J6E.4 PRELIMINARY HEIGHT TO CROWN BASE MODELS FOR GIANT SEQUOIA GROVES

Samantha J. Gill
California Polytechnic State University*

---

* Corresponding author address: Samantha J. Gill, California Polytechnic State University, Natural Resources Management Dept. and BioResource and Agricultural Engineering Dept., San Luis Obispo, Ca, 93407. (805) 756-6205.
Email: sgill@calpoly.edu

1. INTRODUCTION

Detailed information about tree crowns is important in predicting the spread of fires within forested ecosystems. The transition of surface fires to crown fires is extremely important to fire managers for suppression reasons (Alexander, 1987). Height to crown base of live trees is one of the main factors that contribute to the class of crown fire in a coniferous forest (Alexander, 1987 and Van Wagner, 1968). Because information on crown size and shape are important indicators of fire threat and spread, models of crown parameters such as height to crown base are needed.

Models height to crown base can be incorporated into fire spread models such as FARSITE. Height to crown base prediction models may also be used to fill in missing data for use in other forest ecosystems models such as growth and yield models (Biging et. al, 1994, Ritchie and Hann, 1987, Zumrawi and Hann, 1989). A logistic equation is often used to predict height to crown base because this ensures that the predicted height to crown base is less than the total height of the tree (Biging et. al, 1994, Ritchie and Hann, 1987, Zumrawi and Hann, 1989). Height to crown base models presented in this paper also use logistic equations. This paper presents preliminary results of height to crown base models for five species of conifer trees within the Giant Sequoia Monument, California.

2. DATA

Data collection for this project took place within five groves of the Sequoia National Monument in California. The overall plot design followed the U.S. Forest Service Forest Inventory and Analysis (FIA) protocol, slightly modified by Jump and Levitan (1998) for integrated resource inventory within giant sequoia groves. Trees with diameters between 2.54 to 12.45 cm (1 to 4.9 inches) were sampled using a variable radius plot (VRP) with an angle gauge of 1.15 m^2/ha (5 ft^2/ac), larger trees were sampled using VRP with an angle gauge of 9.18 m^2/ha (40 ft^2/ac). Each sample tree was measured for DBH, total height, height to crown base, crown radius toward the plot center and crown radius perpendicular to that measurement. Seedlings were measured using 0.004 ha (0.01 acre) circular plots, snags with 0.10 ha (0.25 acre) circular plots. Ocular estimates of understory vegetation (hardwoods, shrubs, forbs and grasses), duff and fuelbed depth will be performed on each plot. To estimate canopy cover, three 30.48 m (100 foot) transects were conducted. These transects started from the plot center and were placed in a random direction. Within each of these transects the location of tree crown projection to the ground was recorded. A

Species	Obs.	DBH (cm.)		Height (m)		height to crown base (m)	
		Mean	S.D.[a]	Mean	S.D.	Mean	S.D.
giant sequoia	60	71.4	22.6	34.8	8.7	12.9	7.6
incense cedar	181	56.3	24.2	23.1	7.7	7.9	4.6
ponderosa pine	81	70.8	18.9	34.1	8.5	12.7	6.9
sugar pine	89	73.2	21.6	35.5	7.4	12.6	5.0
white fir	281	55.3	21.8	29.8	7.5	9.0	4.7
all species	693	61.0	23.4	29.7	9..0	9.9	5.5

Species	crown radius (m)		basal area (m^2/ha)		canopy cover (%)		Trees per hectare	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
giant sequoia	3.0	1.0	69.2	29.8	63.2	18.8	433.6	432.5
incense cedar	3.3	1.3	57.9	25.2	63.5	19.5	410.1	355.7
ponderosa pine	4.1	1.4	53.4	29.5	62.5	19.5	296.2	287.2
sugar pine	4.9	1.6	53.7	20.9	65.3	17.7	302.3	326.6
white fir	3.4	1.0	56.8	23.8	67.1	17.8	391.5	348.5
all species	3.6	1.3	57.4	25.3	65.1	18.6	377.8	351.2

[a] Standard deviation

Table 1: Summary statistics.

total of 693 trees from five species were measured covering a wide range of sizes and densities. Species included in this project are giant sequoia (*Sequoiadendron giganteum*), white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertina*), incense-cedar (*Calocedrus decurrens*). Refer to Table 1 for summary statistics of the data.

