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Research Article

Diameter at Breast Height-Crown Width Prediction Models for *Anogeissus Leiocarpus (DC.) Guill &Perr* and *Combretum Hartmannianum Schweinf.*

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ABSTRACT— **This study was carried out at El-Nour Natural Forest Reserve, Rosaries district, Blue Nile State with objective of predicting Crown width from Diameter at Breast Height for *Anogeissus leiocarpus* (DC.) *Guill & Perr*, and *Combretum hartmannianum Schweinf* species. Five models for predicting crown width were tested for these two species. For each species, dbh, total height and crown width were recorded. DataFit-9 statistical package of the Oakdale Engineering was used to fit the selected models. Akaike's information criterion (AIC), adjusted coefficient of determination (Ra2), root mean squared error (RMSE), numerical and graphical analyses of the residuals were used for evaluating the models.**

The results of the study showed that, all fitted models were found to give satisfactory results with Ra^2 range of 0.65 to 0.74 and RMSE of 1.12 to 1.40. The AIC values range from 114.8 for *Combretum hartmannianum Schweinf* and to 356.4 for *Anogeissus leiocarpus (DC.) Guill & Perr*. The study concluded that, the crown width could be estimated by the mean of diameter at breast height as it is easy to measure for ground-based inventory and stand structure determination. The crown width-diameter models examined in this study produced reasonably precise estimates for crown width and could be used to predict the crown width of the species under consideration.

The study recommended that, Future research is needed with a greater variety of site and stand conditions in addition to a greater variety of tree sizes and ages. It should be noted that, the models used by this study were based on data collected from El-Nour Natural Forest Reserve in Blue Nile State; therefore, it should be used with caution outside this area.

Index Terms — **Forest canopy, Tree crown, Crown width, Diameter at breast height, Non-linear regression and models evaluation.**

I. INTRODUCTION

Diameter at breast height and crown width are important tree characteristics where many of the forestry activities and processes were related with it, therefore any attempt that can improve the accuracy of measuring, predicting and analyzing these parameters should be taken into consideration. The crowns of trees have been subjected to much less study than their stems, primarily due to their lower marketable value. However, crown size, being closely related to the photosynthetic capacity of a tree, is an important parameter in studies of the growth of individual trees [1]. It is also very relevant in studies of the growth of stands due to the close correlation between crown size and stem diameter, and the 'packing' or density of trees in a stand [2].

Some parameters (e.g., diameter or age) are easy to measure with simple instruments and it is widely used by forest inventories. However, a number of studies have shown that other variables which are not so easily obtained are also good predictors of forest dynamics and they can improve the reliability of tools like growth and yield models. One of these parameters is crown size, which has received increasing attention as a mean to estimate tree growth [3].

In some studies tree crown diameter is well correlated with tree bole diameter, where it can be used for determining stand density and stocking relationships [4 - 10]. Same relationship was used by [4 ,11] for tree and stands volumes estimation.

Measurement of tree crown width is more difficult and more time consuming than that of Diameter at Breast Height (dbh) [12]. Crown width is used in tree and crown level growth-modelling systems, where simple competition indices are not available to adequately predict recovery from competition when a competitor is removed [13]. Crown width is also used in calculating competition indices based on crown overlap [14, 15] and predicting above ground biomass. Modern forest management requires precise, accurate, timely and complete forest information. Forest information can be acquired by forest inventory, which includes collection of individual tree parameters such as location, Diameter at Breast Height (dbh), tree height, tree crown size and tree species within a sampled forest plot, and also includes the derivation of forest stand measurements such as forest density, age, mean height, and crown closure, etc using statistical extrapolation of plot measurements [16]. Crown width models can be

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formulated from open-grown trees or from stand grown trees [17].
Sudan natural forests [18]. In order to reduce the inventory cost and time, modelling of crown width-diameter at breast height can be used as proposed method to overcome the problem of higher inventory cost.
The objective of this study is to evaluate the performance of five predicting models for crown width-diameter at breast height (Cw-dbh) relationship for *Anogeissus leiocarpus (DC.) Guill & Perr,* and *Combretum hartmannianum Schweinf* in Blue Nile State, Sudan.

