Scientific Research Publishing

Open Journal of Ecology, 2020, 10, 571-584
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

Development of Allometric Models for Estimating the Biomass of *Sclerocarya birrea* (A.Rich) Hoscht and *Boscia senegalensis* (Pers.) Lam. ex Poir.

Ramata Talla[1,2], Moustapha Bassimbé Sagna[1,2], Mariama Dalanda Diallo[2,3,4], Aly Diallo[2,5], Daouda Ndiaye[1,2], Oumar Sarr[1], Aliou Guisse[1,2,4*]

[1]Cheikh Anta Diop University, Department of Plant Biology, Dakar, Senegal
[2]Observatoire Homme-Milieux international de Téssékéré, CNRS/Université Cheikh Anta Diop, Dakar, Senegal
[3]Gaston Berger University, UFR of Agronomic Sciences, Aquaculture and Food Technologies, Saint Louis, Senegal
[4]UMI 3189 "Environnement, Santé, Sociétés" UGB, UCAD, CNRS, CNRST, USTTB, Dakar, Senegal
[5]Assane Seck University, Department of Agroforestry, Néma, Ziguinchor, Senegal
Email: *aliou.guisse@ucad.edu.sn

How to cite this paper: Talla, R., Sagna, M.B., Diallo, M.D., Diallo, A., Ndiaye, D., Sarr, O. and Guisse, A. (2020) Development of Allometric Models for Estimating the Biomass of *Sclerocarya birrea* (A.Rich) Hoscht and *Boscia senegalensis* (Pers.) Lam. ex Poir. *Open Journal of Ecology*, **10**, 571-584.
https://doi.org/10.4236/oje.2020.108035

Received: June 30, 2020
Accepted: August 22, 2020
Published: August 25, 2020

Abstract

The objective of this study was to develop allometric models for estimating the biomass of *Sclerocarya birrea* (A.Rich) Hoscht and *Boscia senegalensis* (Pers.) Lam. ex Poir. The inventory of these ligneous was carried out at Widou Thiengoly (North of Senegal). The sample consists of 43 individuals of *Boscia senegalensis* and 15 individuals of *Sclerocarya birrea*. The selected individuals were dendrometrically characterized before being cut, compartmentalized (trunk, branches, and twigs) and weighed entirely. Simple regression tests were performed to examine the most explanatory dendrometric parameter (x) for biomass (y) according to two types of models: the linear model ($y = ax + b$) and the polynomial model of degrees 2 ($y = ax^2 + bx + c$). The criteria for selection and validity of the models are based firstly on the tests of normality, nullity, heterogeneity and autocorrelation of the residues. The results showed that the most explanatory dendrometric parameter of the biomass was the crown surface for *Boscia senegalensis* and the 1.30 m diameter for *Sclerocarya birrea* of all the tests performed, the second-order Polynomial model is the best predictor of above ground biomass for these two species. Thus, the allometric models established to predict the biomass of these two species are: $y = 0.0023x^2 + 0.4851x - 0.0519$ for *Boscia senegalensis* and $y = 0.35x^2 + 10.35x - 12.90$ for *S. birrea*; with very significant correlation coefficients (R^2) of 0.85 and 0.94 respectively. These results can be used for a sequestered carbon assessment study and will play a role in monitoring the carbon market in Africa.

Keywords

Allometric Equation, *Boscia senegalensis*, *Sclerocarya birrea*, Ferlo, Senegal

1. Introduction

In the current context of increased anthropization, the world's ecosystems are undergoing intense deforestation, causing a significant increase in greenhouse gas emissions to the atmosphere and global warming [1]. To address this major challenge, greenhouse gas (GHG) reduction mechanisms were introduced as part of the Kyoto Protocol in 2005, in which carbon appears to be at the center of economic, environmental and social issues in the world. In the Sahel, the recurrence of droughts in recent decades, relating to rainfall deficits, has led to a reduction in the productivity of vegetation [2]. At the same time, natural ecosystems are subject to overexploitation by local populations and overgrazing by livestock [3] [4]. In Senegal, in the Sahelian zone, certain woody trees play a primordial environmental and socio-economic role. As part of the Sahel regreening project in the context of the Great Green Wall (GMV), the main plant species used in this program to combat desertification are, among others, *Balanites aegyptiaca* (L.) Del, *Acacia tortilis* (forsk.) Hayne ssp. *raddiana* (Savi) Brenan, *Acacia senegal* (L.), *Sclerocarya birrea* (A.Rich) Hoscht and *Boscia senegalensis* (Pers.) Lam. ex Poir. [5] [6]. The productivity of these species in the Senegalese Sahel will directly contribute to the increase of their biomass in reforested ecosystems and indirectly their capacity to sequester atmospheric carbon. Indeed, the study of woody biomass provides information on the atmospheric carbon sequestration potential of a species [7] [8]. This therefore responds particularly to the global concern of mitigating climate change due to emissions of greenhouse gases, notably carbon [9] [10]. Previous work has been the subject of biomass studies of species such as *Acacia senegal* with [11] and [12] and *Afzelia africana*, *Ficus gnaphalocarpa* and *Pterocarpus erinaceus* with [13]. Our study is part of this continuity, as it complements the work already carried out in the area [14]. In addition, the literature review reveals almost no data on *Sclerocarya birrea* (A.Rich) Hoscht and *Boscia senegalensis* (Pers.) Lam. ex Poir.

