Improvement of the quality and precision of biomass and carbon equations: case study of mixed-deciduous degraded forest of Thailand

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Abstract

Environmental pressures brought about by climate change have increased the urgency for biomass assessment to measure the potential of forests to be carbon sinks and carbon sources. The researcher suggests that improving the quality and precision of models used for measuring carbon stock in forests is thus important. This study aims to investigate the relationships between independent factors, such as dry weight biomass (*B*), and dependent factors, such as diameter at breast height (*D*), height (*H*), and wood specific gravity (ρ), to formulate biomass equations for four common tree species: *Sterculia pexa*; *Millettia brandisiana*; *Grewia eriocarpa*; and *Bridelia ovata*. Regression models, each with different independent variables (*D*, ρD, D^2H, and ρD^2H), were studied. The results showed a strong correlation between *B*, *D*, and *H*, but not ρ. However, ρ showed a significant variation between the four species which indicated that proper species identification is required for accurate modelling. The best regression models for estimating biomass had two forms: $\ln(B) = c + \alpha\ln(D)$ and $\ln(B) = c + \alpha\ln(\rho D^2H)$.

The dry weight of individual trees using the regression model with ρD^2H had an average estimated error of 0.09–2.66%. The dry weight using *D* had an average estimated error of 0.28–1.77%. Thus, it was most appropriate to use ρD^2H as the independent variable in the model. Furthermore, linear regression indicated a significant statistical difference between the four species. In conclusion, the researcher found that formulating species-specific regression models is essential in assessing biomass and carbon, particularly for the mixed-deciduous degraded forest areas in this study.

Key word: Mixed-deciduous secondary forest/ Aboveground biomass/ Specific-species regression model/ Biomass equation/Carbon sequestration.

1. Introduction

Aboveground biomass of forest is the most important biomass source on the earth. It provides people ecological goods such as food and fuel, as well as a variety of ecological services in particular carbon sequestration and regulation. Because of human activity, the level of greenhouse gases in the atmosphere has risen, and this will eventually bring about climate change effects. According to this impact pathway, forest plants are expected to be the only feasible way to sequester and restore forest carbon levels to the former state of the ecosystem. Therefore, the amount of forest area will be directly related to the carbon concentration.

As the report entitled "The Forestry Statistics of Thailand, 2006" notes, forest cover in the period 2000 to 2006 decreased annually at an average rate of 0.37% (33.15 to 30.96%). In contrast, the same agency (Luangjame, 2005) reported that the amount of carbon sequestration by forest decreased in the period 2000 to 2004 at only 0.26 % annually (4579.28 and 4532.73 million ton). This data makes it possible to assume that although the amount of natural forest in Thailand has visibly decreased, but secondary forestry plantations are still being increased resulting in net positive carbon growth.

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It also means that the methodologies used to calculate carbon sequestration in reports using previously published allometric regression may have been incorrect. It is suspected that inaccurate equations have resulted in overestimations. This is due to large-scale biomass estimates conducted using aerial photogrammetry, and estimating biomass using the Ogawa equation (Ogawa, 1965), adapting it to mixed forests in large-scale areas, not for particular species and sites that are recommended by Ketterings (Ketterings et al., 2001).

In order to improve future estimates of carbon stocks and carbon sequestration rates of natural and secondary forests in Thailand, this study attempts to determine allometric regressions in four dominant species of the mixed-deciduous forest in the western part of Thailand, as Kanchanaburi province. The result of this study will further be useful in following up the carbon sequestration situation in Thailand, which is an important objective as carbon sequestration can have a major impact on climate change.

