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Height–Diameter Equations for Eight Midwestern Rainforest Species in Nigeria, Using Monserud's Model

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ABSTRACT

Height-diameter equations are frequently employed in predicting the mean total height for trees in the absence of all other growth variables except diameter at breast height (dbh). Diameter at breast height is one of the easily measured variables with less measurement error when compared to tree height. This study presents a set of height-diameter equations for 8 Midwestern Rainforest species in Nigeria using Mansard's method. Mansard's nonlinear regression techniques were used to develop the equations; and these provided a logical means of predicting unknown tree heights from known DBH for the 8 Midwestern Rainforest species in Nigeria. The resulting equations revealed plausible regression coefficients of the prediction models with coefficient of determination (R^2)values ranging between 0.749 – 0.934; which indicate the strong relationship of height and diameter for sustainable prediction of tree height when only diameter measurement is available.

Keywords: *Midwestern rainforest, height-diameter equations, prediction.*

1. INTRODUCTION

Tree height remains an intriguing component of a comprehensive growth and yield model owing to its significant place in volume estimation and its great contributions to reasonable valuation of standing tree species. This importance is much more substantial when its relationship is verged on interaction between diameter at breast height (1.3m or 4.5ft above ground). Leduc and Goelz (2009) reported that tree height is a critical component of a complete growth and yield model because it is one of the primary components used in volume calculation, and that it is an important descriptive individual tree variable that facilitates volume estimation when only diameter is measured or known among other growth variables. Specifically, development of such model involving only height and diameter might appear spurious or cynical but Curtis (1967) investigated many brands of height diameter equations and critically opined that "any reasonable and moderately flexible curve will produce similar outputs".

Nevertheless, with several developments in complex analytical and mathematical concepts, it's pertinently possible in defining and evaluating such functions following assumptions of regression analyses (Sharma and Parton, 2007; Leduc and Goelz, 2009; Jayaraman and Zakrzewki, 2001). Importantly, many of these height-diameter equations are handy for estimating perpendicular forest structure and for predicting heights in several forest growth simulators (e.g Larsen and Hann, 1987; Calama-Mantero, 2004; Wykoff et.al. 1982).

Notable number of model functions have been developed and used to predict tree height from diameter by species (Curtis 1976; Colbert et.al. 2002; Mansard 1975; Ek et.al.1984; Larsen and Hann 1987; Parresol 1992); but significantly, the flexible among them is Mansard's (1975) having a combination of flexible and effectiveness qualities and thus making it robust for model fitting and prediction.

This article therefore presents equations for predicting total tree height for eight rainforest species in Nigeria using Mansard's model. The species of interest in this study include Allanblackia floribunda,Anonidium mannii, Celtis Zenkeri, Diospyrous suavelens, Hylodendrum gambunense, Gossweilerodendron balsamiferon, Guarea cedrata and Strombosia pustulata.

2. METHODS

The data employed in the development of the model came from traditional measurement of total heights and diameters of tree from Permanent Sample Plots (PSPs) 82 of Urhonigbe Forest Reserve in one of the Nigeria's Strict Natural Reserve (SNR) established in 1956 and covering about 30,791 hectares of land area. It lies with latitudes 5° 57'59'' and 5°59'31'' N and longitudes 6°05'38'' and 6°06'45''E; and located east of Sakponba Forest Reserve in Edo State Nigeria (Figure 1).