The objective of this study is to develop allometric models for the estimation of the biomass of these two Sahelian species in the Ferlo.

2. Material and Methods

2.1. Presentation of the Study Area

The study was conducted in Widou Thiengoly, a village in the north of Senegal in the Sylvopastoral area of Ferlo (**Figure 1**). The choice of site is justified by the

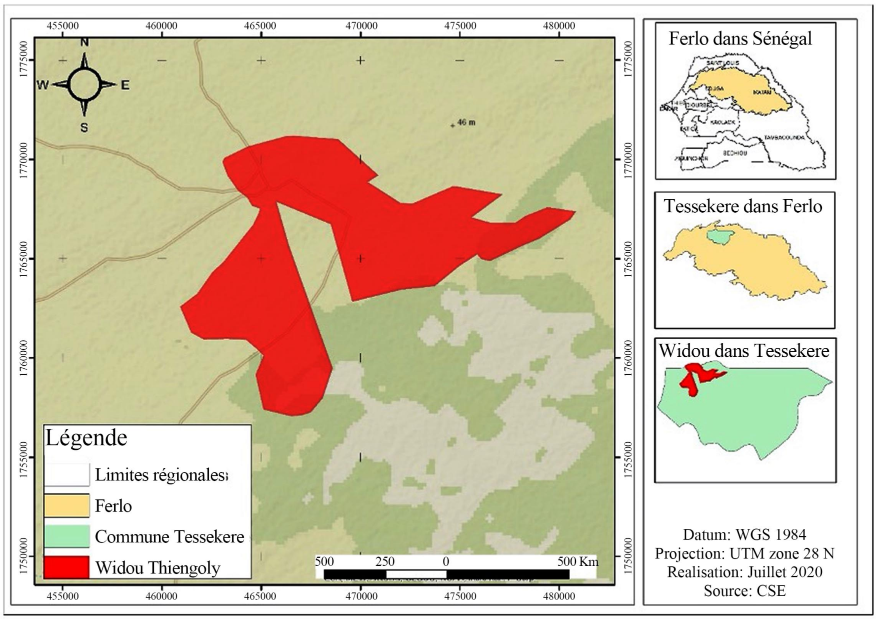


Figure 1. Location of the study area (Widou Thiengoly).

abundance of the two Sahelian species *Sclerocarya birrea* and *Boscia senegalensis* in the area. This part commonly called the Ferlo (Sylvopastoral zone of Senegal), belonging to the Sahelian bioclimatic zone [15] [16], is located between latitudes 15˚ and 16˚30 north and longitudes 13˚30 and 16˚ west, over an area of 70,000 km^2 [17].

The region's climate, of a semi-arid tropical type, is characterized by an alternation of a long dry season from October to June and a short rainy season between July and September. Average annual precipitation in recent decades has rarely reached 300 mm [18] and is unevenly distributed in time and space. The months of August and September, which record the maximum rainfall (around 150 mm), are considered to be the heart of the rainy season. Temperatures vary throughout the year with minimums of 15˚C and maximums of 46˚C to 48˚C [19]. Ferlo shelters a steppe with shrubby dominated by woody trees such *as Balanites aegyptiaca* (L.) Del, *Boscia senegalensis* (Pers.) Lam. ex Poir., *Acacia senegal* (L.), *Acacia tortilis* (forsk.) Hayne ssp. *raddiana* (Savi) Brenan, and *Calotropis procera* (Aiton) W. T. Aiton [18] [20]. In terms of soil morphology, the study area belongs to the sandy Ferlo, characterized by a succession of dunes and shallows with little accident, with a different type of soil depending on whether one is on a dune summit or below slope [21].

2.2. Plant Material

Two species were the subject of this study, *Sclerocarya birrea* (A.Rich) Hoscht and *Boscia senegalensis* (Pers.) Lam. Ex Poir. *Sclerocarya birrea* belongs to the *Anacardiaceae* family, order of Sapindales. The tree has a single trunk and develops a broad crown and a gray mottled bark. The tree can reach 18 m in height mainly in low latitudes and open forests. *Boscia senegalensis* is a species that belongs to the *Capparaceae* family, of the order Capparales. It is a shrub or shrub 1 to 5 m high, conical in shape, the crowns are very dense and the trunks of small diameters very branchy. These two species have a wide distribution in the Sahelian to Sudanian zone, on dry stations, rocky, lateritic, sandy soils (dunes). They returned from Mauritania to Senegal and can be found as far as Ethiopia. They are fairly common, locally abundant and gregarious [22].