2. Methodology

The study area is located within the former forest concession area in the Kanchanaburi campus of Mahidol University. It is located in Lumsoom, Saiyok District, Kanchanaburi Province, Thailand. Geographically, the forest concession area extends from 1560000 N through 1566000 N latitude, and 511000 E through 518000 E longitudes, and covers an area of 42,481.25 ha. The study area is typical of tropical forest in which it receives an annual precipitation averaging 1,293 mm and experiences warm temperatures of 43.5°C in average and sometimes as low as 5.2°C (the period 1951 – 2003). The natural vegetation in the study area is mainly dominated by mixed deciduous forest. Most of the commercial trees commonly found belong to several families such as *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa*, *Bridelia ovata*, *Anomianthus dulcis*, *Bauhinia malabarica*, *B. scandens*, *Caesalpinia sappan*, *Zollingeria dongnaiensis*, *Xylia xylocarpa*, *Homalium tomentosum* and *Ziziphus oenoplia*. Succession by pioneer species is common in the logged area.

The selected species are: *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata*. This selection represents the four families of Sterculiaceae, Leguminosae-Papilionoideae, Tiliaceae and Euphorbiaceae. Locally common, these usually constitute approximately 30% of the trees in secondary growth forest that is 20 years old, even with different land use histories prior to abandonment.

For each species, 8-9 individuals were selected to destructively estimate total biomass. The trees were selected according to the stem size classes of each species. For example, size classes of species 2-30 cm diameter at breast height (D) were then set at 2-5 cm, 6-10 cm, 11-20 cm, and >20 cm. In each species, not more than 9 trees and 2 trees per size class were cut (Whittaker, 1974). No tree that was already damaged or broken was taken. Total height (H) was measured after cutting the tree. For each, tree components were separated into four fractions: (1) leaves, (2) branches (D < 6.4 cm), (3) large branches and stems (D > 6.4 cm) with basal stem (Ketterings et al., 2001). The samples were dried in ovens for three days at a constant temperature of 103 ºC. The samples were reweighed after drying to determine moisture content. The subsequent moisture content value was used to determine the total dry weight of the tree and its components. In addition, a wood disk (D > 6.4 cm) of constant thickness (3 cm) was oven dried then converted to wood specific gravity (Ketterings et al., 2001). As well, wood specific gravity is the ratio between the oven dry mass and the fresh volume of the green wood (Fearnside, 1997; Nogueira, 2005). A wood disk of constant thickness (3 cm) was taken for all trees to determine the mean basic specific gravity of the bole. This is calculated as the arithmetic mean of the specific gravity at breast height (1.30 m) (Nogueira, 2005). Sub-samples of all fractions were collected in the field and stored in sealed plastic bags to prevent loss of moisture. The fresh volume was determined by displacing water in a container placed on the same scale. For the dry weight of each sample, a vented electric oven was used at 103 ºC, weighing the samples when they were considered completely dry, as well as when the weight was stable for three consecutive days.

In the assumption of Ketterings et al. (2001), one species has $B = aD^bH$, a common form of relation of the variables. If *D* and *H* for trees of a given environmental condition are related by $H = kD^c$, the equation $B = aD^bH$ becomes $B = akD^{b+c}$. where a=b+2c. The parameter *b* can be estimated from the site-specific relationship between *D* versus *H*, a= r ρ , in which *r* is expected to be relatively stable across the site. As well, parameters a and r is constant coefficient, estimated by generalized linear model (McCullagh and Nelder, 1989; Genstat, 1993).

However, in this study *H* was measured for each tree, so the specific species regression used was $B = aD^bH$, in which the relationship between of *D* and *H* is given by D^2H. If the allometric regression is in power function form, logarithmic transformation generally solves the problem of heteroscedasticity owing to the variance of the dependent variable increasing in proportion to the value of the independent variable. This study will show linear regression in each species and compare the slope of linear regression among species using *D*, D^2H and ρD^2H as independent variables. The study will investigate the most appropriate mixed species or specific species regressions for estimating aboveground biomass by using an average unsigned deviation (%) value.

The standard form for allometric equation, $y_i = a(x)^b$, was analyzed, where y_i is the dependent variable (Biomass, B). The studied independent variable (*x*) was composed of Diameter (D), Diameter and height (D^2H) and Diameter, height and specific gravity, ρ (ρD^2H). These equations use the fit of a linear regression model in form [ln(*y*) = *a* + *b*ln(*x*)] (Chave, 2004).

