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Research Note No. 28 December 16, 1989

A CHANGE IN THE HEIGHT-TO-CROWN BASE MODEL FOR SIX CONIFER SPECIES OF THE CALIFORNIA MIXED CONIFER REGION

By

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INTRODUCTION

Crown information is commonly used to aid in the prediction of individual tree growth. Daniels and Burkhart (1975) use crown length in conjunction with a competition index to reduce potential diameter increment for loblolly pine. Crown length is updated annually by adding height growth and subtracting change in clear bole length. Clear bole length is predicted annually using a static predictive equation as a function of tree and stand parameters. Crown ratio, which is used as a height growth adjustment variable, is also updated annually using the clear bole length function. The growth simulator, Prognosis (Wykoff, Crookston and Stage, 1982), uses crown ratio as a variable for predicting diameter increment which in turn drives the height growth model. Crown ratio is predicted using a multiple linear regression model developed by Hatch (1980) as a function of stand and tree parameters. Updating crown ratio is accomplished by adding the difference between the end of the cycle estimate and the beginning of the cycle estimate to the actual or, if not the first growth cycle, the most recent estimate of crown ratio. CACTOS (Wensel, Meerschaert, and Biging, 1987) operates in a similar manner in that a static prediction equation of height-to-crown base is used at the beginning and end of the growth cycle, the difference is taken, and that difference is used to update the most recent value of height-to-crown base.

Since the height-to-crown base recedes up the bole relatively slowly and the measurement is prone to subjectivity, a fairly long period of time may have to elapse to obtain reasonable

estimates of change in height-to-crown base. The simulators above implement static crown parameter predictive models rather than change models for the simple reason that data available on crown change over time is very limited. Krumland and Wensel (1981) used a data set which contained 3 measurements of permanent plots with 5 year remeasurement cycles and which contained suitable crown information to develop a change in height-to-crown base model for the growth simulator CRYPTOS. The predicted five year change in height-to-crown base for coastal Douglas-fir is given as follows:

$$CBG5 = \frac{0.138 \cdot CL + 0.279 \cdot HTG5}{1 + \exp(-6.59 + 6.70 \cdot CC_{htcb})}$$

where CL = current crown length,

HTG5 = estimated 5-year height growth

CC_{htcb} = estimated canopy closure % at the live crown base of the subject tree.

Examining the signs on the coefficients we see that with greater crown lengths and larger predicted height growth, predicted change in height-to-crown base increases. Presuming that an optimal crown length exists which is at some measure between the total height and certainly not less than 30% of the total height, this relationship is logical, particularly if the lower crown becomes a liability with regard to growth. We also see in the function that as crown closure increases, predicted change in height-to-crown base decreases. This is the opposite of what we would expect since increased density is expected to accelerate crown recession.

Using the permanent plots which comprise the database for the CACTOS simulator, we have developed a change in height-to-crown base model which uses a potential change multiplied by a competition function, much like the diameter and height growth models which are incorporated into the simulator (Wensel, Meerschaert and Biging, 1987). The purpose in creating these models is to provide a logical means for updating the status of trees on a plot at the end of each 5 year growth cycle in the CACTOS growth simulator.

DATA

The data which was used in this study were collected by the industrial members of the Northern California Forest Yield Cooperative and represent the growth of six conifer species (Table 1) in young-growth forest stands within the ownership of the industry cooperators. This database consists of 569 remeasured permanent plots located throughout the mixed conifer region of Northern California (Wensel and Robards, 1989). The plots were measured around 1979 and again approximately five years later. Height-to-crown base was measured on every tree along with DBH and total height. Instructions for measuring height-to-crown base included "balancing" the crown. From the perspective of the observer, two sides of the crown are visible on either side of the bole. If these two sides are not equal then an average height-to-crown base must be estimated. If major portions of the crown are segmented along the bole a visual approximation of the height-to-crown base would include combining the pieces into one solid crown. Even given a tree which has a perfectly symmetrical and unsegmented crown, measurements of height-to-crown base by two observers will not likely yield the same value. Add to the imprecision height-to-crown base averaging and balancing and the field estimation becomes quite inexact.

The dataset was split into two parts by taking every other plot for the species ponderosa pine and white fir. The first half was used to fit the models and the second half was used to validate the models. The remainder of the species: sugar pine, incense cedar, Douglas-fir and red fir were not split due to an insufficient number of observations. To fit the models the data was screened as follows:

- small trees were excluded (< 5.5 DBH, < 10 feet total height)
- trees with damaged crowns were excluded
- trees whose height-to-crown base moved more than 75% of the tree's initial crown length were excluded

A summary of selected variables for the various datasets is given in Table 2 for ponderosa pine and white fir.