The above-ground biomass of its two woody species was used to develop an allometric model for the evaluation of their biomass.

2.3. Sampling and Dendrometric Characterization of Woody Species

The sample size was calculated from Dagnélie's formula [23]:

$$n = U^2 1-\alpha/2 \ \left(P\left(1-P\right)\right)/d^2 \tag{1}$$

with $U1-\propto/2 = 1.96(\approx 2)$ and $1 \le d \le 15$.

P = percentage of the species;

A = (the ratio of the density of the species studied to the total density of woody species);

d = is the error rate;

U = is the u of the normal law which is read on the table.

Based on this calculation, the study focused on 43 individuals of the species *Boscia senegalensis* and on 15 individuals of *Sclerocarya birrea*; randomly selected from Widou Thiengoly village routes. Dendrometric measurements of standing individuals were carried out to characterize the species. They concern: the diameter at chest height (1.30 m from the ground) and the diameter at the base (0.30 m from the ground), the total height and the two crossed diameters of the crown ($d1$ and $d2$). It is then possible to calculate the area of the crown (m^2) by the following formula [24]:

$$SH = 1/4\,\pi D1 * D2\,. \tag{2}$$

2.4. Biomass Measurement in the Field

To develop allometric models, the direct method based on tree felling and was used. The sampled subjects are cut down and compartmentalized (trunk, branches, twigs and twigs-leaves). The total fresh mass of each part is weighed with a balance of 200 kg and that of the compartments with a precision balance of 7 kg. These different weighings are noted in the statement sheet. From each compartment, samples were taken and stored in plastic bags to determine the dry biomass.

2.5. Determination of Dry Biomass

In the laboratory, the samples from the different compartments were weighed again and then dried in an oven at 70˚C to constant weight. The dry biomass (Ms) of small sample was determined which made it possible to calculate the humidity rate of the different parts of each individual according to the formula below:

$$Th = (Pf - Ps)/Pf \quad (3)$$

Th = Humidity level of the sample;

Pf = fresh weight of the sample;

Ps = dry weight of the sample;

Thus, the total dry biomass of each individual was calculated by the following formula:

$$Ms = Pft - (Pft \times Th) \quad (4)$$

Ms = dry mass;

Pft = Total fresh weight.

2.6. Data Processing

The dry biomass data were processed using the Excel spreadsheet and the R x 64 Software version 3.5.1 was used as the basis for the statistical tests. Simple regression tests were performed using XLSTAT 2014 software in Excel to see the relationship between the calculated dry biomass and the various dendrometric parameters measured. With these tools, several allometric equations were tested in order to retain those which seem to be the most explanatory of aboveground biomass according to dendrometric parameters.

The allometric equations were subjected to a series of statistical tests in order to meet all the validation conditions [25] [26]. Thus, each model is subject, at the probability threshold of 5%, respectively to:

- Normality test (Shapiro-Wilk test) to check the normality of the residuals;
- Test of the zero mean (One Sample Test) to check the nullity of the residuals;
- Heteroscedasticity test (studentized Breusch-Pagan) to check the heterogeneity of the residues;
- Autocorrelation test (Durbin-Watson test) for the independence of the residues.

When an equation meets these tests, an analysis of the information criterion (AIC) of the residual error (E) and especially of the standard residual error (CSR) is carried out. AIC establishes a compromise between bias and variance for a model [27]. The residual error (E) expresses the error linked to the prediction of a model. It is expressed as a percentage [28]. For each fraction of the biomass, we prioritized the models using the correlation coefficient (R) of the regression between the predicted biomass and the observed biomass. Theoretically, the best equations are those with the correlation coefficient close to unity, the lowest residual error and the AIC, and the calculated values of the various tests greater than the theoretical values [26] [27] [29].

3. Results

3.1. Dendrometric Characteristics of the Sample

The results of the population structure of the sampled *Sclerocarya birrea* and

Boscia senegalensis are presented in Table 1.

Analysis of Table 1 shows that the populations of *Sclerocarya birrea* and *Boscia senegalensis* inventoried at Widou Thiengoly are morphologically different.

Indeed, the standard deviation noted in *Boscia senegalensis* is much greater in terms of the diameter at 0.30 m from the ground. And a much greater variability is noted with the diameter at 1.30 m in *Sclerocarya birrea*. Thus, the high standard deviations show that there is a large difference between the sampled individuals, reflecting a large intra-site variability.

3.2. Development of Allometric Model for Biomass

A correlation matrix (Table 2) allowed to see the relation which exists between the calculated dry biomass and the different dendrometric parameters measured: crown surface, height and the diameters (diameter at 0, 30 and diameter at 1, 30).

The results of the correlation showed that the most explanatory dendrometric parameter of the biomass of the species *Boscia senegalensis* is the surface of the crown and that of the species *Sclerocarya birrea* is the diameter at 1.30.

These two parameters for each species subjected to tests on five (5) models of equations (polynomial, linear, power, exponential and logarithmic) for a possible prediction of the biomass. Table 3 shows the results obtained.