For each linear regression model, the following indicators of goodness of fit were reported as: (1) r^2 of the simple regression (or R^2 of the multiple regression), (2) Standard error, (3) Significance of t-value, (4) Average unsigned deviation. For each tree used in a regression, the difference between predicted dry weight and observed dry weight was expressed as a percentage of observed dry weight. The absolute values of all cases (deviations) were then averaged.

3. Results

3.1 Four species regressions using D

The finding of the study were that the correlations between D and B are fitted by non-linear relationship. Then, the ln-ln transformation of B = a$(D)^b$ was used as

$$\ln(B) = c + \beta \ln(D) \qquad \textbf{Model 1}$$

where c = ln a. The regression coefficients and indicators of accuracy and significance are shown in Table 1.

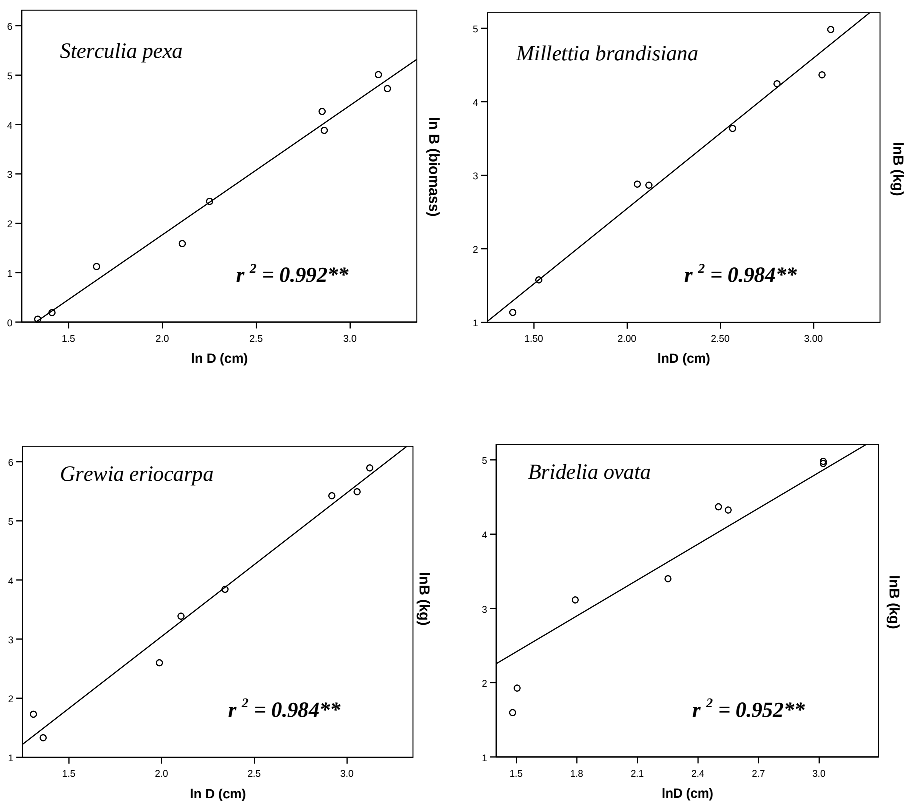

Figure 1 Relationship between ln*B* and ln*D* fitted by linear regression of for *Sterculia pexa* (n=9), *Millettia brandisiana* (n=8), *Grewia eriocarpa* (n=8) and *Bridelia ovata* (n=8).
****** highly significant

Table 1 Comparing linear regressions for *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata*, where *D* is the independent variable and tree size classes are set at 2-5 cm, >5-10 cm, >10-20 cm and >20 cm.

