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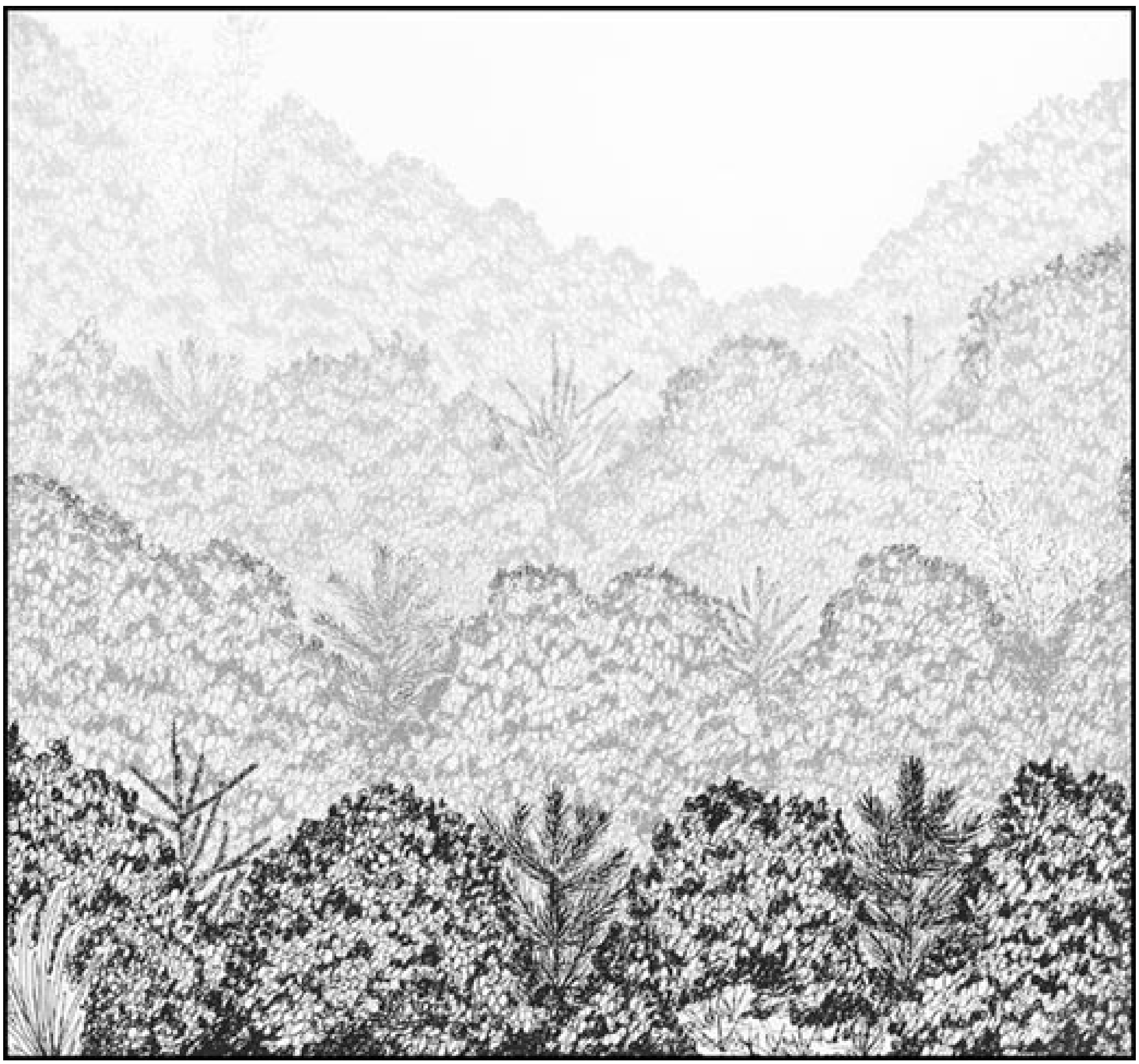
Crown Area Equations for 13 Species of Trees and Shrubs in Northern California and Southwestern Oregon

Fabian C.C. Uzoh **Martin W. Ritchie**



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Abstract:

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The equations presented predict crown area for 13 species of trees and shrubs which may be found growing in competition with commercial conifers during early stages of stand development. The equations express crown area as a function of basal area and height. Parameters were estimated for each species individually using weighted nonlinear least square regression.

Retrieval terms: growth and yield, simulators

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In Brief...

Growth and yield simulators are valuable tools in forest management decision making. A number of simulators have been developed to meet current management challenges. However, little attention has been given to the impact of brush and non-commercial hardwood trees on stand dynamics. This presents a serious problem when attempting to predict the early stages of stand development where shrubs and sprouting hardwood trees may have a significant impact on growth of commercial species. Crown area may be useful as an index of the competition level. One means of estimating crown area is to predict it as a function of variables which may be readily available in a simulator, such as height or diameter. In this paper, we present crown area equations for 13 species of plants common to southwestern Oregon and northern California. Crown area is expressed as a function of stem basal area and height for each plant. Parameters were estimated for each species individually using weighted nonlinear least square regression. For the purpose of this study, crown area is defined as the area of a vertical projection of the crown to a horizontal plane.

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Introduction

Growth and yield models are becoming one of the primary tools aiding forest managers in decision making. Traditionally, modeling efforts have focused on merchantable species. In the western United States, these are primarily coniferous trees. As a result, very little modeling work has been done on hardwood trees or shrubs.

There is increasing interest in simulators which are capable of predicting growth for early seral stages of stand development. These simulators must address the influence of shrubs and hardwood trees. One such model is SYSTUM-1 (Ritchie and Powers 1993). In SYSTUM-1, competing vegetation is quantified as an aggregate percent cover and height by species on each plot. However, SYSTUM-1 is not responsive to changes in species composition on tree growth. Furthermore, growth functions for percent cover and height are not effective in representing response to release treatments. In order to address this problem, stem growth models are being developed for shrubs and hardwood trees in which crown area is expressed as a function of crown volume. This work is part of a larger effort to develop a suite of functions which will allow simulators to better respond to questions relating to the impact of non-commercial species on growth of commercial conifers.

The objective of this study is to develop equations to predict crown area as a function of plant height and basal diameter. Crown area and crown cover values have been used in studies of biomass production (Martin and others 1981; Mitchell and others 1987) as well as in predicting the competitive effects of shrubs on tree growth (e.g. Dahms 1950; Oliver 1979). A crown area function may help existing simulators such as SYSTUM-1 provide more reliable predictions of shrub cover over time. For the purpose of this study, crown area is defined as the area of a vertical projection of the crown to a horizontal plane.

This paper presents equations that predict crown area for the following 13 species of trees and shrubs: Vine maple (*Acer circinatum* [Pursh]), Manzanita (green leaf) (*Arctostaphylos patula* [Adams]), Golden chinkapin (*Castanopsis chrysophylla* [Dougl.] A.DC.), Whitethorn (mountain) (*Ceanothus cordulatus)*, Deerbrush (*Ceanothus integerrimus* [Hook. & Arn.]), Snowbrush (*Ceanothus velutinus* [Dougl.]), Tanoak (*Lithocarpus densiflorus* [Hook and Arn.] Rehd.), Black oak (*Quercus kelloggii* [Newb.]), Pacific madrone (*Arbutus menziesii* [Pursh]), Bitter cherry (*Prunus emarginata* [Dougl.]), Pacific rhododendron (*Rhododendron macrophyllum* [D. DON.]), Huckleberry (bush) (*Vaccinium ovalifolium* [Smith]), and Bigleaf maple (*Acer macrophyllum* [Pursh]).