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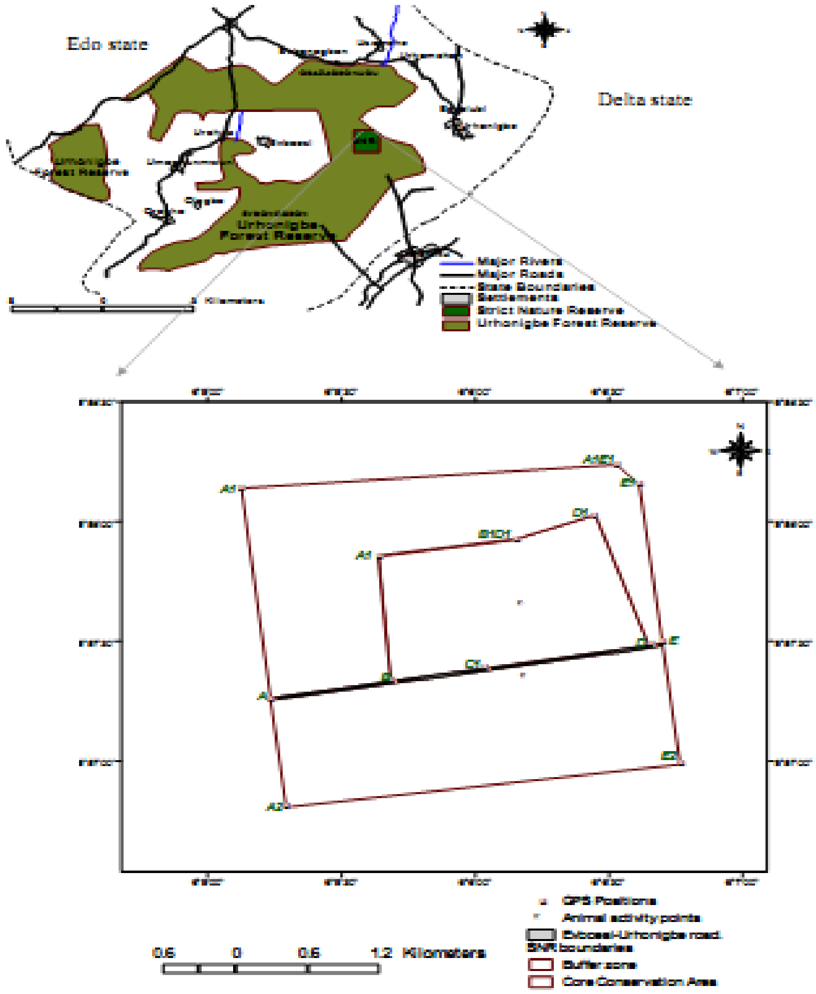

Fig 1: Map of Permanent Sample Plots (PSPs) 82 of Urhonigbe Forest Reserve, Nigeria.

Data collected on height and diameter measurements were analyzed and summarized by mean, standard error of the mean, minimum and maximum for each species considered. Mansard's model used for the model evaluation was of the form:

$$Ht = bh + e^{\beta_0 + \beta_1 D^{\beta_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

where, Ht is total height, bh is the breast height (1.3m) and D is diameter at breast height while β_1-β_2 are model coefficients.

According to Lasen and Hann (1987), this model imposes the constraint that as D approaches zero, Ht tends to bh. Subsequently, logarithm transformation method was used before fitting the model to the data with β_2 fixed at -0.2. Thus,

$$Ht = bh + e^{\beta_0 + \beta_1 D^{\beta_2}} \quad \ldots\ldots\ (ii)$$

Becomes

$$\ln(Ht - bh) = e^{\beta_0 + \beta_1 D^{\beta_2}} \quad \ldots\ldots\ (iii)$$

$$\ln(Ht - bh) = e^{\beta_0 + \beta_1 D^{-0.2}} \quad \ldots\ldots(iv)$$

Therefore,

$$LnHt = \beta o + \beta_1 D^{-(0.2)} + \beta_2 lnbh \ \ldots\ldots\ (v)$$

All fitted equations were evaluated using Residual standard error and coefficient of determination (R^2). The coefficient determination which indicates the proportion of the variation in the dependent variables explained by the model was computed from the relationship:

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$$R^2 = \frac{SS_{yy} - SS_R}{SS_{yy}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$= \frac{SS_{yy}}{SS_{yy}} - \frac{SS_R}{SS_{yy}} \ldots\ldots\ldots\ldots$$

$$R^2 = 1 - \frac{SS_R}{SS_{yy}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

3. RESULTS AND DISCUSSION

Prediction equations of form (v) were fit to each of the eight species used in the model evaluation. The data statistics according to species are summarized by mean, standard deviation, minimum, and maximum in Table 1. The coefficient and fit statistics for the eight 8 species are reported in Table 2. The equations are plotted for each species and the residual plots for models are shown in Figures 2 – 9. The residual plots closely followed the trends in the fitted data as shown in the figures. Equations coefficients presented in the study are appropriate for the prediction of tree height within the array of diameters found in the data set.

Hylodendron gabunense was the most abundant species in the dataset but with slightly high R2 value of 0.873 and one of the lowest residual standard mean errors (RSME) values of 0.267. Allanblackia floribunda was the least abundant species but had the highest R2 and RSME values of 0.934 and 0.872 respectively. The fit statistics for Anonidium mannii and Celtis zenkeri are relatively similar or not significantly different from each other while Diospyros suaveolen, Hylodendron gabunense, and Strombosia pustulata also followed similar trend of fit statistics (Table 2). The only two species (Gossweilerodendron balsamiferum and Hylodendron gabunense) of the same family (Caesalpinioideae) significantly differ from each in their fit statistics; with Gossweilerodendron balsamiferum having R2 value of 0.795 and RMSE value of 0.319 while Hylodendron gabunense had 0.873 and 0.267 for R2 and RSME respectively. This variation may be related to the wide difference in the abundance of the two species. Similar trends were observed in the works of Lootens et.al 2007; Larsen and Hann 1987 and Colbert et.al 2002 on height–diameter relationships. This development also showed that fitted model coefficients are similar in sign and magnitude as well as conformed to the findings of various studies that had once used Monserud's equation is other geographical region (e.g Lootens et.al 2007).