II. MATERIALS AND METHODS

The present study was conducted in El-Nour Natural Reserved Forest which is posed in Blue Nile State, Sudan, between longitudes $11^{0}\ 48^{/}19^{//}$ N and $11^{0}\ 53^{/}30^{//}$ N and latitudes $34^{0}\ 28^{/}\ 47^{//}$ E and $34^{0}\ 32^{/}\ 35^{//}$ E with total area of about 11,100 feddan. The forest host more than 55 species dominated by *Sterculia setigera, Combretum hartmannianum, Acacia seyal, Terminalia brownii, Terminalia laxiflora, Anogeissus leiocarpus, Balanites aegyptiaca, Combretum micranthum* and *Lannea fruticosa* [18]. The topography of El-Nour Forest is generally flat or semi-flat with cracky clay soil in northern-part and sandy soil in southern-part of the forest.
The selection of species for this study was principally based on the facts that, these two species are endangered woody plants in addition to their economic value and its uses by local communities around the forest. *Anogeissus leiocarpus* is used locally for fire wood, charcoal, local buildings, beams and rafters [19]. Its bark is also used for cough, rheumatism and bronchitis [20]. *Combretum hartmannianum* is one of the important Sudanese trees which have medicinal uses and high caloric value. This species is at risk of disappearing, as it has very low germination percentage (2% and less), which negatively affect the reforestation efforts of the tree [21]. It is used for Fire wood, charcoal, fence posts and framework of thatched houses. Some portions of the tree are used as perfume. [19]. Boiled leaves used to cure ascites ; bark & leaves extract used for jaundice [20].The wide uses of these two species in the area in the absence of proper natural regeneration, due to High cost of inventory operations compared with it outcome value of harvested timber represented the main problem of overgrazing, wild fires and draught, has resulted in gradual depletion of these species especially in areas close to villages. Estimation of the present growing stock in such large area using the traditional inventory system is expected to be both uneconomic and time consuming. Taking all these facts in consideration it become necessary to find out cheapest and less time consuming alternatives like a dbh-Cw relationship as a base for using remote sensing and GIS techniques.
Selective sampling was used for data collection where each individual open grown tree was considered as a sample and dbh, total tree height and crown width (Cw) were recorded for all sampled trees. The dbh (cm) was measured over bark at 1.3m to the nearest millimetre by using tree calliper and diameter tape for larger trees (**Table 1**). Total tree height (m) was measured by using Suunto Clinometers' (**Tables 1**), while crown width (m) was measured in eight directions from the main bole (every 45^{0} beginning with magnetic north) to the vertically projected edge of the crown (**Table 1**).
Five equations were selected for modelling the dbh-Cw relationship (**Table 2**), while DataFit-9 was used to fit these models [22]. Akaike's Information Criterion (AIC), adjusted coefficient of determination (Ra^2), root mean squared error (RMSE), numerical and graphical analyses of the residuals were used for evaluating the models. Model resulting in the largest Ra^2, least RMSE, and smallest values of AIC and average bias was selected as the best model for the selected tree species [23]. For data analysis, the dbh and crown width were taken as independent and dependent variables respectively.
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Table 1. Diameter, height and crown width characteristics

Species	N	Max	Min	Mean	S.dev	CV%
Diameter at breast height characteristics (cm)						
Anogeissus leiocarpus	255	70.2	19.5	39.61	2.711	6.84
Combretum hartmannianum	205	68	8	34.2	12.42	36.32
Total tree height characteristics (m)						
Anogeissus leiocarpus	255	23.5	6.5	13.1	2.707	20.66
Combretum hartmannianum	205	24	4.5	13	3.864	29.72
Crown width characteristics (m)						
Anogeissus leiocarpus	255	21	4.75	9.862	2.711	27.49
Combretum hartmannianum	205	15.5	1.5	7.74	3.096	40

Table 2. Regression models

Code	Function form	Reference
M 1	$Cw = b_0 + b_1*dbh$	[8]
M 2	$Cw = b_0*b_1^{dbh}$	[17]
M 3	$Cw = b_0*dbh^{b1}$	[17]
M 4	$Cw = (dbh) / (b_0+b_1 dbh)$	[24]
M 5	$Cw = b_0 + b_1*dbh+$	[24]

Cw: Crown width, dbh: diameter at breast height, b_0, b_1, b_2 and $b_3$are equation parameters.