Methods

The data for this study were collected from temporary plots in 29 plantations in northern California and southwestern Oregon during the summers of 1987, 1988, and 1989 *(fig. 1)*. The plantations were between 25 and 45 acres in size. On each plantation, 30 plots (15 non-tree-centered and 15 tree-centered plots) 2.6 meters in radius were established systematically at 40-meter intervals along a continuous transect that changed direction every 200 meters. The choice of the initial starting point at each plantation was made by selection from a random number table. Even digits (0,2,4, etc.) designated a tree-centered plot, odd digits a vegetation plot.

When a tree-centered plot was chosen, the plot center was moved from the transect center line to coincide with the location of the nearest seedling. However, if there were no seedlings within 2.6 meters of the 40-meter mark on the transect, the plot number was recorded, no other data taken, and the transect continued. Plot type refers to whether the plot was tree-centered or not. Data collected from the two types of plots were the same. A plant was considered to be in the plot if the center of the plant where it emerged from the ground was within 2.6 meters of plot center. For all plants in the plot, the data were collected from the entire plant, including those parts that extended outside the plot. Parts of a plant that did not emerge from the soil surface within the plot were not measured. The only exception to this rule was during estimation of percent cover (percent cover is the ocular estimation of percent of grasses and forbs at each plot). The majority of the plants measured were shrub clumps often from multi-stemmed individuals.

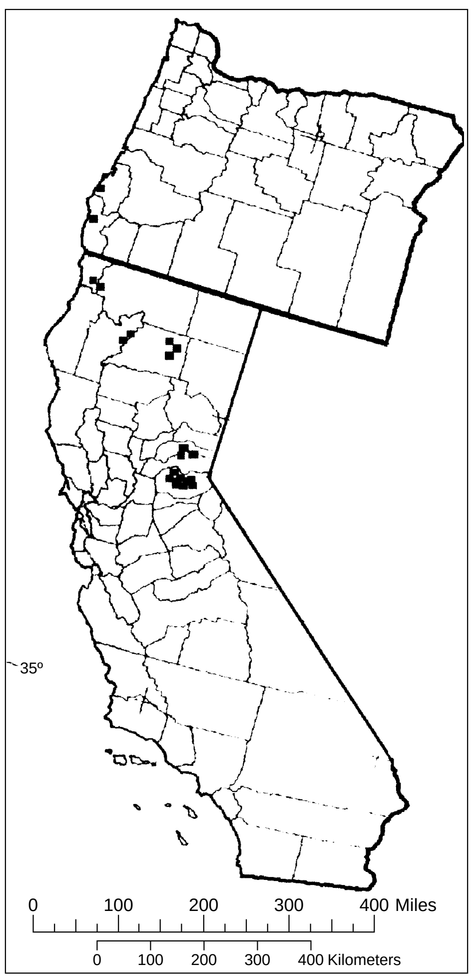

Figure 1—Location of plantations in study area (northern California and southwestern Oregon). Each location may have more than one plantation.

Measurements

The following were recorded for each woody plant in a plot:

- Species,
- Distance in decimeters from the plot center to the center of the root crown (i.e., center of where the plant originates from the ground for multi-stemmed individuals),
- Height (HCB) to base of crown (in meters),
- Long width of the crown (CWL) in decimeters,
- Width of the crown perpendicular to long width of the crown (CWS) in decimeters,
- Diameter (D) of each stem 8 centimeters from the root collar or burl (nearest cm), and
- Total height (HT) in meters.

Crown area (CA) in square meters is calculated by:

$$CA = CWL \times CWS \times \pi / 400$$

Plant basal area (BA) in square centimeters is calculated as:

$$BA = \sum_{i=1}^{ns} (\pi/4) \times D_i^2$$

where:

ns = number of stems per plant.

Analysis and Results

We assumed that there is no plot effect, and we treated each individual plant as if it were drawn at random from all possible plants. Two model forms were considered:

$$CA = a \times (1 - EXP(HT \times b)) + error \qquad [1]$$

$$CA = (a \times BA^{b}) \times (1 - EXP(c \times HT)) + error \qquad [2]$$

where a, b, and c = regression coefficients. Because of the availability of height measurements, and the difficulty of measuring basal area in shrubs, a model using only height may be more desirable. Of these two, Eq. [2] had the lower mean square error across species. Further, unweighted fit R^2 values for equation [1] ranged from .0603 to .6802 while R^2 values for Eq. [2] ranged from .4288 to .9237. Also, a more generalized method of model comparison (Anderson-Sprecher 1994) was used to compare the two equations. Their GR^2 parameter is an index of how much the full model (Eq. #2) improves over the reduced model (Eq. #1). The values of GR^2 are presented in *table 1*. Given the values of R^2 and GR^2, Eq. [2] was chosen. The estimate of the coefficient of determination, R^2, was calculated using the formula: $R^2 = 1 - [SSE/CTSS]$, where SSE = Sum-of-squares error about the equation; and CTSS = Corrected total sum of squares. The estimate of was GR^2 calculated using the formula: $GR^2 = 1 - [RSS(full)/RSS(reduced)]$, where RSS(full) = Residual sum of squares about Eq. [2], and RSS(reduced) = Residual sum of squares about Eq. [1]. This approach provides a generalized R^2 value which implies a comparison with the reduced model CA = a + error (Anderson-Sprecher 1994).

Crown area is modeled as a function of stem basal area and height. Preliminary plotting of crown area against the independent variables revealed the following:

Table 1—*Unweighted models GR^2 values for the 13 non-conifer species.*

Species	GR^2
Vine maple (*Acer circinatum* [Pursh])	0.727
Manzanita (green leaf) (*Arctostaphylos patula* [Adams])	0.373
Golden chinkapin (*Castanopsis chrysophylla* [Dougl.] A.DC.)	0.549
Whitethorn (mountain) (*Ceanothus cordulatus)*	0.495
Deerbrush (*Ceanothus integerrimus* [Hook. & Arn.])	0.441
Snowbrush (*Ceanothus velutinus* [Dougl.])	0.728
Tanoak (*Lithocarpus densiflorus* [Hook and Arn.] Rehd.)	0.479
Black oak (*Quercus kelloggii* [Newb.])	0.705
Pacific madrone (*Arbutus menziesii* [Pursh])	0.656
Bitter cherry (*Prunus emarginata* [Dougl.])	0.408
Pacific rhododendron (*Rhododendron macrophyllum* [D. DON.])	0.877
Huckleberry (bush) (*Vaccinium ovalifolium* [Smith])	0.228
Bigleaf maple (*Acer macrophyllum* [Pursh])	0.809

GR^2= an index of how much the full model (Eq. #2) improves over the reduced model (Eq. #1).