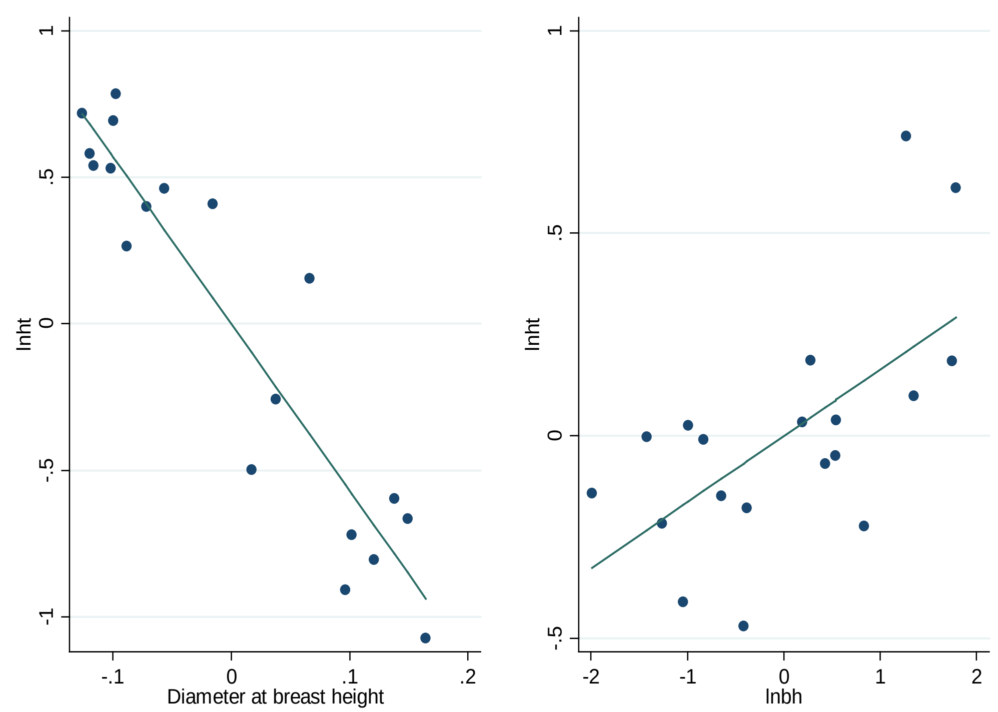

Figure 2 :Residual plots for prediction equation in Allanblackia floribunda

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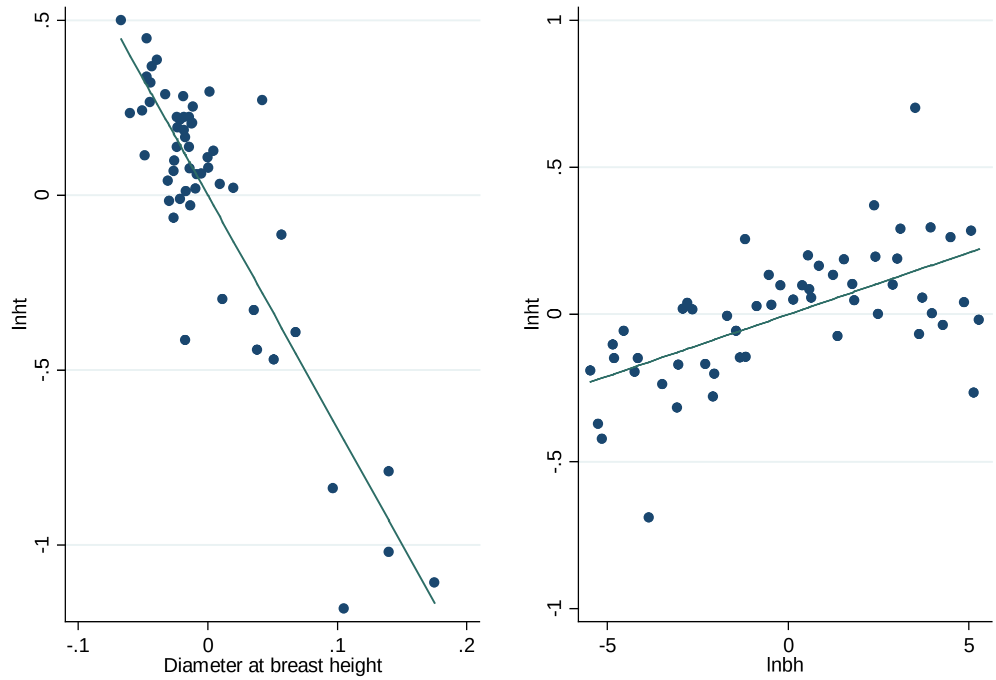