Regression model	Coefficient symbol	Coefficient value	Standard Error	r^2	Average unsigned deviation (%)	Significance level of t-value
Model 1: $\ln(B) = c + \beta \ln(D)$						
Sterculia pexa	c	-3.472	.299	0.992	1.77	< 0.0001
	β	2.626	.124			< 0.0001
Millettia brandisiana	c	-1.548	.270	0.984	0.92	0.001
	β	2.048	.113			< 0.0001
Grewia eriocarpa	c	-1.822	.319	0.984	0.28	0.001
	β	2.433	.134			< 0.0001
Bridelia ovata	c	-1.061	.450	0.952	1.64	0.057
	β	2.050	.193			< 0.0001

For model 1, it was found that the coefficient of determination (r^2) for *Sterculia pexa* was 99%. Whereas the coefficient of determination of *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata* were 98%, 98% and 95%, respectively. Which indicated that there was significantly different in slopes among four species. For comparing all possible pairs of these slopes, the major finding revealed significant difference in slopes between *Sterculia pexa* and *Millettia brandisiana* and between *Sterculia pexa* and *Bridelia ovata* ($p<0.05$).

3.2 Four species regressions using D^2H

Statistically significant correlations were found between Biomass and Diameter and between Biomass and Height at 0.804 and 0.773, respectively. Moreover, significant correlations between Height and Diameter for *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata* are 0.90, 0.90, 0.94 and 0.93, respectively. Hence, the complex variable, D^2H was devised as the independent variable, as shown in Figure 2:

$$\ln(B) = \alpha + \beta \ln(D^2 H)$$ **Model 2**

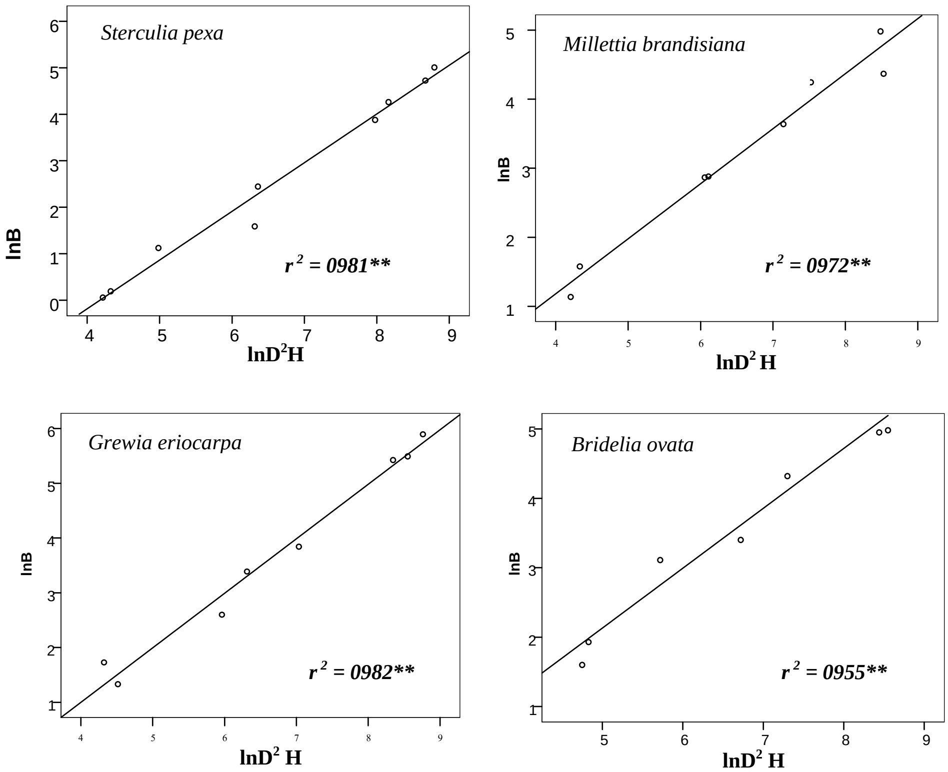

Figure 2 Relationship between ln *B* and ln D^2H fitted by linear regression for *Sterculia pexa* (n=9), *Illettia brandisiana* (n=8), *Grewia eriocarpa* (n=8) and *Bridelia ovata* (n=8).
** highly significant

Table 2 Comparing linear regressions for *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata*, where D^2H is the independent variable and tree size classes are set at 2-5 cm, >5-10 cm, >10-20 cm and >20 cm.