- Crown area increased with basal area and height but not in a linear fashion.
- There was a strong relationship between crown area and basal area.
- There appeared to be increasing variance of crown area over both basal area and height.

Initially, parameters were estimated for all 13 species using unweighted nonlinear least squares regression. Plotting of the residuals indicated that the values of the residuals were increasing over the estimate. To improve parameter estimates, we employed an iteratively reweighted nonlinear least squares fit. We tried two weights to homogenize variance. We weighted by $\sqrt{1/expected(CA)}$ and *1/expected(CA)*. These two weights correspond to assumptions that variance of residuals increased with expected(CA) and square of expected(CA) respectively. Residual plots and Furnival's (1961) index were used to compare unweighted regression with each of the weighted regressions to determine which weight best met the assumptions of homogeneity of variance and normality of the error term. In all cases, the weighted regressions provided the lowest index of fit. The weight of *1/expected(CA)* provided what appeared to be the best fit for 7 of the 13 species. In most instances, convergence occurred before six iterations. *Tables 2* and *3* present the regression coefficients and associated statistics for the modeling data set for Eq. [2]. *Figures 2-14* show resulting functions over basal area for five levels of height. Comparison of these plots with those from unweighted fits did not reveal any dramatic statistically significant difference. The SAS (SAS Institute Inc. 1987) statistical software package was used to estimate the regression parameters.

Concluding Discussion

These equations are intended primarily for the purpose of predicting missing data values for data describing the structure of young plantations. Crown area is a variable which may be useful in describing levels of competition in such stands (e.g., Tappeiner and others 1984). Since height growth is easily measured on shrubs and hardwoods in young stands, a crown area using only height as a predictor is preferable. However, we found substantial improvements using total basal area and height in the model. We believe the models using height alone were inadequate for predicting crown area; therefore we did not present the results of these fits.

In the chosen model, crown area increases monotonically with increasing basal area and height. This may provide for reasonable behavior beyond the range of the data in our sample. However, we have no basis for assessing the robustness of these equations to extrapolation. Although the model chosen contains an asymptote which is conditional on the value of BA, for most of the species, the sampled data range is well below any implied asymptote. Therefore no conclusions may be drawn about maximum crown area from these equations.

The species depicted in *figures 2-14* show substantial variability. The variability between species is to be expected given the wide range in form of these species. The tanoak and madrone models are very similar within the ranges of data common to both species. However, the tanoak sampled in this study covered a much wider range in basal area than was found among the sampled madrone.

Table 2—Crown area model parameter estimates for the 13 non-conifer species for Eq. [2]. Standard errors appear in parentheses beneath each coefficient.

		Parameters estimates					
Species	Weights	*N*	*a*	*b*	*c*	*S*	R^2
Vine maple	1/expected(CA)	85	0.040789	0.650943	-2.198338	0.0234	0.788
				(0.00476)	(0.04801)	(0.935723)	
Manzanita	$\sqrt{1/expected(CA)}$	1172	0.148292	0.729466	-0.636752	0.0099	0.827
				(0.00356)	(0.00768)	(0.189866)	
Chinkapin	1/expected(CA)	22	0.125473	0.450952	-1.668147	0.0527	0.766
				(0.04451)	(0.08102)	(0.175212)	
Whitethorn	1/expected(CA)	1179	0.159864	0.739687	-1.608342	0.0273	0.669
				(0.00707)	(0.00951)	(0.368471)	
Deerbrush	1/expected(CA)	1957	0.324670	0.666789	-0.416567	0.0201	0.625
				(0.00569)	(0.00163)	(0.002064)	
Snowbrush	$\sqrt{1/expected(CA)}$	64	1.053987	0.705213	-0.144486	1.2971	0.825
				(0.00163)	(0.00427)	(0.013631)	
Tanoak	1/expected(CA)	1081	1.532414	0.455347	-0.142682	0.0747	0.786
				(0.00567)	(0.00097)	(0.001591)	
Black oak	1/expected(CA)	163	1.294278	0.532337	-0.102492	0.0167	0.923
				(0.00215)	(0.00196)	(0.011933)	
Madrone	1/expected(CA)	143	0.692053	0.526578	-0.194721	0.0837	0.850
				(0.00215)	(0.00332)	(0.007936)	
Bitter cherry	$\sqrt{1/expected(CA)}$	596	0.19766	0.740537	-0.503159	0.0219	0.761
				(0.00355)	(0.00162)	(0.003152)	
Rhododendron	$\sqrt{1/expected(CA)}$	53	0.03509	0.904504	-2.011825	0.1475	0.982
				(0.01441)	(0.00335)	(0.009857)	
Huckleberry	$\sqrt{1/expected(CA)}$	282	0.18478	0.603152	-0.914294	0.0388	0.750
				(0.00881)	(0.00132)	(0.004025)	
Bigleaf maple	$\sqrt{1/expected(CA)}$	108	0.05086	0.566284	-1.989914	0.0432	0.476
				(0.00596)	(0.00136)	(0.002046)	

N = number of observations
S = standard deviation of residuals
CA = crown area

Table 3—*Summary statistics for data used in crown area equations*

Species	Minimum	Maximum	Mean	Std Dev
Vine maple				
Height (m)	0.200	3.100	0.969	0.682
Basal area (cm^2)	0.785	19.635	3.070	2.966
Crown area (m^2)	0.008	0.236	0.052	0.050
Manzanita				
Height (m)	0.100	2.500	0.715	0.414
Basal area (cm^2)	0.785	6280	26.859	30.633
Crown area (m^2)	0.008	5.655	0.547	0.815
Chinkapin				
Height (m)	0.200	1.000	0.582	0.274
Basal area (cm^2)	0.7854	66.759	9.948	16.066
Crown area (m^2)	0.008	0.707	0.174	0.207
Whitethorn				
Height (m)	0.100	1.900	0.921	0.336
Basal area (cm^2)	0.785	275.675	31.679	34.524
Crown area (m^2)	0.008	12.370	1.148	1.627
Deerbrush				
Height (m)	0.100	5.500	1.426	0.906
Basal area (cm^2)	0.785	231.692	17.768	23.236
Crown area (m^2)	0.008	12.252	0.984	1.451
Snowbrush				
Height (m)	0.030	4.670	2.192	1.389
Basal area (cm^2)	0.785	451.607	70.269	93.90
Crown area (m^2)	0.00008	47.967	6.159	8.393
Tanoak				
Height (m)	0.04	6.060	1.354	1.369
Basal area (cm^2)	0.785	633.031	30.485	66.246
Crown area (m^2)	0.00008	19.400	1.354	2.452
Black oak				
Height (m)	0.100	3.700	0.718	0.795
Basal area (cm^2)	0.785	228.551	14.923	20.780
Crown area (m^2)	0.008	4.673	0.389	0.779
Madrone				
Height (m)	0.050	8.100	1.239	1.477
Basal area (cm^2)	0.785	113.097	12.620	22.099
Crown area (m^2)	0.00008	5.697	0.582	0.983
Bitter cherry				
Height (m)	0.100	4.000	0.866	0.699
Basal area (cm^2)	0.785	71.471	6.161	9.396
Crown area (m^2)	0.0079	3.793	0.289	0.532
Rhododendron				
Height (m)	0.100	2.010	1.165	0.457
Basal area (cm^2)	0.785	230.122	36.766	47.401
Crown area (m^2)	0.00008	5.091	0.815	1.023
Huckleberry				
Height (m)	0.050	2.090	0.918	0.392
Basal area (cm^2)	0.785	179.071	23.723	28.213
Crown area (m^2)	0.00008	4.823	0.650	0.646
Bigleaf maple				
Height (m)	0.200	3.100	0.980	0.905
Basal area (cm^2)	0.785	16.493	2.247	3.704
Crown area (m^2)	0.008	0.251	0.056	0.259