3. METHODS

Nonlinear regression models were fit separately to each species within the data set. Logistic equations have been used for fitting height to crown base by other researchers (see Biging et. al, 1994, Ritchie and Hann, 1987, Zumrawi and Hann, 1989) and were used in this study. The general model forms considered in this project were

$$ht \cdot (1 - e^{-(\sum_{i=1}^{k} b_i \cdot x_i)^2}) \qquad [1]$$

$$\frac{ht}{1 + e^{(\sum_{i=1}^{k} b_i \cdot x_i)}} \qquad [2]$$

These logistic equations ensure that the predicgted height to crown base is less than the total height of the tree. Biging et. al (1994) squared the exponent of the logistic equation to further ensure that this condition is met. Independent variables considered in modeling were height (ht), DBH, quadratic mean of the two crown radii measurements (crrad), basal area per acre (BA), trees per hectare (TPH), and canopy cover (cc). Both equations [1] and [2] were fit with several combinations of independent variables. Models were judged using adjusted R^2, root mean squared error (RMSE) and the significance of the coefficients of the independent variables.

4. RESULTS AND DISCUSSION

Fit statistics for models with significant coefficients are presented in Table 2. Unless otherwise noted, the coefficients of all models are significant at the $\alpha = 0.05$ level. Because all forest inventories do not measure the same tree and stand variables, several models for each species are presented to allow the reader to choose the model most appropriate for their needs. Adjusted R^2 and root mean square error for these models are similar to those reported by Biging et. al, 1994, Ritchie and Hann, 1987, and Zumrawi and Hann, 1989. For each model, coefficients and their standard errors are presented in Table 3.

The most commonly used variables in these models were canopy cover and basal area per acre. At least one density measure (basal area per acre, trees per hectare, or canopy cover) was used in at least one of the model for all species except sugar pine, thus indicating the importance of density on crown development. The models for incense cedar contained no significant (at $\alpha = 0.10$) tree variables. In fact, the only variable that was significant in any of the models for incense cedar was basal area per acre. Crown radius at the height to crown base was the most commonly used tree variable for predicting height to crown base. Unfortunately, it is a variable that is not commonly measured in forest inventories. Canopy cover is another variable found to be significant in many of these models that is not commonly measured. Models exist that predict crown radius of forested trees (Gill et al., 2000) and maximum crown radius (Farr, et. al., 1989; Paine and Hann, 1982; Uzoh and Ritchie, 1996; and Warbington and Levitan, 1992) and canopy cover (Warbington and Levitan, 1992 and Gill et al., 2000). However, it must be remembered that more uncertainty and increased variability is added when models of parameters are used in models that were developed using measured variables.

5. Conclusion

Height to crown base models presented here may be used within models that predict the spread of fires. Adjusted R^2 in the range of 0.23 to 0.52 indicate the inherent variability in modeling tree crowns and this variability must be considered when applying these models. However, it is not practical to measure every tree and so models such as these are a necessity. More data is being collected for this project and all models will be refit and alternative models may be developed. Further research is needed in the modeling of not only height to crown base, but also other crown parameters and the understory of the forest that contribute to the ladder fuels. Future projects will attempt to develop models of height to crown base and ladder fuels that take into account the spatial relationship of the forest. Better models of tree crowns should be a real asset to the fire spread models.

6. Literature Cited

Alexander, M. E. 1987. Help with making crown fire hazard assessments. Symposium and workshop for protecting people and homes from wildfire in the interior west. Missoula, MT, October 6-8: 147-156.

Biging, G. S., T. A. Robards, E. C. Turnblom, and P. C. Van Duesen. 1994. The predictive models and procedures used in the forest stand generator (STAG). Hilgardia 61(1): 36pp.

Farr, W. A., D. J. DeMars and J. E. Dealy. 1989. Height and crown width related to diameter for open-grown western hemlock and Sitka spruce. Canadian Journal of Forest Research. 19:1203-1207.

Gill, Samantha J., Gregory S. Biging, and Edward C. Murphy. 2000. Gill, S.J., G.S. Biging, and E.C.