METHODS

<u>Model Formulation</u>

The model is conceived of as being a potential height-to-crown base (HTCB) change multiplied by a potential adjustment factor and a competition factor. The potential change in HTCB is obviously constrained to be less than or equal to the tree's crown length. An enveloping function which contains all but the most extreme changes in HTCB was desired. This was accomplished by categorizing the data into 10 foot crown length classes, determining an enveloping point within each crown class, and fitting the potential model to these data using nonlinear regression. The enveloping points were obtained by fitting a

Chi-square distribution to the data in each category so that a critical value could be computed at 75% probability of inclusion. The Chi-square distribution was selected for two reasons: the shape of the distribution closely matched that of the data and the distribution could be defined easily by the mean of the change in HTCB. The potential model form was designed to range between zero and some maximum change in HTCB as is shown in equation [1]

$$POT = c_0 \cdot \left(1.0 - e^{-c_1 \cdot CRLEN}\right) \qquad [1]$$

where POT = potential change in HTCB for 5 years,
CRLEN = the crown length of the tree at the beginning of the 5 year cycle, and
c_0 and c_1 are coefficients.

The potential adjustment component was necessary to account for the relative ability of the crown base to move given the proportion of the bole in crown and the total height growth potential of the tree. If the crown ratio (CR) of a tree is near one the crown base has a higher likelihood of increasing some fixed amount than a tree with a CR near zero, unless of course the tree dies and all of the crown is lost, but the mortality model must account for this possibility. A tree on a high site is likely to have a higher absolute change in HTCB than a similarly aged tree on a low site simply because the length of the bole is made larger by the greater total height growth. Since the potential adjustment factor can either increase or decrease [1], the function was designed to range between zero and some maximum.

$$POTADJ = \frac{d_0}{1.0 + e^{d_1 + d_2 CR + d_3 SITE \text{ (or Total Height)}}} \qquad [2]$$

where POTADJ = potential adjustment factor,
CR = live crown ratio,
SITE = Biging (1985) site index, breast height age 50
d_i = coefficients, i=0,...,3.

The competition component was formulated to be constrained between zero and one so that with increased crown competition the HTCB will achieve more of it's potential change.

The variable used for measuring crown competition is CC66, the same competition variable as is used in the CACTOS growth models (Wensel, Meerschaert and Biging, 1987). This variable measures the crown closure of the plot at 66% of the subject tree's height. The formulation of the competition function is the same as is found in the growth models:

$$COMP = e^{d_4 CC66^{d_5}} \qquad [3]$$

where CC66 = crown closure of the plot at 66% of the subject tree's height,
d_4 and d_5 = coefficients.

All of the above model components were fit using nonlinear regression. Model [1] was fit first and then fixed to facilitate finding coefficients for [2] and [3]. The small number of observations for sugar pine and red fir made it necessary to fix their potential at ponderosa pine's and white fir's potential respectively. Due to the number of parameters in the combined [2] and [3] function, the components were fit separately to ensure a solution. In some instances certain components or variables were found to be insignificant contributors to the regression and were dropped from the analysis for a particular species. Notably, this occurred in estimating the competition component for DF, WF, and RF. For these three species we could not demonstrate a competitive affect on crown recession. Hence for these three tolerant species the crown recession is based upon a potential and a potential adjustment. Since crown ratio is used as a variable in the crown adjustment component there is still an adjustment in the prediction based upon the individual tree's competition level .

Validation

A true validation was performed for ponderosa pine and white fir where a dataset which was not used in the model fitting was available to test the new models. The modeled datasets were also included in the analysis although they are expected to show increased precision over the test datasets. In addition, the current method used in CACTOS for updating HTCB, differencing two static predictions, was tested on all these datasets. In these tests the newest HTCB prediction equations from STAG Version 3.3 were used (Biging and Robards, 1989).

RESULTS AND DISCUSSION

The coefficients and fit statistics are shown in Table 3. The average variability in prediction around the regression ranges from 5.8 feet to 7.6 feet for a five year period. The average change in HTCB for this period ranged from 2.39 to 5.11 feet. Hence, the variability around the regression line exceeds the magnitude of the prediction. The average residuals are small, however, and in no case statistically significant, indicating an unbiased model. We can conclude from this that the regressions are unbiased, but that there is much variability in the underlying system.

Site index was significant in the potential component adjustment factor for all species but ponderosa pine where total height was determined to provide more information and was thus substituted. Since site information was missing for incense cedar that variable was omitted from the model for that species.

The coefficients for the competition component for DF, WF, and RF proved to be statistically insignificant and we could not demonstrate a competitive effect on crown recession. The lack of a competitive effect on change in HTCB, as demonstrated by CC66, in the more tolerant species is not surprising given those species higher tolerance for shading. For these three tolerant species the crown recession is solely based upon a potential and a potential adjustment. Because crown ratio is used as a variable in the crown adjustment component there is still an adjustment in the prediction based upon the individual tree's competition level.

The results of the validation are shown in Table 4. The best data for judging the adequacy of the models comes from examining the test datasets for PP, and WF. For the largest dataset, WF, the new dynamic models developed in this paper were clearly superior, having average residuals of only 0.3 feet in comparison to the 2.4 foot residuals from the static difference models of CACTOS for the test dataset. For PP these results were nearly identical in magnitude, but not in sign, with average residuals of -0.8 feet for the new models and 0.7 feet for the current CACTOS models when judged on the test dataset.