The relationship between crown area and height and basal area may be influenced by origin of the plant. Among these plantations, shrubs and hardwoods have developed both from seed and sprouts after fire or release treatment, and we make no effort here to distinguish between the two. Parameter estimates may be influenced by the particular mix of seed and sprout origin of individuals in the data set. Model performance may be enhanced if this factor is explicitly included in the model.

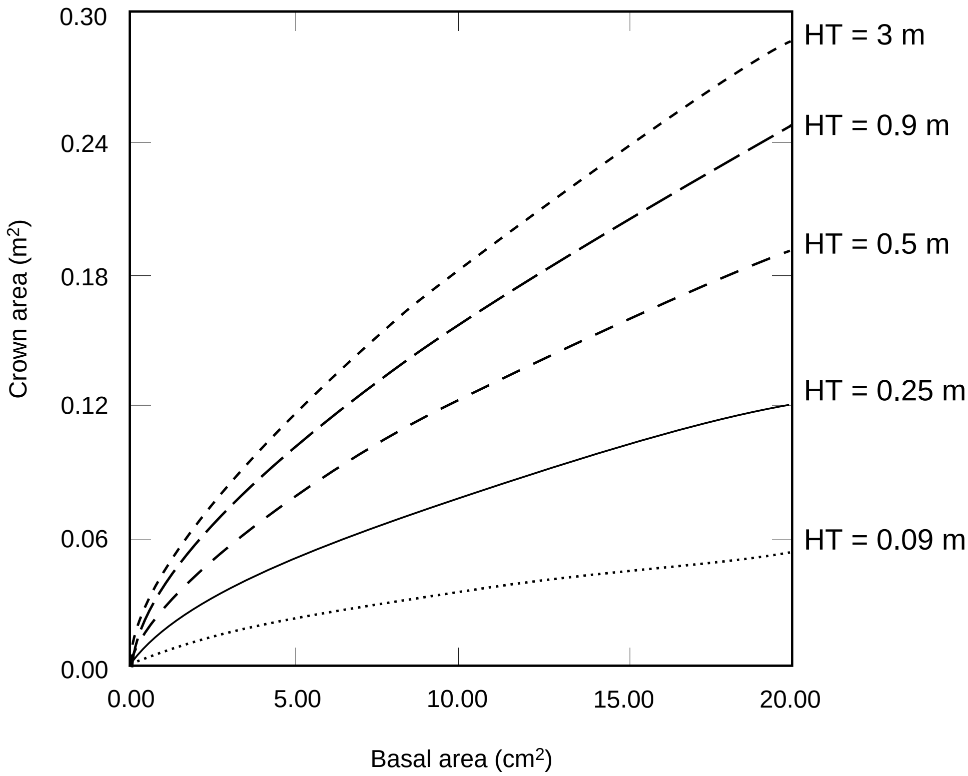

Figure 2—Plot of fitted equation for vine maple—crown area as a function of height (m) and basal area (cm^2).

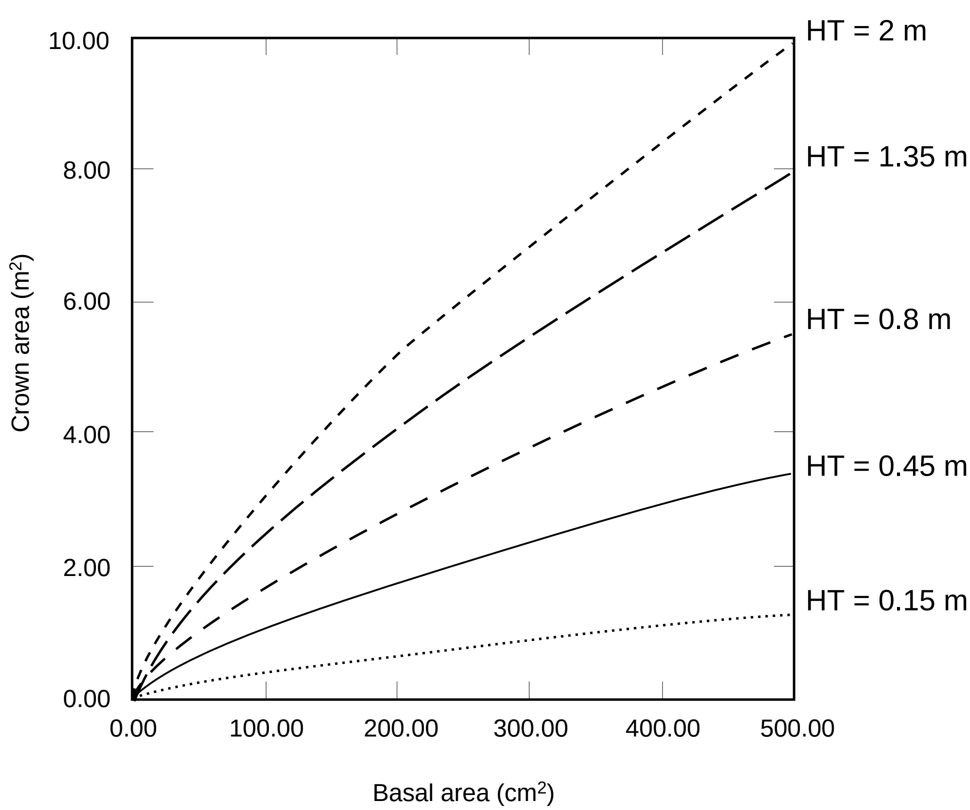

Figure 3—Plot of fitted equation for manzanita—crown area as a function of height (m) and basal area (cm^2).