III. RESULTS AND DISCUSSION

For data analysis, the dbh was taken as the independent variable, while the crown width was taken as the dependent variable. **Table 3** and **Table 4** show, the regression parameter estimates and fit statistics for the five tested models, while, **Fig. 1** and **Fig. 4** describe the crown width curves predicted by the same models, and **Fig. 2** and **Fig. 5** illustrated the curves of top three models for *Anogeissus leiocarpus* and *Combretum hartmannianum* respectively. **Fig.3** and **Fig.6** represented the residual plots of one top model for each species.

Generally, all fitted models gave acceptable results with Ra^2 range from 0.6494 to 0.6661 and RMSE of 1.4074 to 1.4183 for *Anogeissus leiocarpus*, and 0.7141 to 0.7409 and 1.1165 to 1.2231 for *Combretum hartmannianum*. The AIC values range from 114.8 to 168.1 for *Combretum hartmannianum* and 348.6 to 356.4 for *Anogeissus leiocarpus.*

Table 3. Parameter estimates and fit statistics for *Anogeissus leiocarpus*

Models Statistics (n = 255)					**Coefficient Estimates**				
Code	R^2	Ra^2	RMSE	AIC	P	Value	S	t-ratio	Prob(t)
M 1	0.6682	0.6661	1.4074	348.6	b_0	2.7892	0.4898	5.6942	0.0000
					b_1	0.1776	0.0119	14.925	0.0000
M 2	0.6657	0.6636	1.4091	349.8	b_0	0.6776	0.1225	5.5321	0.0000
					b_1	0.7285	0.0481	15.139	0.0000
M 3	0.6642	0.6620	1.4101	350.5	b_0	5.0597	0.2393	21.143	0.0000
					b_1	1.0165	0.0011	962.12	0.0000
M 5	0.6640	0.6616	1.4165	352.3	b_0	3.4874	1.4711	2.3621	0.0189
					b_1	0.1436	0.0686	2.0857	0.0380
					b_2	0.0004	0.0008	0.5014	0.6165
M 4	0.6516	0.6494	1.4183	356.4	b_0	4.6881	0.3310	14.166	0.0000
					b_1	0.1975	0.0079	24.861	0.0000

Table 4. Parameter estimates and fit statistics for *Combretum hartmannianum*

Models Statistics (n = 255)					**Coefficient Estimates**				
Code	R^2	Ra^2	RMSE	AIC	P	Value	S	t-ratio	Prob(t)
M 2	0.7439	0.7409	1.1165	114.76	b_0	0.8368	0.3746	2.2336	0.0266
					b_1	0.2017	0.0103	19.599	0.0000
M 1	0.7427	0.7398	1.1172	115.40	b_0	0.9008	0.1538	5.8555	0.0000
					b_1	0.6175	0.0500	12.360	0.0000
M 5	0.7259	0.7225	1.1250	145.87	b_0	0.1938	0.7540	0.2570	0.7975
					b_1	0.2454	0.0457	5.3729	0.0000
					b_2	-.0006	0.0007	-.9827	0.3270
M 4	0.7172	0.7141	1.1325	148.43	b_0	5.2341	0.3735	14.0146	0.0000
					b_1	0.2004	0.0095	21.0091	0.0000
M 3	0.7160	0.7141	1.2231	168.10	b_0	3.2963	0.1960	16.8217	0.0000
					b_1	1.0241	0.0014	723.963	0.0000