The tests are carried out with a probability calculated at the threshold of 0.001; well below the critical threshold of 5% for all models. This indicates that all of the allometric equations have good correlation coefficients overall. Thus, the regressions whose coefficient of determination R^2 is greater than or equal to 0.80 have been retained.

The best models are then the polynomial regressions of order 2 ($y = ax^2 + bx + c$) and linear ($y = ax + b$) which are highly significant (P-value > 0.0001) and which have the best coefficients of determination (R^2) close to 1.

Figure 2 and Figure 3 show the results obtained for *Boscia senegalensis* (E1 and E2) and for *Sclerocarya birrea* (E3 and E4) for the linear and polynomial order model.

3.3. Equation Selection Tests

Table 4 presents the results of the various statistical tests of the allometric equations. The equations E2 and E4 (polynomials) for *Boscia senegalensis* and *Sclerocarya birrea* have respectively a residual error equal to 2.965e−09 and 4.664e−14 and they present lower AIC compared to equations E1 and E3. This confirms that the polynomial model of order 2 is the most explanatory of the aboveground biomass of *Boscia senegalensis* (for y = dry biomass and x = surface of the crown) and of *Sclerocarya birrea* (for y = dry biomass and x = diameter at 1.30 m). As for the linear equation, its residual error as well as the AIC are both high. This provides fairly solid arguments in favor of choosing the order 2 polynomial model.

Table 1. Population structure.

	Diameter at 0.30 (cm)	Diameter at 1.30 (cm)	Height (m)	Diameter of the Crown (m)
Boscia senegalensis	5.76 ± 1.26	2.87 ± 1.18	2.03 ± 0.47	2.79 ± 0.8
Sclerocarya birrea	24.83 ± 6.35	21.54 ± 7.33	7.22 ± 1.15	6.79 ± 2.01

Table 2. Relationship between dry biomass and dendrometric parameters.

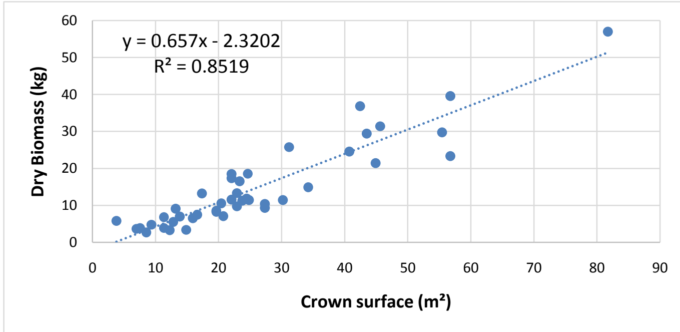
	Diameter at 0.30 (cm)	Diameter at 1.30 (cm)	Height (m)	Crown surface (m^2)
Boscia senegalensis	0.55	0.40	0.69	**0.85**
Sclerocarya birrea	0.86	**0.97**	0.18	0.21

Table 3. Allometric equations developed from the different models for *Boscia senegalensis* and *Sclerocarya birrea*.

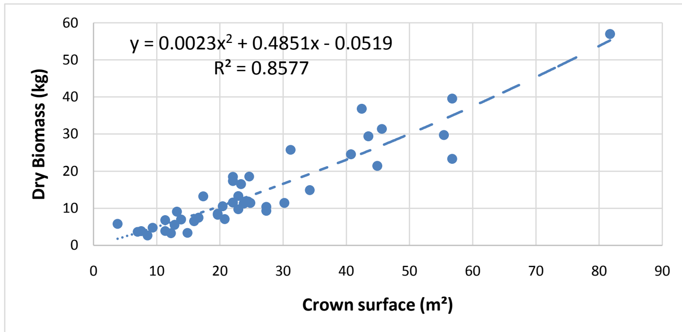
	Models	Regression formula	R^2	Probability	Number of trees
Boscia senegalensis	Polynomial of order 2	$Y = 0.0023x^2 + 0.48x - 0.05$	0.85	<0.0001	43
	Linear	$Y = 0.65x - 2.32$	0.85		
	Power	$0.46 * x^{(1.03)}$	0.77		
	Exponential	$3.97e^{(0.04*x)}$	0.75		
	Logarithmic	$14.91\ln(x) - 31.11$	0.67		
Sclerocarya birrea	Polynomial of order 2	$Y = 0.35x^2 + 10.35x - 12.9$	0.94	<0.0001	15
	Linear	$Y = 24.84x - 137.95$	0.94		
	Power	$3.65 * x^{(1.5)}$	0.93		
	Exponential	$60.97\, e^{(0.07*x)}$	0.92		
	Logarithmic	$464.8\ln(x) - 992.9$	0.92		

Table 4. Values of the various statistical parameters of the allometric equations (CSR: Standard Residual Error, AIC: Akaike Information Criterion).