Model	species	adjusted R^2	RMSE
$ht\cdot(1-e^{-(b_0+b_1\cdot cc+b_2\cdot crrad)^2})$	giant sequoia	0.3887	5.99
$ht\cdot(1-e^{-(b_0+b_1\cdot cc)^2})$	giant sequoia	0.355	6.199
$\frac{ht}{1+e^{(b_0+b_1\cdot cc+b_2\cdot crrad)}}$	giant sequoia	0.401	5.925
$\frac{ht}{1+e^{(b_0+b_1\cdot cc)}}$	giant sequoia	0.355	6.148
$\frac{ht}{1+e^{(b_0+b_1\cdot crrad)}}$ [a]	giant sequoia	0.269	6.542
$ht\cdot(1-e^{-(b_0+b_1\cdot\ln(BA))^2})$	incense cedar	0.313	3.873
$\frac{ht}{1+e^{(b_0+b_1\cdot\ln(BA))}}$	incense cedar	0.312	3.875
$ht\cdot(1-e^{-(b_0+b_1\cdot cc+b_2\cdot\ln(BA))^2})$ [a]	ponderosa pine	0.515	3.814
$ht\cdot(1-e^{-(b_0+b_1\cdot\ln(BA))^2})$	ponderosa pine	0.500	3.875
$ht\cdot(1-e^{-(b_0+b_1\cdot cc)^2})$	ponderosa pine	0.482	3.955
$ht\cdot(1-e^{-(b_0+b_1\cdot TPH)^2})$	ponderosa pine	0.491	3.909
$\frac{ht}{1+e^{(b_0+b_1\cdot cc+b_2\cdot\ln(BA))}}$ [a]	ponderosa pine	0.516	3.813
$\frac{ht}{1+e^{(b_0+b_1\cdot\ln(BA))}}$	ponderosa pine	0.501	3.871
$\frac{ht}{1+e^{(b_0+b_1\cdot cc)}}$	ponderosa pine	0.489	3.956
$\frac{ht}{1+e^{(b_0+b_1\cdot TPH)}}$	ponderosa pine	0.491	3.910
$ht\cdot(1-e^{-(b_0+b_1\cdot\frac{DBH}{ht}+b_2\cdot ht)^2})$ [a]	sugar pine	0.507	3.528
$ht\cdot(1-e^{-(b_0+b_2\cdot ht)^2})$	sugar pine	0.490	3.587
$\frac{ht}{1+e^{(b_0+b_1\cdot\frac{DBH}{ht}+b_2\cdot ht)}}$ [a]	sugar pine	0.506	3.528
$\frac{ht}{1+e^{(b_0+b_2\cdot ht)}}$	sugar pine	0.490	3.584
$ht\cdot(1-e^{-(b_0+b_1\cdot cc+b_2\cdot\ln(BA))^2})$	white fir	0.257	4.064
$ht\cdot(1-e^{-(b_0+b_1\cdot\ln(BA))^2})$	white fir	0.218	4.171
$\frac{ht}{1+e^{(b_0+b_1\cdot ht+b_2\cdot cc+b_3\cdot\ln(BA))}}$	white fir	0.270	4.029
$\frac{ht}{1+e^{(b_0+b_1\cdot ht+b_2\cdot\ln(BA))}}$	white fir	0.230	4.139
$\frac{ht}{1+e^{(b_0+b_1\cdot cc+b_2\cdot\ln(BA))}}$	white fir	0.258	4.064

[a] Some coefficients significant at $\alpha = 0.10$, but not at $\alpha = 0.05$ level.

Murphy 1999. Modeling conifer tree crown radius and estimating canopy cover. *Forest Ecology and Management*. 126: 405-416.