Figure 3: Residual plots for prediction equation in Anonidium mannii

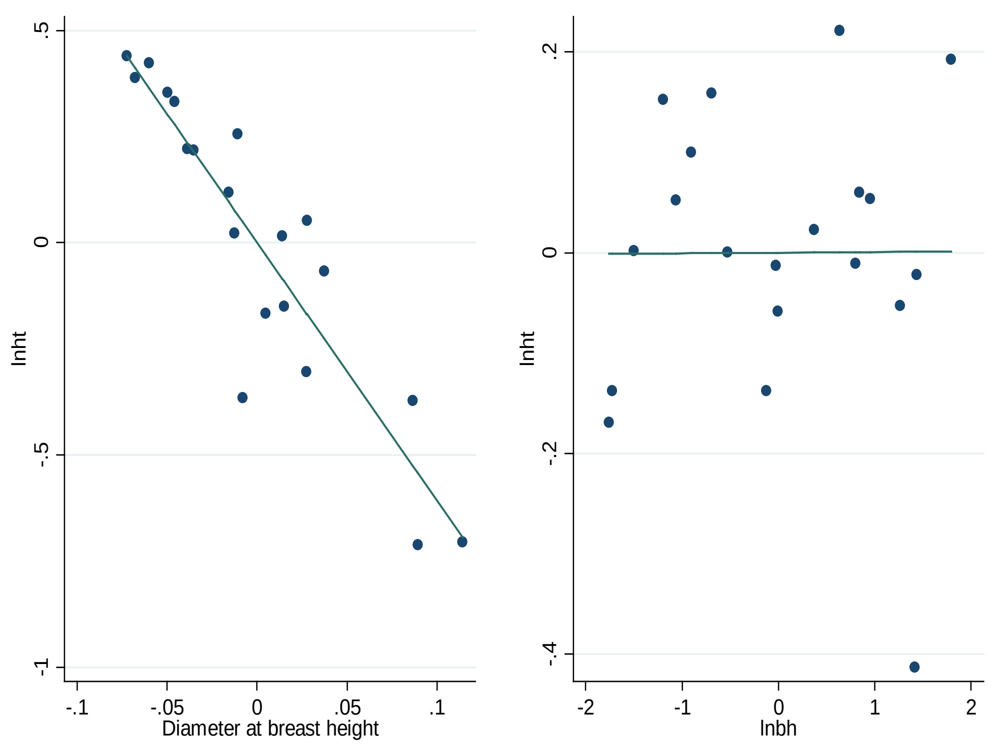

Figure 4: Residual plots for prediction equation in Celtis zenkeri

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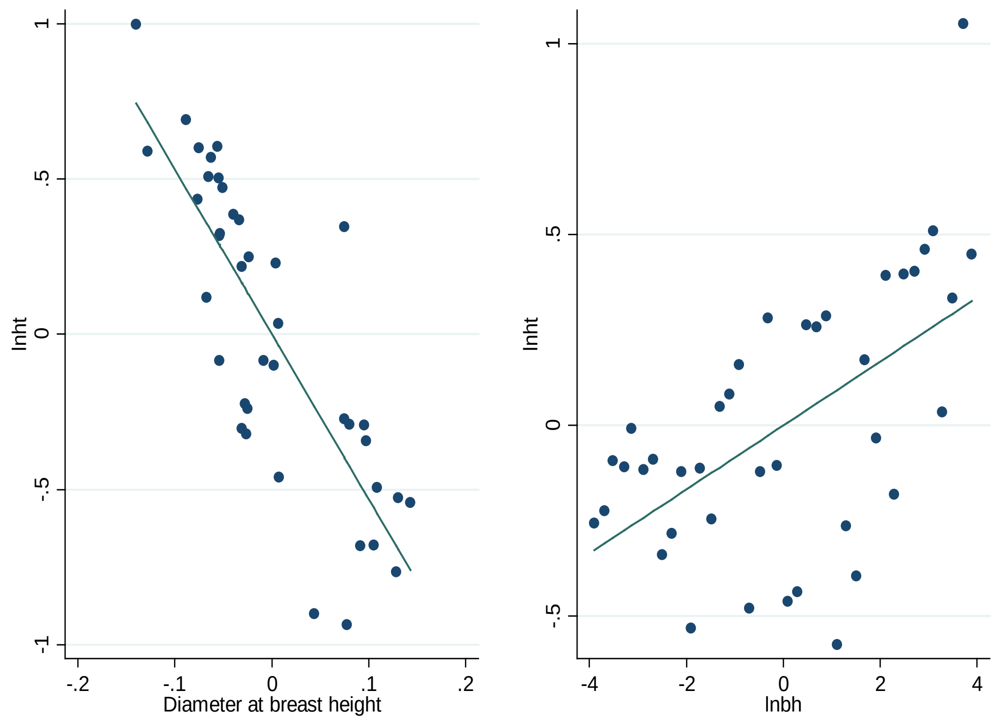