For SP, IC, DF, and RF there were no data reserved for testing. In these instances we can only compare the residuals of the actual to predicted using the same data as were used to fit the model. In all cases, but DF, the new models gave substantially lower overall average residuals than the current CACTOS models and for DF the residuals were equivalent.

An examination of the signs of the coefficients is instructive in understanding the behavior of the model. The larger the crown ratio, the greater the site or the larger the tree's total height, and the higher the crown competition the greater the change in the HTCB.

Based upon this analysis it appears that the new dynamic models developed in this research note do improve upon the static predictive equations currently used in CACTOS version 4.1.

Table 1. Species codes, common and scientific names.

Abbreviation	Common Name	Scientific Name
PP	ponderosa pine	*Pinus ponderosa* (Laws.)
SP	sugar pine	*Pinus lambertiana* (Dougl.)
IC	incense cedar	*Libocedrus decurrens* (Torr.)
DF	Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
WF	white fir	*Abies concolor* (Gord. and Glend.) Lindl.
RF	red fir	*Abies magnifica* (A. Murr.)

Table 2. Statistics for selected variables from the screened and unscreened "fit" dataset and the test dataset for ponderosa pine and white fir.

PP	Fit dataset						Test dataset		
	screened			unscreened					
Variable	Numbers of trees	$\overline{X}$	S_x	Numbers of trees	$\overline{X}$	S_x	Numbers of trees	$\overline{X}$	S_x
ΔHTCB	1269	3.85	9.30	1306	3.66	10.91	1199	2.39	9.85
CRLEN	1269	35.58	18.04	1306	35.06	18.20	1199	33.17	16.94
CR	1269	0.50	0.18	1306	0.49	0.18	1199	0.47	0.18
SITE	1269	74.70	16.42	1306	74.84	16.36	1199	74.82	16.00
THT	1269	73.71	29.37	1306	73.24	29.33	1199	71.63	26.29

WF	Fit dataset						Test dataset		
	screened			unscreened					
Variable	Numbers of trees	$\overline{X}$	S_x	Numbers of trees	$\overline{X}$	S_x	Numbers of trees	$\overline{X}$	S_x
ΔHTCB	1469	4.83	8.19	1532	5.11	9.70	1834	4.73	9.89
CRLEN	1469	35.41	17.18	1532	34.89	17.35	1834	32.44	16.76
CR	1469	0.55	0.19	1532	0.54	0.20	1834	0.51	0.19
SITE	1469	75.91	15.80	1532	76.04	15.74	1834	76.20	15.56
THT	1469	66.38	27.19	1532	65.85	27.13	1834	64.19	25.88

Table 3. Coefficients and fit statistics (in feet) for the new dynamic models for change in HTCB.

Coefficient/ Statistic	Variable name	PP	SP	IC	DF	WF	RF
				POTENTIAL			
c_0	intercept	45.52132	45.52132	16.19779	10.46894	24.26573	24.26573
c_1	crown length	0.01054	0.01054	0.01583	-0.01875	0.03137	-0.03137
				POTENTIAL ADJUSTMENT			
d_0	asymptote	7.81501	7.63165	5.72290	10.25557	4.90919	5.38521
d_1	intercept	4.48131	2.73998	1.11481	1.71887	0.85322	0.64527
d_2	crown ratio	-7.57971	-6.43712	-10.97283	-4.74406	-3.22079	-4.69171
d_3	site used for all species but PP height used for PP	-0.02877	-0.04299	0.0	-0.08593	-0.03301	-0.03206
				COMPETITION			
d_4	intercept	-0.56434	-0.77365	-0.00574	0.0	0.0	0.0
d_5	CC_{66}	-0.66824	-0.29887	-1.81125	0.0	0.0	0.0
Average residual		-0.1	-0.2	0.0	0.0	-0.1	-0.2
$S_{y \cdot x}$		7.6	7.5	5.8	6.7	7.5	6.7
Number of trees		1269	753	1573	1493	1469	274

Table 4. Validation of current static prediction model for change in HTCB used in CACTOS Version 4.1 (S) and the new dynamic model (D) and their comparison in feet for a 5 year period.

	PP (Test)	PP (Fit)	SP	IC	DF	WF (Test)	WF (Fit)	RF
$\Delta HTCB$	2.39	3.67	3.25	2.67	2.26	4.75	5.10	2.52
$\Delta HTCB-\Delta HTCB_S$	0.68	1.24	1.26	1.25	0.04	2.40	2.66	0.99
$\Delta HTCB-\Delta HTCB_D$	-0.81	-0.17	-0.48	0.20	0.04	0.32	0.25	-0.15
$\Delta HTCB_D-\Delta HTCB_S$	1.42	1.36	1.68	0.93	0.01	1.82	2.17	1.10
Number of Trees	1199	1306	1231	2959	2826	1834	1532	485

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