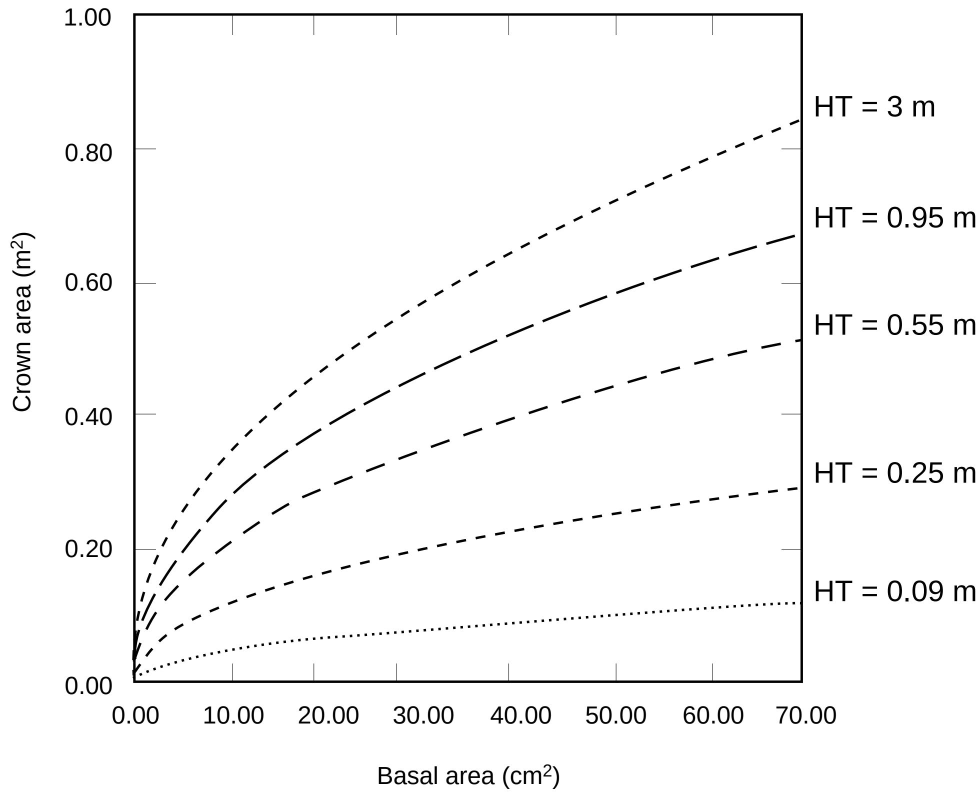

Figure 4—Plot of fitted equation for chinkapin—crown area as a function of height (m) and basal area (cm^2).

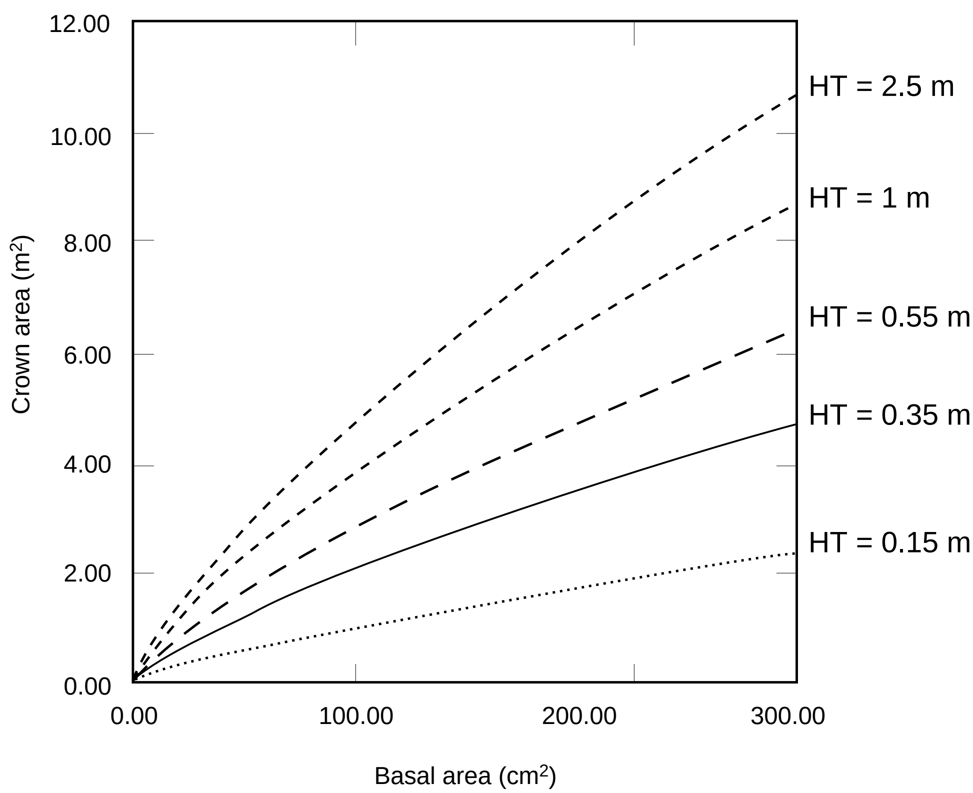

Figure 5—Plot of fitted equation for whitethorn—crown area as a function of height (m) and basal area (cm^2).

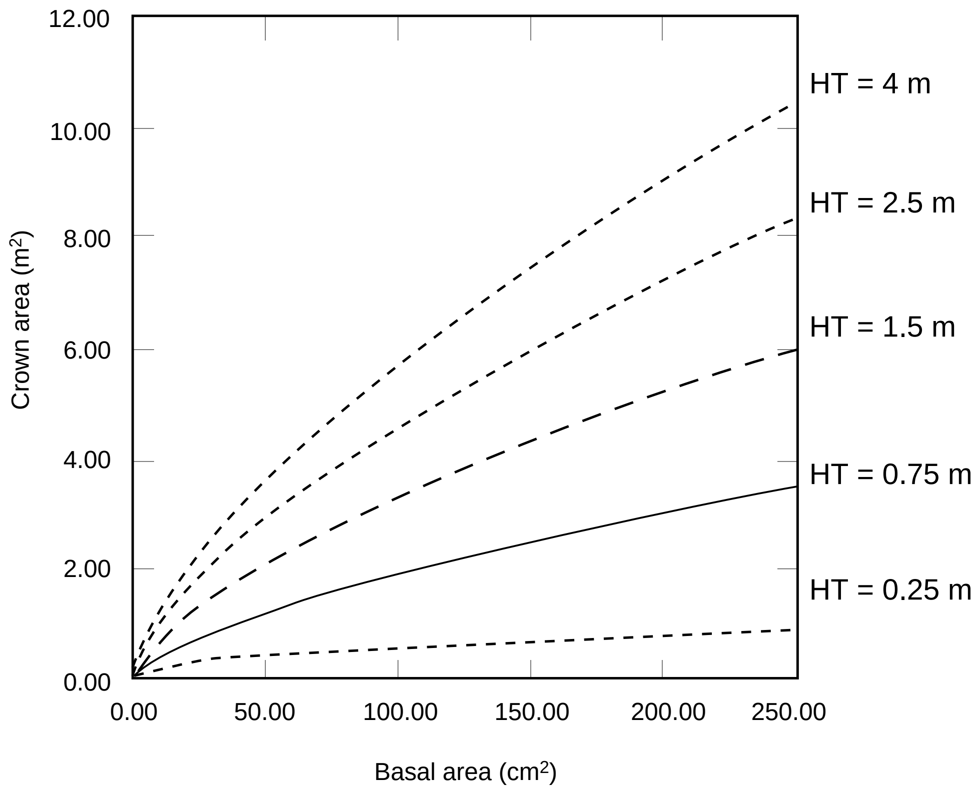

Figure 6—Plot of fitted equation for deerbrush—crown area as a function of height (m) and basal area (cm^2).