Equations	*Boscia senegalensis*		*Sclerocarya birrea*	
	Linear (E1)	Polynomial (E2)	Linear (E3)	Polynomial (E4)
Shapiro Wilk test "Normality"	0.32	0.47	0.47	0.78
Breusch-Pagan Test "homocedasticity"	0.84	0.05	0.05	9.86
Durbin-Watson Test "of residue independence"	0.87	0.139	0.139	0.83
RSE	0.037	2.965e-09	12.36	4.664e-14
AIC	−10.38	−1686.78	−77.28	−919.04

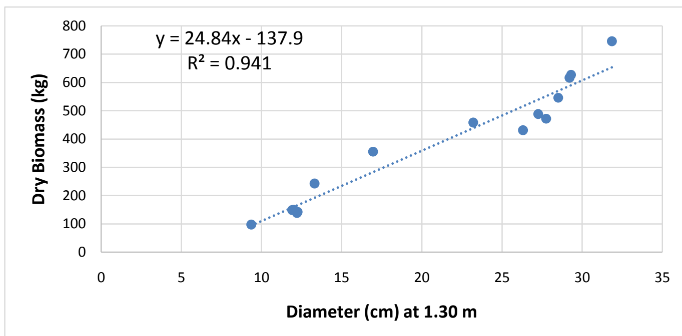


E1

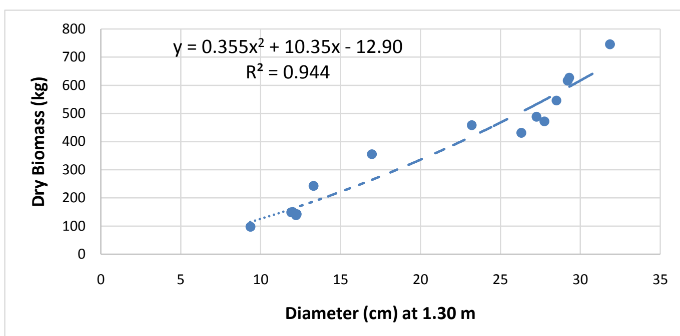


E2

Figure 2. *Boscia senegalensis* allometric equations obtained for (E1 = linear and E2 = polynomial order mode).



E3



E4

Figure 3. *Sclerocarya birrea* allometric equations obtained (E3 = linear, E4 = polynomial order mode).

4. Discussion

The approach based on allometric equations which make it possible to directly estimate the total or partial biomass of a tree as a function of predictors was recommended in this study. Thus, to develop allometric models of the two species, the sample size was 43 individuals for *Boscia senegalensis* and 15 individuals for *Sclerocarya birrea*. This seems sufficient to us because [25] demonstrated that the sample size in the development of allometric models is variable because it takes into account the resources and time allocated to the study. This is how studies of allometric models were developed with a number of trees greater than 100 individuals [24] [28] [30] [31]. Other models involved fewer than 100 trees; [32] and [33] had used 52 and 42 trees respectively in studies for which very few individuals of large diameters were taken into account. The lowest sampling rates are by [34] [35] [36] [37] in which the number of individuals retained was less than 20 due to the limited availability of trees. This same case applies to Sclerocarya birrea, a species which has significantly decreased in the Ferlo area since the beginning of the drought in the 1970 [38].

This study showed that the most important predictor of the biomass of Boscia senegalensis in Ferlo is the area of the crown (m^2). Our results are in line with those of [30] who developed regressions to estimate the biomass of two species of shrubs native to the Sahel morphologically very close to *B. senegalensis*; these are *Guiera senegalensis* JF Gmel (Gs) and *Piliostigma reticulatum* (DC.) Hochst (Pr). However, these authors used the mean crown diameter as an explanatory factor for the biomass. Other authors like [39] and [40], have shown that the crossed crown diameter explains part of the variance of the residues in the Amazon basin and in the Congo basin. [40] indicates that taking crown dimensions into account significantly improves biomass estimates. These words are confirmed by recent work by Panzou [41].

However, estimating the diameter of the crown or the crown surface of these species poses risks in terms of confusion between individuals. The difficulty with this method is to obtain precise measurements of the diameter of the crowns of these very gregarious species and widely spread on the ground. However, the diameter at the base of the subjects is just as difficult to measure, because the species *B. senegalensis* is most often multi-stemmed, low-branched with very small trunks, often exploited for their wood; so that the residual branches are only regrowth [29]. Indeed, the introduction of crown mass in the reference models illustrates the interest that should be given to the architecture of trees. For the species *S. birrea*, the total dry aerial biomass of the species was determined according to the diameter at breast height (DHP or diameter at 1.30 m). [31] states that DHP is the most used parameter in allometric equations. Recent work by [42] confirmed that the best predictor of tree biomass was diameter at breast height. Several equations were tested (linear, logarithmic, power, exponential, polynomial of degree 2) with the dendrometric parameters measured in the field. The best prediction models are the second order polynomial allometric equation and the linear equation. Furthermore, the work of [26] [27] [29] and [43] have shown that a model can have a high coefficient of determination, meet all preliminary tests (p-value > 0.05) and be subsequently rejected by the assessment of certain validation criteria, notably the different statistical tests, standard residual error, Akaike information criterion (AIC).