Figure 5: Residual plots for prediction equation in Diospyros suaveolen

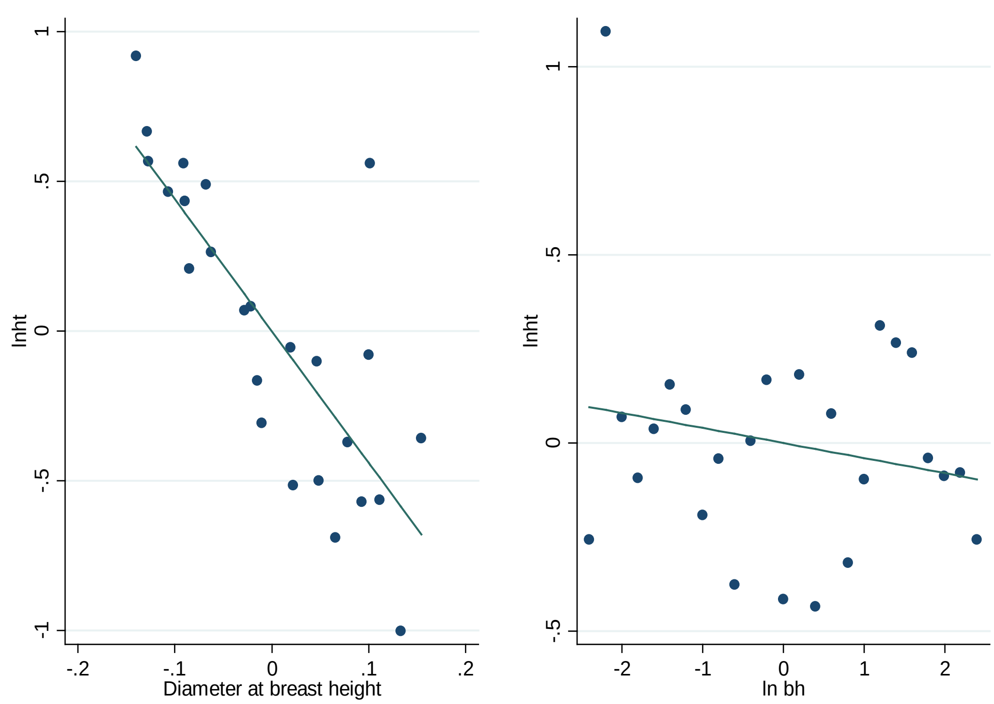

Figure 6 : Residual plots for prediction equation in Gossweilerodendron balsamiferum

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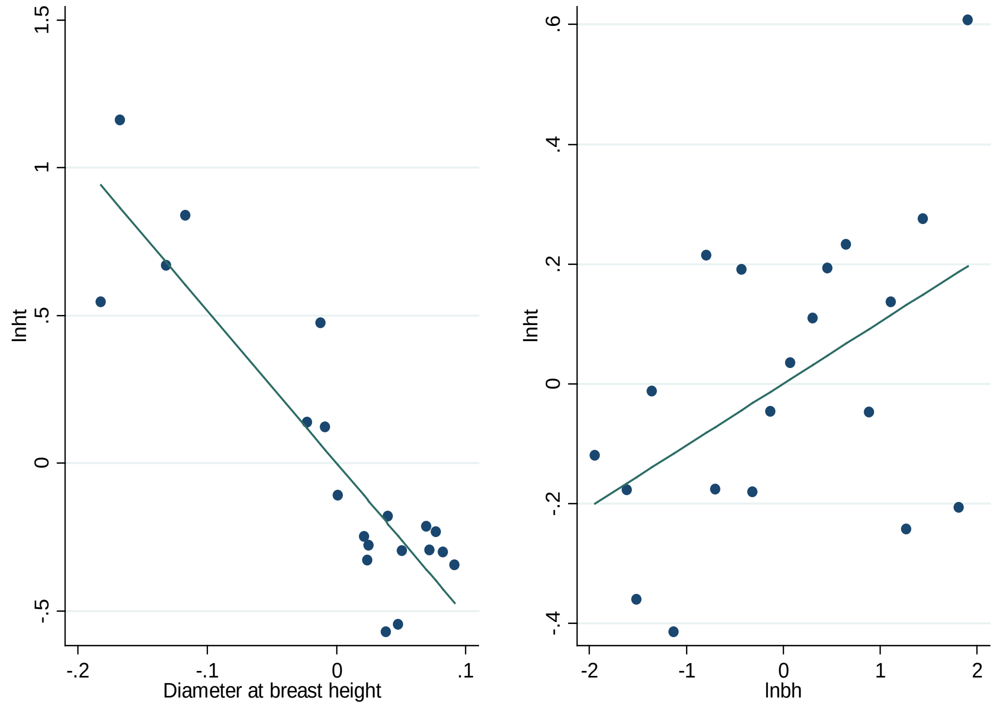