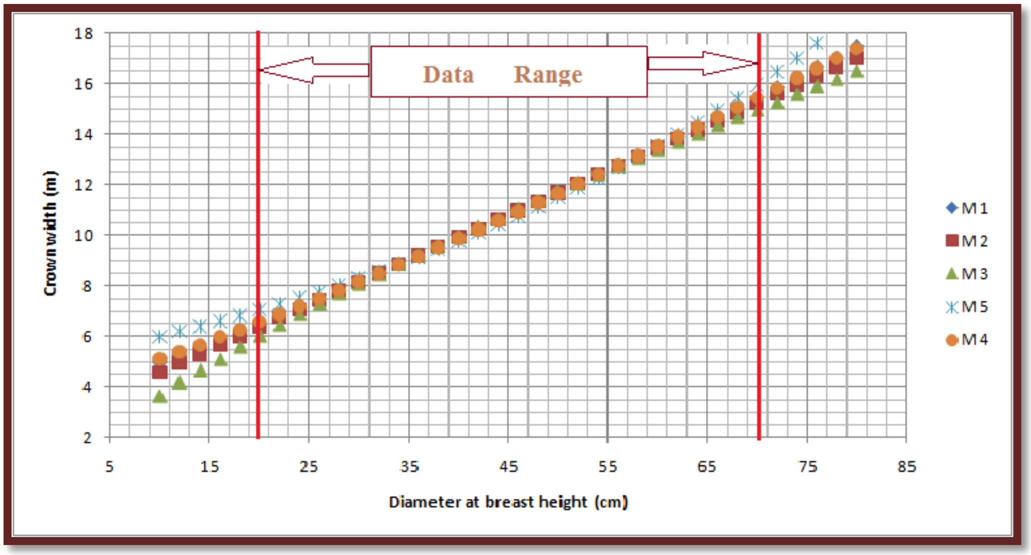

Figure 1. Predicted for *Anogeissus leiocarpus* (All tested models)

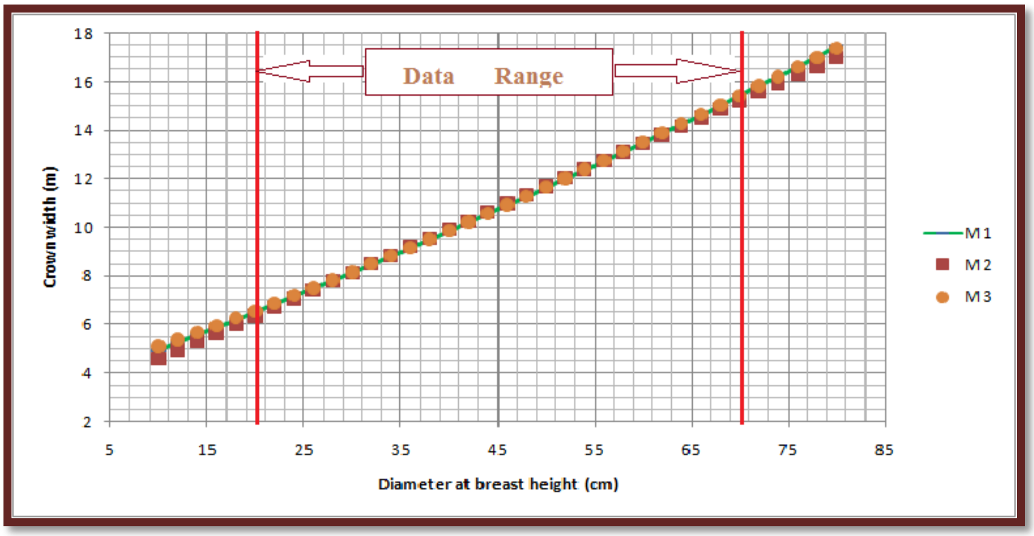

Figure 2. Predicted for *Anogeissus leiocarpus* (Top models)