These observations were decisive in choosing the polynomial equation of order 2 for which the residual error and the AIC were lower; at the expense of the linear equation Similar studies were conducted by Kuyah *et al.* [44] and selections were made based on the Akaike criterion. Likewise Mbow *et al.* [28] developed allometric equations, the selection of which was based mainly on the low value of the standard residual error. For each model they developed, the CSR is less than 0.19. Fayolle *et al.* [45], for their part, selected cubic rate models by combining CSR with AIC. According to them, the best model is the one with the lowest AIC value and a low CSR value. The same procedure was applied in this study for the validation of the polynomial equations of the two species B*oscia senegalensis* and *Sclerocarya Birrea*.

5. Conclusions

This study made it possible to develop efficient models for estimating the biomass of the two woody species at Ferlo: *Boscia senegalensis* and *Sclerocarya birrea* by testing two mathematical models; linear and polynomial. The results of various statistical validation tests made it possible to select the polynomial equation of degrees 2 expressing the total dry aerial biomass of the species as a function: of diameter at breast height for *S. birrea* and of the crown surface for *B. senegalensis*. This work enabled us to retain the diameter at 1.30 m for the prediction of the aerial biomass of *S. birrea* and the crown surface *for B. senegalensis*. The mathematical models used are as follows:

- *Sclerocarya birrea*: $Y = 0.35\text{DHP}^2 + 10.35\text{DHP} - 12.90$ (Y = above ground biomass and DHP = diameter at breast height);
- *Boscia senegalensis*: $Y = 0.0023\text{SH}^2 + 0.4851\text{SH} - 0.0519$ (Y = above ground biomass and SH = crown surface).

These results could be very useful in assessing the amount of carbon sequestered by these species in the Ferlo area. In one way or another, they are a springboard for decision-making on climate change and adaptation policy.

Acknowledgements

We would like to thank the UMI 3189 "Environment, Health, Societies" (UCAD, CNRS, CNRST, USTTB, UGB), and the Labex DRIIHM, programme "Investments for the future" ANR-11-LABX-0010, for funding our work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Houghton, J.T., Meira, F., Treantonk, D. and Mamatyi, M. (1997) Greenhouse Gas Inventory Workbook, Intergovernmental Panel on Climate Change (IPCC). Organization for Economic Co-Operation and Development (OECD) and the International Energy (IEA), Paris, 4-5.

[2] Grouzis, M. and Albergel, L.J. (1989) From Climatic Risk to Ecological Constraint: Incidence of Drought on Crop Production and the Environment in Burkina Faso. In: Eldin, M. and Milleville, P., Eds., *Risk in Agriculture*, Across Champs, Orstorn Paris, Coll, 243-254.

[3] Ganaba, S. (1994) Role of Root Structures in the Dynamics of Woody Populations in the Region of the Oursi Pond (Burkina Faso) between 1980 and 1992. Doctoral Thesis 3rd Cycle, University of Ouagadougou, Ouagadougou.

[4] Grouzis, M. and Akpo, L.E. (1997) Influence of Tree Cover on Herbaceous Above- and Below-Ground Phytomass in the Sahelian Zone of Senegal. *Journal of Arid Environments*, **35**, 285-296. https://doi.org/10.1006/jare.1995.0138

[5] LUCOP (2008) Management and Development of Natural Resources in the Tillabéri Region, Niger-German Program for the Fight against Poverty Tillabéri and Tahoua-Nord.

[6] Dia, A. and Duponnois, R. (2012) The Major African Project of the Great Green Wall: Concepts and Implementation. IRD Editions.

[7] Ouedraogo, W.O., Gomgnimbou, A.P., Santi, S., Ilboudo, D. and Toguyeni, A. (2019) Quantification of Biomass and Carbon Storage of the Forest Massif of the National School of Water and Forests of Dindinteresto Province of Houet in Burkina Faso. *International Journal of Biological and Chemical Sciences*, **13**, 3276-3288.

[8] Panzou, G.J.L. (2020) Biomass and Carbon Stocks in Central Africa: The Importance of Tree Allometry. *Bois & Forets des Tropiques*, **343**, 85-86. https://doi.org/10.19182/bft2020.343.a31853

[9] IPCC (Intergovernmental Panel on Climate Change) (2007) Assessment of Climate Change. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Main Drafting Team, Pachauri, R.K. and Reisinger, A., IPCC, Geneva, Switzerland.

[10] Atsri, H.K., Kokou, K., Abotsi, K.E., Kokutse, A.D. and Cuni-Sanchez, A. (2020) Above-Ground Biomass and Vegetation Attributes in the Forest-Savannah Mosaic of Togo, West Africa. *African Journal of Ecology*, 1-13. https://doi.org/10.1111/aje.12758

[11] Mbow, C. (2009) Potential and Dynamics of Carbon Stocks in the Sudanese and Sudanese-Guinean Savannas of Senegal. UCAD State Doctorate Thesis in Sciences, Cheikh Anta Diop University (UCAD), Dakar, Senegal.