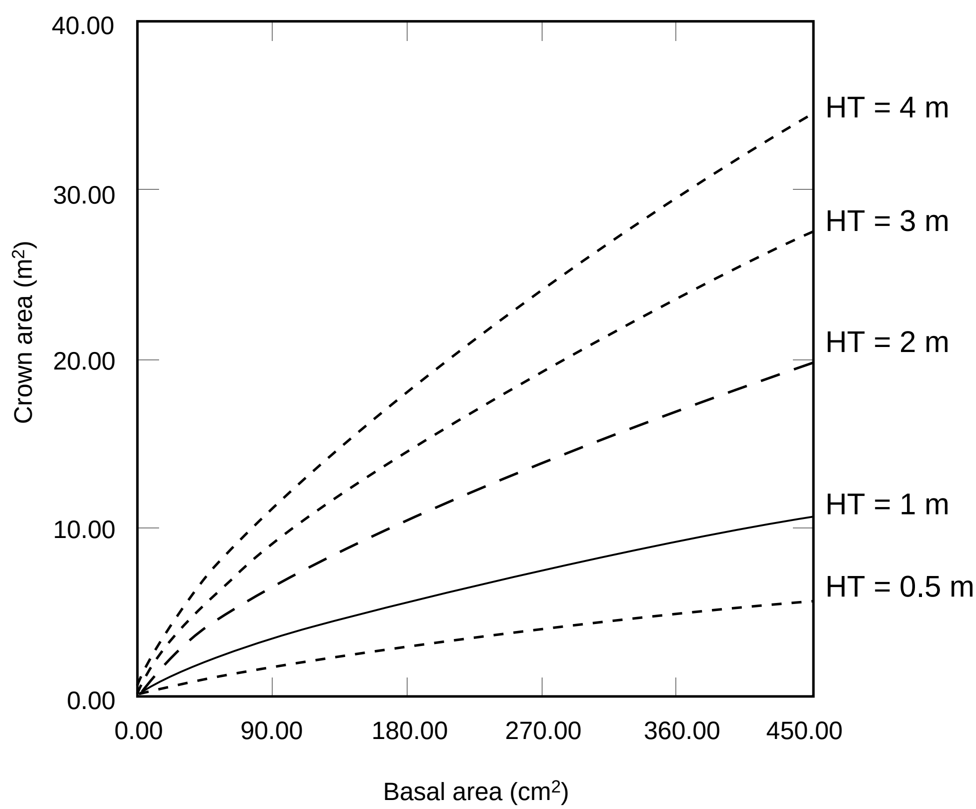

Figure 7—Plot of fitted equation for snowbrush—crown area as a function of height (m) and basal area (cm^2).

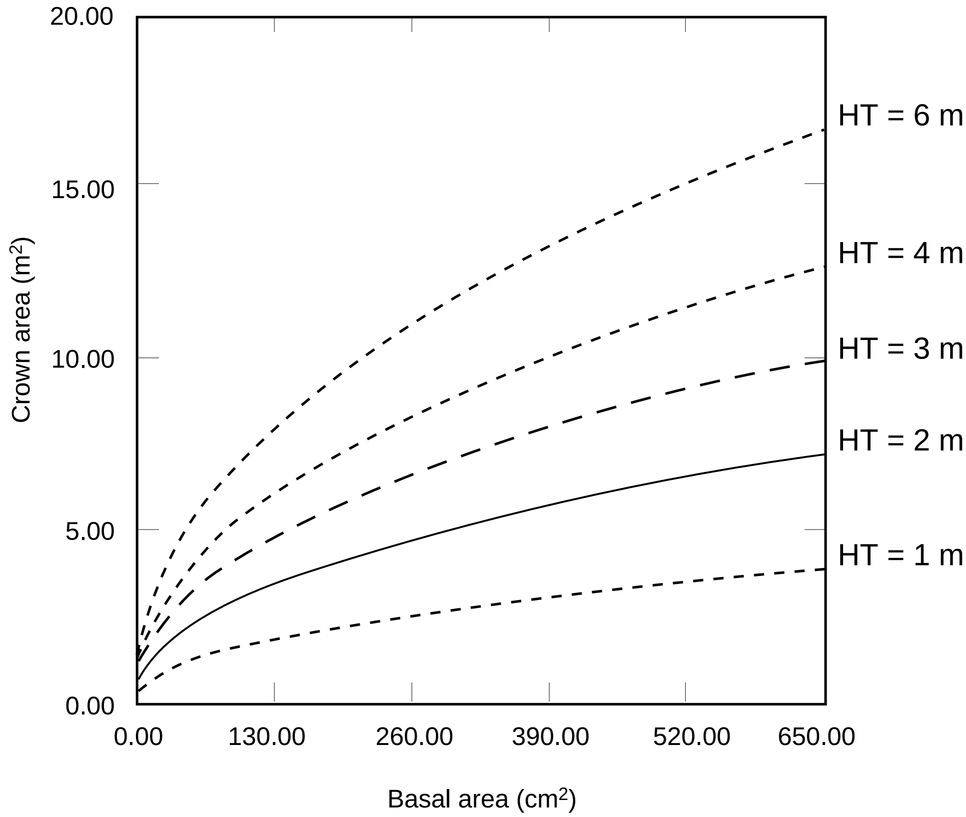

Figure 8—Plot of fitted equation for tanoak—crown area as a function of height (m) and basal area (cm^2).

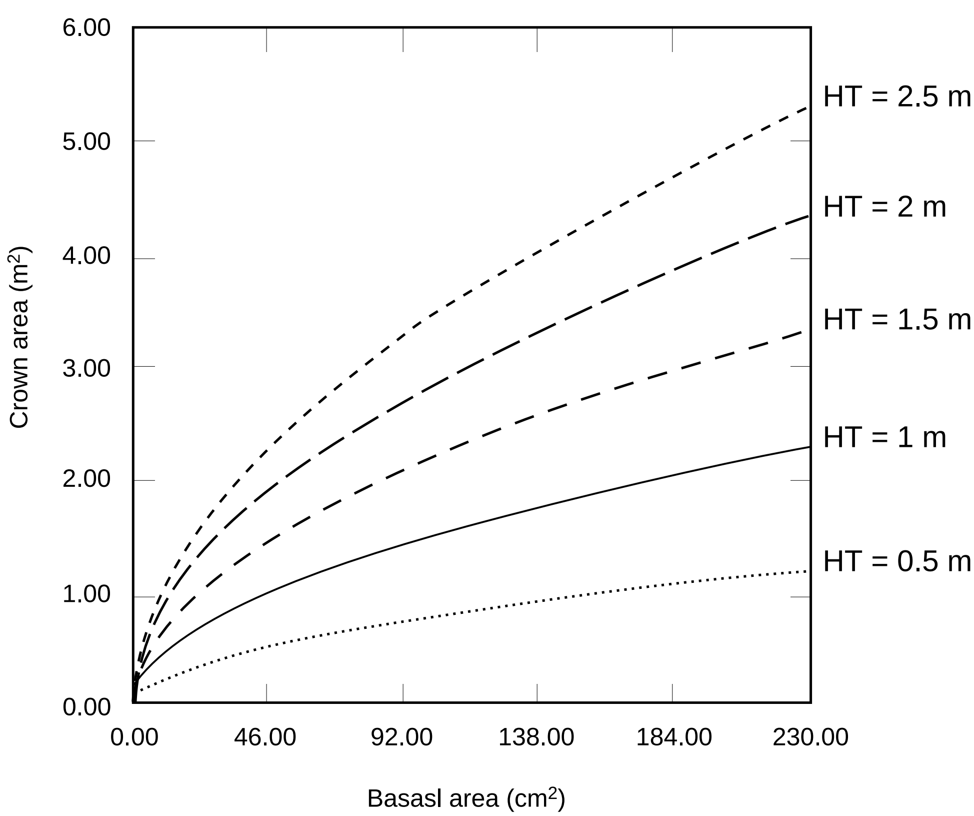

Figure 9—Plot of fitted equation for black oak—crown area as a function of height (m) and basal area (cm^2).