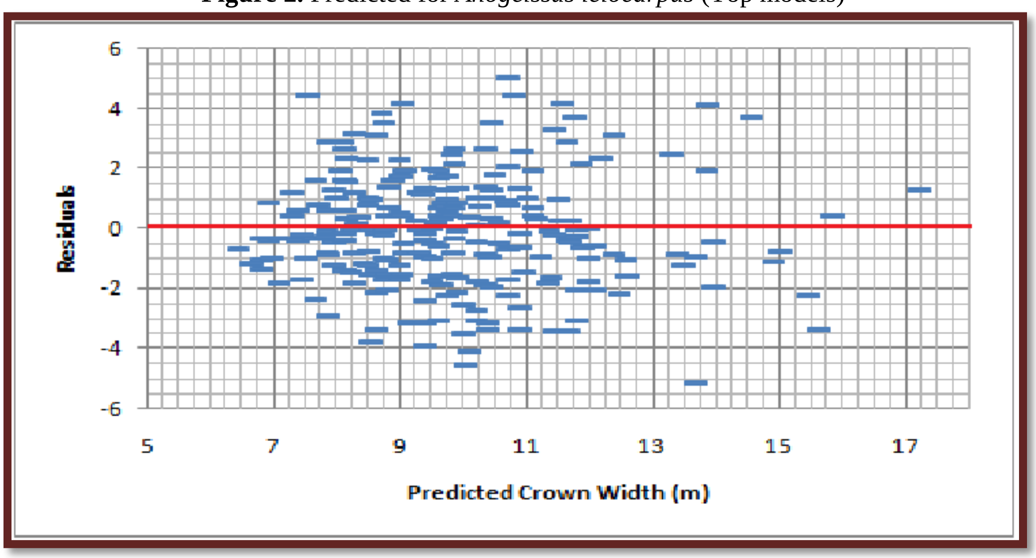

Figure 3. Residual plot for *Anogeissus leiocarpus*

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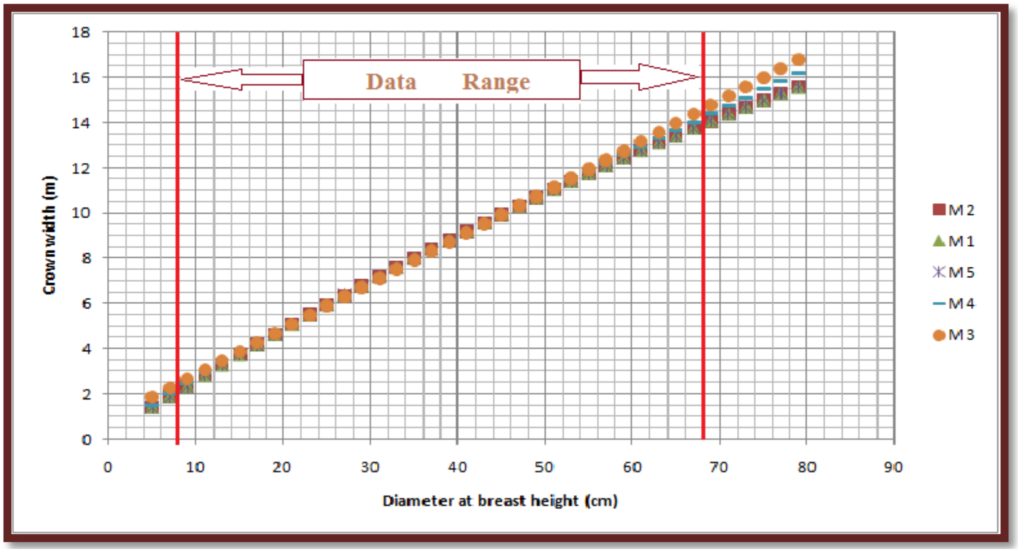

Figure 4. Predicted for *Combretum hartmannianum* (All tested models)

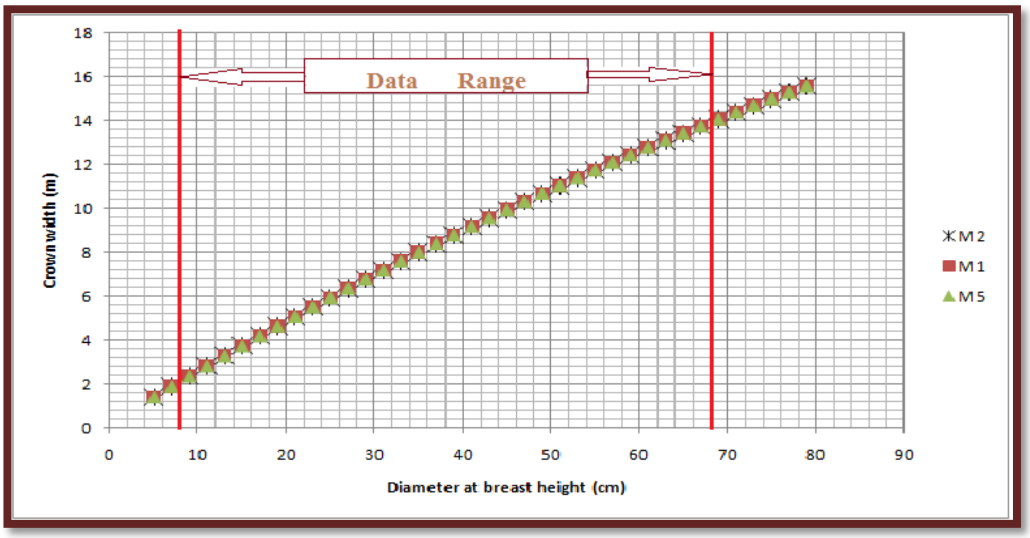

Figure 5. Predicted for *Combretum hartmannianum* (Top models)

