide sufficient detail for studies of ecosystem functions or species that respond to fine-scale, individual tree architecture.

While the ground-based model has some shortcomings when estimating the canopy volume of individual trees, stand-level estimation is consistent with more detailed model estimations. Further tests of this method are needed in other forests. Because the ground-based model uses geometric shapes often approximated by conifer crowns, we hope this model may have wider applications to other coniferous forests.

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LITERATURE CITED

Carey, A.B. 1985. A summary of the scientific basis for spotted owl management. Pp. 100–114 *in* R.J.

Gutierrez and A.B. Carey, tech. eds. Ecology and Management of the Spotted Owl in the Pacific Northwest. USDA Forest Service PNW-GTR-185.

Carey, A.B., S.P. Horton and B.L. Biswell. 1992. Northern spotted owls: influence of prey base and landscape character. Ecol. Monogr. 62: 223–250.

Cohen, W.B. and T.A. Spies. 1992. Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery. Remote Sensing Environm. 41: 1–17.

Erwin, T.L. 1983. Tropical forest canopies: the last biotic frontier. Bull. Entomol. Soc. Am. 29: 14–19.

Franklin, J.F. and R.H. Waring. 1980. Distinctive features of the northwestern coniferous forest: development, structure, and function. Pp. 59–86 *in* R.H. Waring and Schleisinger, eds. Forests: Fresh Perspectives from Ecosystem Analysis. Oregon Sate Univ. Press. Corvallis, Oregon.

Franklin, J.F. and D. DeBell. 1988. Thirty-six years of tree population change in an old-growth *Pseudotsuga-Tsuga* forest. Canad. J. Forest. Res. 18: 633–639.

Lyons, B. "Crown structure and spatial distribution of epiphytes on three height classes of western hemlock in an old-growth forest, Wind River WA." Masters thesis, The Evergreen State College, Olympia, Washington, 1998.

Massman, W.J. 1982. Foliage distribution in old-growth coniferous tree canopies. Canad. J. Forest. Res. 12: 10–17.

Metacreations, 1998. Ray dream studio 5. Metacreations, Inc. Carpenteria, California.

North, M.P. "Stand structure and truffle abundance associated with the northern spotted owl." Ph.D. diss., University of Washington, Washington, 1993.

Parker, G.G., A.P. Smith, and K.P. Hogan. 1992. Access to the upper forest canopy with a large tower crane. BioScience 42: 664–670.

Perry, D.R. 1977. A method of access into the crown of emergent canopy trees. Biotropica 10: 155–157.

Pike, L.H., R.A. Rydell and W.C. Denison. 1977. A 400 year-old Douglas-fir tree and its epiphytes: biomass, surface area, and their distributions. Canad. J. Forest. Res. 7: 680–699.

Rosenberg, D.K., C.J. Zabel, B.R. Noon and E.C. Meslow, 1994. Northern spotted owl: influence of prey base—a comment. Ecology 75: 1512–1515.

Schowalter, T.D., J.W. Webb and D.A. Crossley. 1981. Community structure and nutrient content of canopy arthropods in clearcut and uncut forest ecosystems. Ecology 62: 1010–1019.

Sillett, S.C. 1995. Branch epiphyte assemblages in the forest interior and on the clearcut edge of a 700-year-old Douglas-fir canopy in western Oregon. Bryologist 98: 301–312.

Terborgh, J. 1985. The vertical component of plant species diversity in temperate and tropical forests. Amer. Nat. 126: 760–766.

Van Pelt, R. "Understory tree response to canopy gaps in old-growth Douglas-fir forests of the Pacific Northwest." Ph.D. diss., University of Washington, Seattle, 1995.

Van Pelt, R. and M. P. North. 1996. Measuring canopy structure in Pacific Northwest old-growth forests using a stand-level crown model. Northwest Sci. 70: 15–30.

Wu, Y. and A.H. Strahler. 1994. Remote estimation of crown size, stand density, and biomass on the Oregon Transect. Ecol. Applications 4: 299–312.