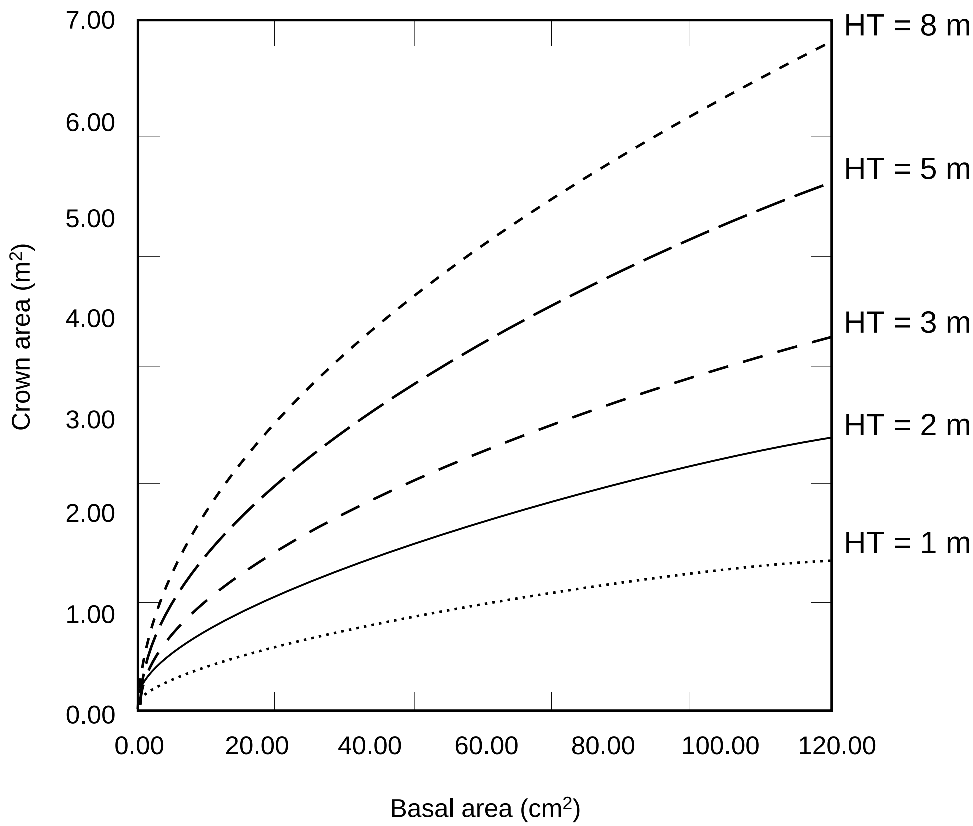

Figure 10—Plot of fitted equation for madrone—crown area as a function of height (m) and basal area (cm²).

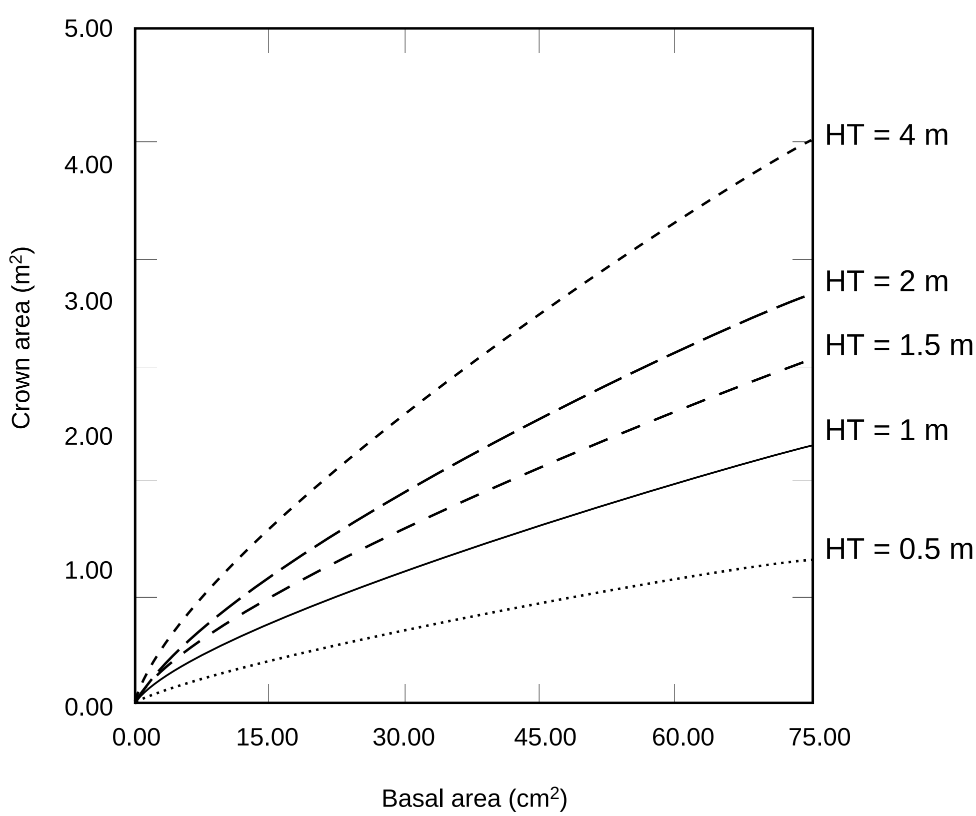

Figure 11—Plot of fitted equation for bitter cherry—crown area as a function of height (m) and basal area (cm²).