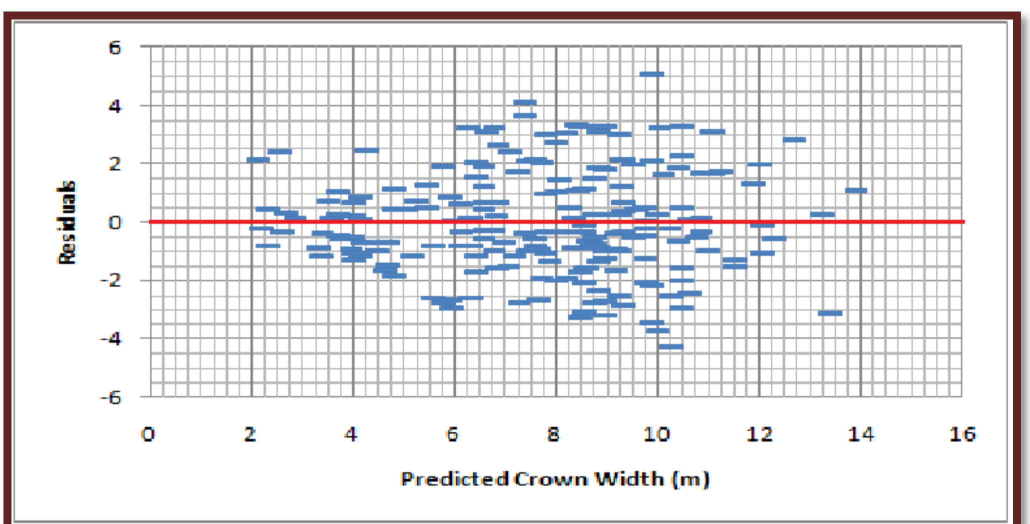

Figure 6. Residual plot for *Combretum hartmannianum*

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Generally, among all tested models, M1 and M2 show higher performance for both two species **(Tables 3 and 4)**, **(Figures 1 and 4)**.The highest Ra^2 value was obtained in model (M2) in case of *Combretum hartmannianum* ($Ra^2 = 0.7409$), **(Table 4)**, and the lowest Ra^2 was obtained in model (M4) in case of *Anogeissus leiocarpus* ($Ra^2 = 0.6494$), **(Table 3)**.

Models M2 and M1 were present in both two species among the best three models for two species but in different ranking order. Most of the three best models for the two species consist of two parameters (b_0 and b_1) except M5 in case of *Combretum hartmannianum* which mean that, the two parameter equations were more efficient than their counterparts. All parameters were statistically significant ($p < 0.0001$). These findings were consistent with that concluded by previous research [2, 8, 12, 9, 25].

Figures 2 and 5 represent the crown width predicted curves produced by the top three models for *Anogeissus leiocarpus* and *Combretum hartmannianum* respectively. These crown curves indicated that, all top three models performed well within the data range. The *Combretum hartmannianum* curves produced almost the same curve where they appeared as one curve, such trend could be referred to the general form of *Combretum hartmannianum* in El-Nour forest where it characterized by spherical crown shape for open-grown trees.

IV. CONCLUSIONS

This study concluded that, the crown width can easily be predicted from diameter at breast height with high accuracy (RMSE of about 1.5mm) and precision. These models can be useful in predicting crown width from forest inventories for stocking guideline development, growth models, remote sensing/stand volume estimation, and wildlife suitability index models that used crown characteristics.

Future research is needed with a greater variety of site and stand conditions in addition to a greater variety of tree sizes and ages. It should be noted that, the models developed by this study were based on data collected from El-Nour Natural Forest Reserve in Blue Nile State; therefore, it should be used with caution outside this area.

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