Figure 7: Residual plots for prediction equation in Guarea cedrata

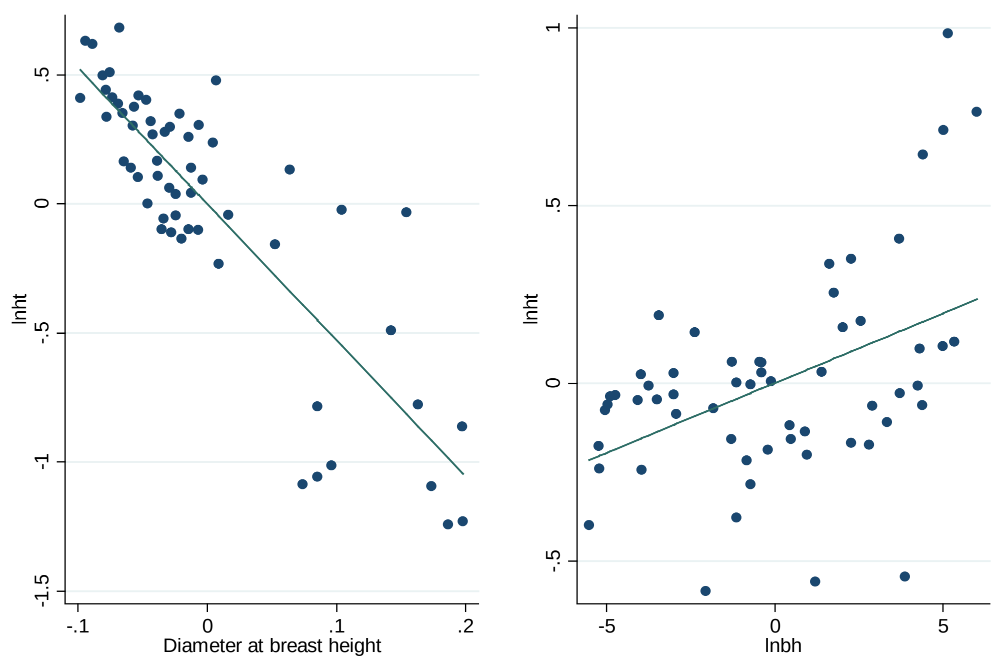

Figure 8 : Residual plots for prediction equation in Hydrodendum gambunense

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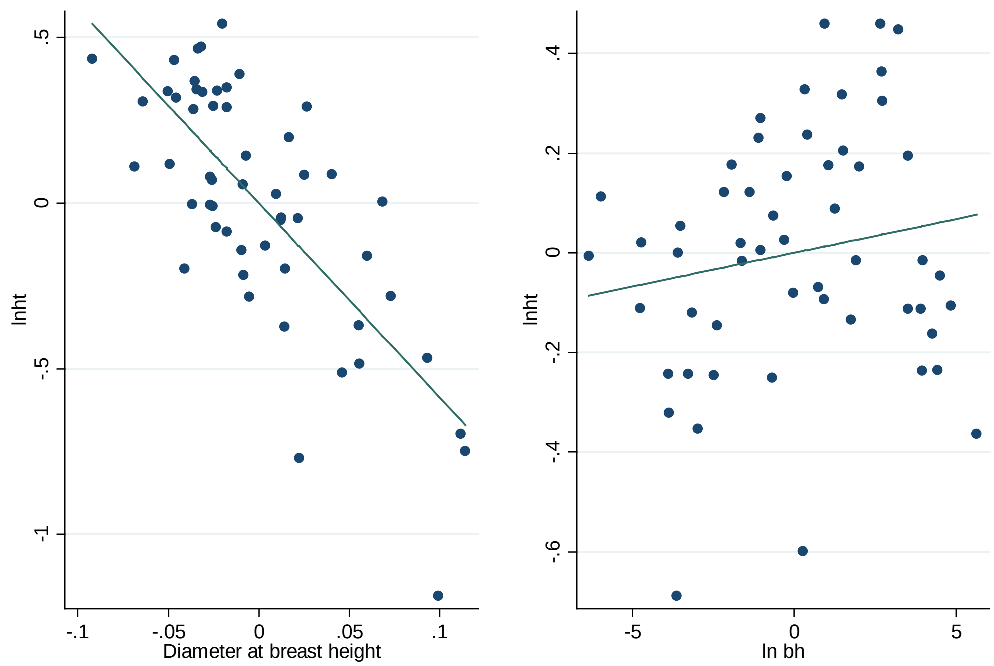

Figure 9 : Residual plots for prediction equation in Strombosia pustulata

Summary of DBH (cm) and height (m) statistics for the eight Midwestern rainforest species

Species	Family	N	DBH (cm)				Height (m)			
			Mean	S.E	Min	Max	Mean	S.E	Min	Max
Allanblackia floribunda	Guttiferae	19	29.42	4.400	4.3	56.8	16.32	2.039	5.0	25.0
Anonidium mannii	Annonaceae	55	30.17	1.427	6.3	52.2	19.45	0.854	6.0	31.0
Celtis zenkeri	Ulmaceae	20	32.75	3.691	8.5	72.1	17.40	1.295	7.0	28.0
Diospyros suaveolen	Ebenaceae	40	18.79	1.866	5.0	58.5	15.33	1.192	6.0	28.0
Gossweilerodendron	Caesalpinioideae	25	28.82	3.758	5.0	67.7	15.32	1.493	5.0	32.0
balsamiferum	Meliaceae	20	13.53	2.976	5.0	48.3	10.80	1.404	5.0	28.0
Guarea cedrata	Caesalpinioideae	58	39.55	2.737	5.1	86.6	21.62	1.097	5.0	42.0
Hylodendron gabunense	Olacaceae	54	25.19	1.356	7.8	60.2	17.71	0.763	5.0	28.0
Strombosia pustulata										

Coefficient for the fitted model for predicting height from diameter at breast height (DBH)

Species	N	β_o	β_1	β_2	RSME	R^2
Allanblackia floribunda	19	6.120	-5.694	0.164	0.872	0.934
Anonidium mannii	55	6.550	-6.648	0.420	0.181	0.903
Celtis zenkeri	20	9.912	-6.068	0.001	0.153	0.919
Diospyros suaveolen	40	5.997	-5.310	0.840	0.295	0.842
Gossweilerodendron balsamiferum	25	5.033	-4.397	-0.040	0.319	0.797
Guarea cedrata	20	5.710	-5.163	0.103	0.228	0.900
Hylodendron gabunense	58	5.843	-5.2.79	0.039	0.267	0.873
Strombosia pustulata	54	6.031	-5.878	0.013	0.247	0.749

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