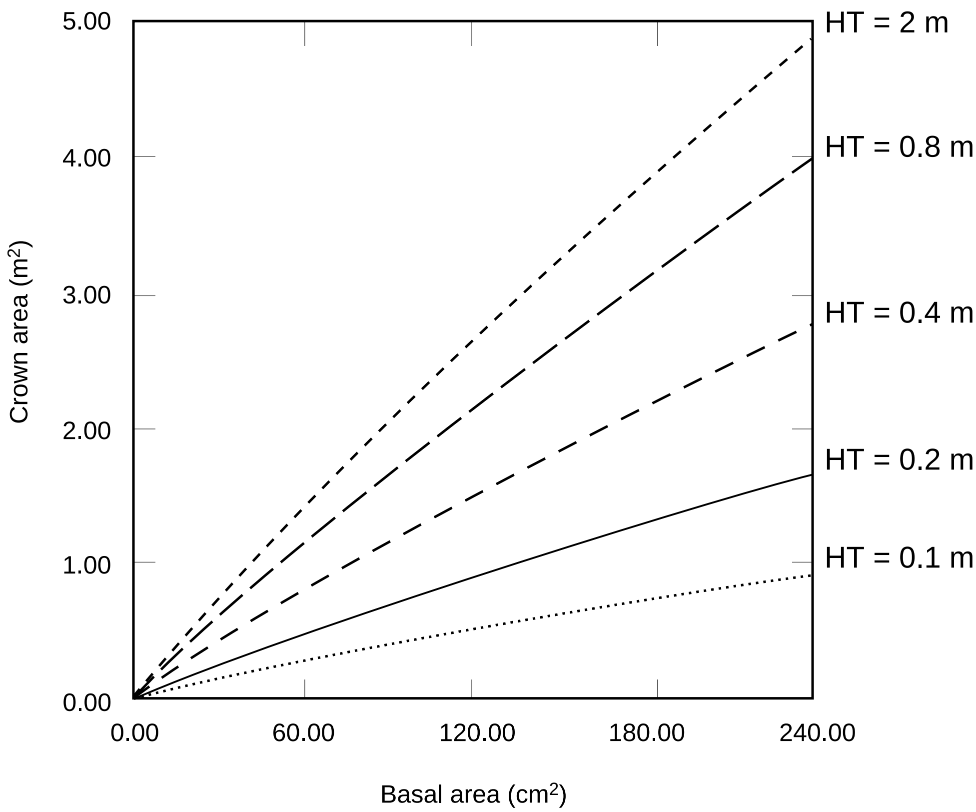

Figure 12—Plot of fitted equation for rhododendron—crown area as a function of height (m) and basal area (cm²).

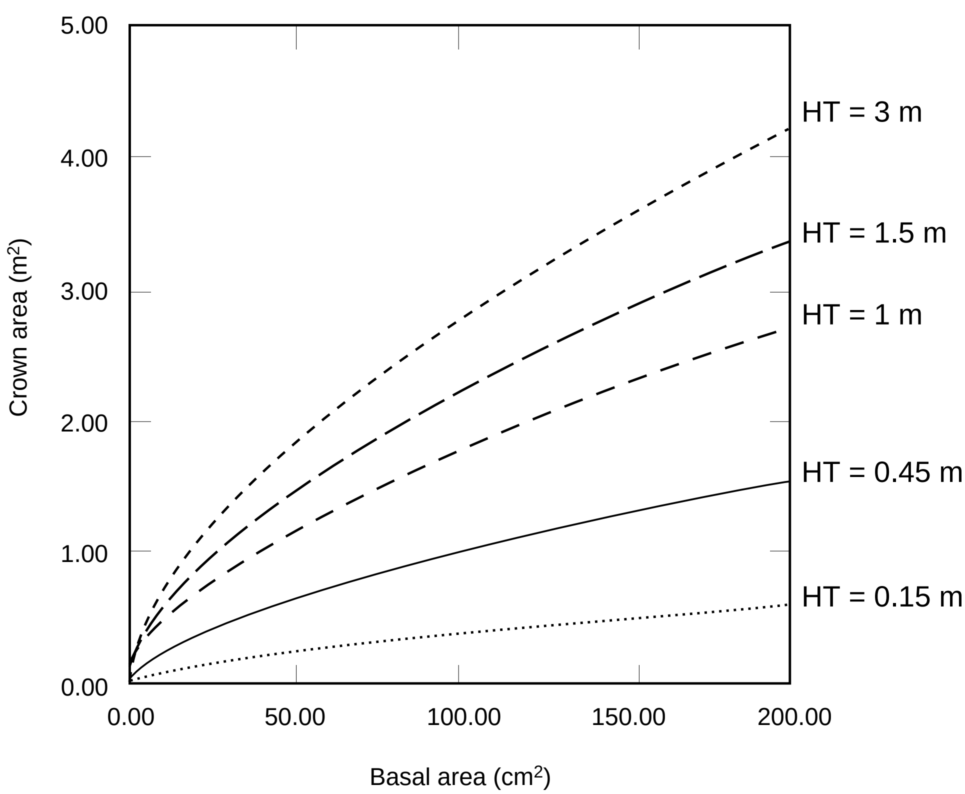

Figure 13—Plot of fitted equation for huckleberry—crown area as a function of height (m) and basal area (cm²).

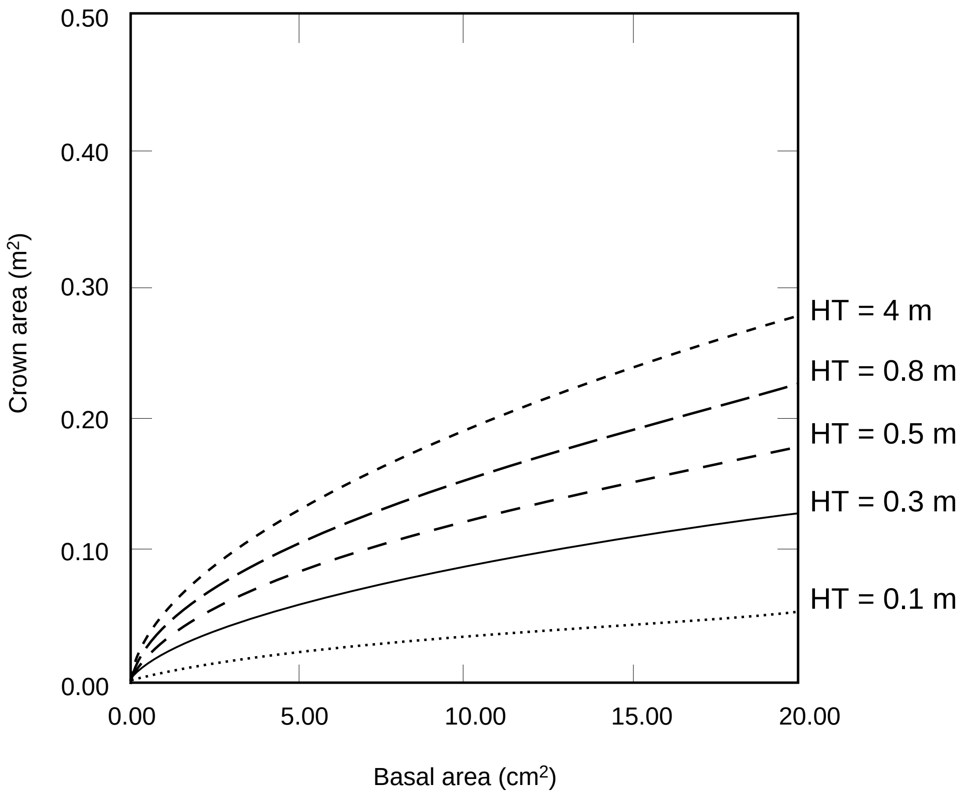

Figure 14—Plot of fitted equation for bigleaf maple—crown area as a function of height (m) and basal area (cm²).

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- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
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