Model	species	b_o	b_1	b_2	b_3
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot cc + b_2 \cdot crrad)^2})$	giant sequoia	1.150 (0.128)	-0.004 (0.001)	-0.061 (0.028)	
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot cc)^2})$	giant sequoia	-0.506 (0.297)	0.017 (0.005)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot cc + b_2 \cdot crrad)}}$	giant sequoia	-1.248 (0.450)	0.017 (0.005)	0.231 (0.104)	
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot cc)}}$	giant sequoia	-0.506 (0.297)	0.017 (0.005)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot crrad)}}$ [a]	giant sequoia	-0.185 (0.364)	0.219 (0.111)[a]		
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot \ln(BA))^2})$	incense cedar	0.338 (0.113)	0.078 (0.029)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot \ln(BA))}}$	incense cedar	1.818 (0.444)	-0.294 (0.111)		
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot cc + b_2 \cdot \ln(BA))^2})$ [a]	ponderosa pine	0.327 (0.090)	0.002 (0.0009)[a]	0.061 (0.024)	
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot \ln(BA))^2})$	ponderosa pine	0.367 (0.088)	0.079 (0.022)		
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot cc)^2})$	ponderosa pine	0.506 (0.057)	0.003 (0.001)		
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot TPH)^2})$	ponderosa pine	0.618 (0.021)	0.0002 (0.00005)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot cc + b_2 \cdot \ln(BA))}}$ [a]	ponderosa pine	1.892 (0.357)	-0.240 (0.091)[a]	-0.006 (0.003)	
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot \ln(BA))}}$	ponderosa pine	1.731 (0.343)	-0.300 (0.086)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot cc)}}$	ponderosa pine	1.163 (0.223)	-0.009 (0.003)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot TPH)}}$	ponderosa pine	0.758 (0.080)	-0.0006 (0.0002)		
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot \frac{DBH}{ht} + b_2 \cdot ht)^2})$ [a]	sugar pine	0.617 (0.098)	-0.079 (0.040)[a]	0.006 (0.002)	
$ht \cdot (1 - e^{-(b_0 + b_2 \cdot ht)^2})$	sugar pine	0.481 (0.072)	0.005 (0.002)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot \frac{DBH}{ht} + b_2 \cdot ht)}}$ [a]	sugar pine	0.771 (0.371)	0.293 (0.151)[a]	-0.021 (0.007)	
$\frac{ht}{1 + e^{(b_0 + b_2 \cdot ht)}}$	sugar pine	1.289 (0.272)	-0.018 (0.007)		
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot cc + b_2 \cdot \ln(BA))^2})$	white fir	0.117 (0.080)	0.002 (0.0006)	0.083 (0.021)	
$ht \cdot (1 - e^{-(b_0 + b_1 \cdot \ln(BA))^2})$	white fir	0.173 (0.081)	0.108 (0.020)		
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot ht + b_2 \cdot cc + b_3 \cdot \ln(BA))}}$	white fir	2.359 (0.407)	0.013 (0.006)	-0.009 (0.002)	-0.326 (0.087)
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot ht + b_2 \cdot \ln(BA))}}$	white fir	2.091 (0.405)	0.013 (0.006)	-0.423 (0.086)	
$\frac{ht}{1 + e^{(b_0 + b_1 \cdot cc + b_2 \cdot \ln(BA))}}$	white fir	2.846 (0.348)	-0.0096 (0.002)	-0.343 (0.087)	

Jump, L.H. and J. Levitan. 1988. *Integrated resource inventory design for giant sequoia groves on the Sequoia National Forest.*

Paine, D. P. and D. W. Hann. 1982. Maximum crown-width equations for southwestern Oregon tree species. Oregon State University, Department of Forestry, Corvallis. Res. Pap. No. 46. 20 pp.

Ritchie, M. W. and Hann, D. W. 1987. Equations for predicting height to crown base for fourteen tree species in southwest Oregon. Research Paper 50, Oregon State University, Forest Research Laboratory. 14 pp.

U.S. Forest Service, Region 5. 2000. *Forest Inventory and Analysis User's Guide*

Uzoh, F. and M. W. Ritchie. 1996. Crown area equations for 13 species of trees and shrubs in northern California and southwestern Oregon. Research Paper PSW-RP-227. Pacific Southwest Research Station. 13 pp.

Van Wagner, C. E. 1968. Fire behaviour in a red pine plantation: field and laboratory evidence. Dep. Publ. No. 1229. Ottawa, ON: Canada Department of Forestry and Rural Development, Forestry Branch. 30pp.

Warbington, R. and J. Levitan. 1992. How to estimate canopy cover using maximum crown width/DBH relationships. Proceedings of the Stand Inventory Technologies 92 Conference. Portland, OR Am. Soc. for Photogrammetry and Remote Sensing, Bethesda, MD. 319-328.

Zumrawi, A. A. and Hann, D. W. 1989. Equations for predicting the height to crown base of six tree species Research Paper 52, Oregon State University, Forest Research Laboratory. 12 pp.

ACKNOWLEDGEMENTS

The author wished to thank USDA Forest Service PSW Research Station and California Agricultural Research Initiative for providing funding for this project. Thanks also to Lew Jump for help in collecting data and Drs. David Weise and Chris Dicus for valuable discussions and help related to the project.