[12] Thiam, S. (2011) Development of an Allometric Model on Acacia Senegal (L) WILD to Improve the Woody Carbon Analysis of the Great Green Wall (GMV) in Senegal. DEA Dissertation UCAD, Cheikh Anta Diop University (UCAD), Dakar, Senegal.

[13] Konare, D. (2019) Allometric Equations for the Evaluation of Leaf Biomass of Three Woody Forage Species. Case of Afzelia Africana, Ficus Gnaphalocarpa and Pterocarpus Erinaceus, Natural Routes of the Kéniéba Circle in Southwest Mali. *Revue Africaine des Sciences Sociales et de la Sante Publique*, **1**, 29-52.

[14] Ndiaye, D. (2019) Oral Communication Seminar to Return the Labex Driihm.

[15] Sy, O. (2009) Role of the Pond in the Management of Sahelian Pastoral Systems in Ferlo (Senegal). *Cybergeo: European Journal of Geography*, **440**, 1-23.

[16] Faye, G.P.L, Frison, S., Wade, J.A., Ndione, A., Beye C. and Rudant, J.P. (2011) Study of the Seasonality of Scat Scatterometer Measurements: Contribution to Monitoring Vegetation in the Sahel, Case of Ferlo in Senegal. *Remove Sensing Journal*, **10**, 23-31.

[17] Miehe, M. (2007) Continuous Monitoring of Vegetation in the Experimental Area at Widou Thiengoly in the Context of Senegalese-German Projects, 1981-2007. Experimental Set-Up, Monitoring Methods and Evaluation Perspectives. *Workshop on the Transfer of Scientific Heritage of the PAPF*, Dakar, 6 June 2007, 26 p.

[18] Ndiaye, O. (2013) Characteristics of the Soils, Flora and Vegetation of Ferlo, Senegal. Doctoral Thesis in Ecology and Agroforestry, EDSEV, UCAD-FST.

[19] Diallo, A. (2011) Characterization of Vegetation and Soils in *Acacia senegal* (L.) Willd Plantations in the Dahra Area-Southern Sandy Ferlo. Doctoral Thesis, UCAD-FST, Plant Biology Department, Dakar, Senegal.

[20] Miehe, S., Kluge, J., Wehrden, H. and Retzer, V. (2010) Long-Term Degradation of Sahelian Rangeland Detectedby 27 Years of Field Study in Senegal. *Journal of Applied Ecology*, **47**, 692-700. https://doi.org/10.1111/j.1365-2664.2010.01815.x

[21] Diouf, M. (2003) Basic Characteristics of the Leafing of a Woody Sahelian Species: Acacia Tortilis (Forsk) Hyane, Variation According to the Topographic Microsites of Ferlo (North-Senegal). Doctoral Thesis of 3rd Cycle, UCAD-FST, Dakar, Senegal.

[22] Arbonnier, M. (2002) Trees, Shrubs and Lianas of the West African Dry Areas. CIRAD Éditions, MNHN, IUCN, Montpellier, Paris, France.

[23] Dagnelie, P. (1998) Statistique théorique et appliqué: Inférence statistique à une et à deux dimensions. De Boeck & Larcier s.a. Paris, Bruxelles, 181-186.

[24] Bakkali, M., Qarro, M., Diouri, M., Barbero, M. and Bourbouze, A. (2000) Aerial Phytomass of the Battandier's Cytis (*Argyrocytisus battandieri* Maire) in the Moroccan Middle Atlas. *Fourrages*, **162**, 169-179.

[25] Picard, N., Saint-Andre, L. and Henry, M. (2012) Manual of Construction of Allometric Equations for the Estimation of the Volume and Biomass of Trees: From Ground Measurement to Prediction. Food and Agriculture Organization of the United Nations, and Center for International Cooperation in Agronomic Research for Development, Rome, Italy.

[26] Sileshi, G.W. (2014) A Critical Review of forest Biomass Estimation Models, Common Mistakes and Corrective Measures. *Forest Ecology and Management*, **329**, 237-254. https://doi.org/10.1016/j.foreco.2014.06.026

[27] Anderson, D.R. and Burnham, K.P. (2002) Model Selection and Inference. A Practical Information-Theoretic Approach. 2nd Edition, Springer, Berlin.

[28] Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Rierab, B. and Yamakura, T. (2005) Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests. *Oecologia*, **145**, 87-99. https://doi.org/10.1007/s00442-005-0100-x

[29] Mbow, C., Verstraete, M.M., Sambou, B., Diaw, A.T. and Neufeldt, H. (2013) Allometric Models for Aboveground Biomass in Dry Savanna Trees of the Sudan and Sudan-Guinean Ecosystems of Southern Senegal. *Journal of Forest Research*, **19**, 340-347. https://doi.org/10.1007/s10310-013-0414-1

[30] Lufafa, A., Bolte, J., Wright, D., Khouma, M., Diedhiou, I., Dick, R.P. and Noller, J.S. (2008) Regional Carbon Stocks and Dynamics in Native Woody Shrub Communities of Senegal's Peanut Basin. *Agriculture*, *Ecosystems & Environment*, **128**, 1-11. https://doi.org/10.1016/j.agee.2008.04.013

[31] Brown, S. (1997) Estimating Biomass and Biomass Change of Tropical Forests: A Primer. Food and Agriculture Organization of the United Nations, Roma.

[32] Ibrahima, A., Schmidt, P., Ketner, P. and Mohren, G.J.M. (2002) Phytomass and Nutrient Cycle in the Moist Tropical Rain Forest in Southern Cameroon. Kribi, Cameroon. The Tropenbos-Cameroon Program, Tropenbos-Cameroon Documents 9, XVI + 81 P. If No. 7: 2007. The French Forest: A Carbon Sink? Its Role in Limiting Climate Change.

[33] Henry, M., Nicolas, P. and Carlo, T. (2011) Estimating Tree Biomass of Sub-Saharan African forests: A Review of Available Allometric Equations. *Silva Fennica*, **45**, Article ID: 38. https://doi.org/10.14214/sf.38

[34] Peltier, R., forkong, C.N., Mama, F., Ntoupka, M., Manlay, R., Henry, M. and Morillon, V. (2007) Assessment of the Carbon Stock and Wood Productivity of a Shea Park in North Cameroon. *Bois & Forêts des Tropiques*, **294**, 39-50.

[35] Larwanou, M., Yemshaw, Y. and Saadou, M. (2010) Prediction Models for Estimating Foliar and Fruit Dry Biomasses of Five Savannah Tree Species in the West African Sahel. *International Journal of Biological and Chemical Sciences*, **4**, 2245-2256. https://doi.org/10.4314/ijbcs.v4i6.64943

[36] Ebuy, J., Lokombe Dimandja, J.P., Ponette, Q., Sonwa, D. and Picard, N. (2011) Biomass Equation for Predicting Tree Aboveground Biomass at Yangambi, RDC. *Journal of Tropical Forest Science*, **23**, 125-132.

[37] Cissé, M.I. and Kone, A.R. (1992) The Fodder Role of *Acacia albida* (Del.): Extent of Knowledge and Prospects for Future Research. *Faidherbia albida in the West African Semi-Arid Tropics*, *Proceedings of a Workshop*, ICRISAT/ICRAF, 22-26 April 1991, 29-37.

[38] Benoit, M. (1988) The Edge of the Koya: Pastoral Space and Landscapes in the North of Senegal (Ferlo). *L'Espace Géographique*, No. 2.

[39] Goodman, R.C., Phillips, O.L. and Baker, T.R. (2014) The Importance of Crown Dimensions to Improve Tropical Tree Biomass Estimates. *Ecological Applications*, **24**, 680-698. https://doi.org/10.1890/13-0070.1

[40] Ploton, P., Barbier, N., Momo, S.T., Rejou-Mechain, M., Boyemba, B.F., Chuyong, G.B. and Henry, M. (2016) Closing a Gap in Tropical Forest Biomass Estimation: Taking Crown Mass Variation into Account in Pantropical Allometries. *Biogeosciences*, **13**, 1571-1585. https://doi.org/10.5194/bg-13-1571-2016

[41] Panzou, G.J., Loubota, Jean-Louis, D. and Jean-Joël, L. (2018) Biomass and Carbon Stocks of African Tropical Forests (Bibliographic Synthesis). *Biotechnology*, *Agronomy*, *Society and Environment*, **20**, 508-522.

[42] Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B. and Henry, M. (2014) Improved Allometric Models to Estimate the Aboveground Biomass of Tropical Trees. *Global Change Biology*, **20**, 3177-3190. https://doi.org/10.1111/gcb.12629

[43] Manzo, O.L., Massaoudou, M. and Hassane, B.I. (2015) Equations allométriques pour l'estimation de la biomasse aérienne de *Faidherbia albida* (Del.) Achev dans les agrosystèmes d'Aguié, Niger. *International Journal of Biological and Chemical Sciences*, **9**, 1863-1874. https://doi.org/10.4314/ijbcs.v9i4.12

[44] Kuyah, S., Dietz, J., Muthuri, C., Jamnadass, R., Mwangi, P., Coe, R. and Neufeldt, H. (2012) Allometric Equations for Estimating Biomass in Agricultural Landscapes: I. Aboveground Biomass. *Agriculture*, *Ecosystems & Environment*, **158**, 216-224. https://doi.org/10.1016/j.agee.2012.05.011

[45] Fayolle, A., Rondeux, J., Doucet, J.L., Ernst, G., Bouissou, C., Quevauvillers, S. and

Lejeune, P. (2013) Réviser les tarifs de cubage pour mieux gérer les forêts du Cameroun. *Bois & Forets des Tropiques*, **317**, 35-49. https://doi.org/10.19182/bft2013.317.a20521