Regression model	Coefficient symbol	Coefficient value	Standard error	r^2	Average unsigned deviation (%)	Significance level of t-value
Model 2: $\ln(DW) = c + \beta \ln(D^2 H)$						
Sterculia pexa	c	-4.375	.379	0.981	3.61	< 0.0001
	β	1.048	.055			< 0.0001
Millettia brandisiana	c	-2.008	.372	0.972	1.05	0.002
	β	.797	.055			< 0.0001
Grewia eriocarpa	c	-2.986	.385	0.982	0.22	< 0.0001
	β	.996	.056			< 0.0001
Bridelia ovata	c	-2.198	.524	0.955	1.42	0.006
	β	.865	.077			< 0.0001

From Table 2, it was apparent that the coefficient of determination of ln (*B*) for *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata* were 98.1%, 97.2%, 98.2% and 95.5%, respectively. The average unsigned deviation of estimates of dry weight in *Sterculia pexa*, *Millettia brandisiana*, *Grewia eriocarpa* and *Bridelia ovata* were 3.61%, 1.05 %, 0.22% and 1.42%, respectively. The complex variable D^2H in the equation ($\ln(B) = c + \alpha \ln(D^2H)$) has been widely used in Thailand for mixed-species regression (Ogawa, 1965). It is believed to be appropriate for estimating biomass in natural forest.

Allometric regression used mixed species for devising the model, although natural forest contained a different mixture of species. Using only D^2H as the independent variable in linear regression ($\ln(B) = c + \beta \ln(D^2H)$), a comparison among four species reveals that there are significantly different among these slope. **C**omparision all possible pairs of four regression lines ($\ln(B) = c + \alpha \ln(D^2H)$) revealed that nosignificant differences were found in the equation lines of *Sterculia pexa* and *Grewia eriocarpa* also the equation lines of *Sterculia pexa* and *Bridelia ovata*.

3.3 Four species regressions using ρ D²H

It was found that the wood specific gravity (ρ) of *Sterculia pexa, Millettia brandisiana, Grewia eriocarpa* and *Bridelia ovata* were weekly correlated with variable Height and variable Diameter. In contrast, it was strongly correlated with Biomass. Hence the complex variable (ρD^2H) was advised as a single variable. The relationship between ρD^2H and ln B in each species was shown in Figure 3.

$$\ln(B) = c + \alpha \ln(\rho D^2 H) \qquad \textbf{Model 3}$$

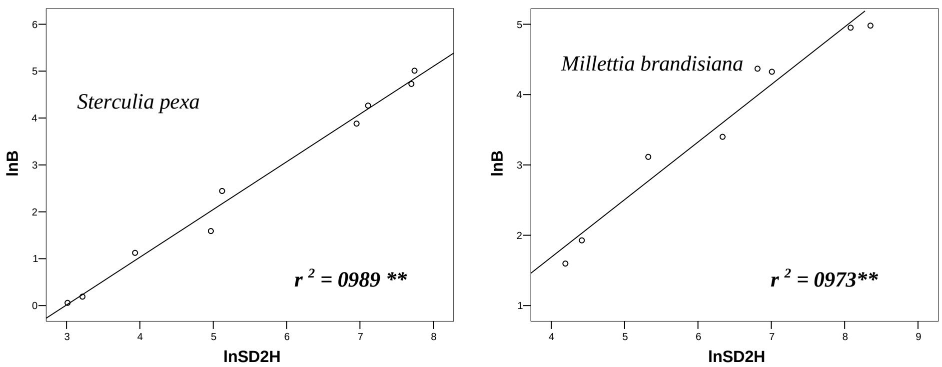

Figure 3 Relations between ln*B* and ln ρD^2H fitted by linear regressions of for *Sterculia pexa* (n = 9), *Millettia brandisiana* (n = 8)
** highly significant

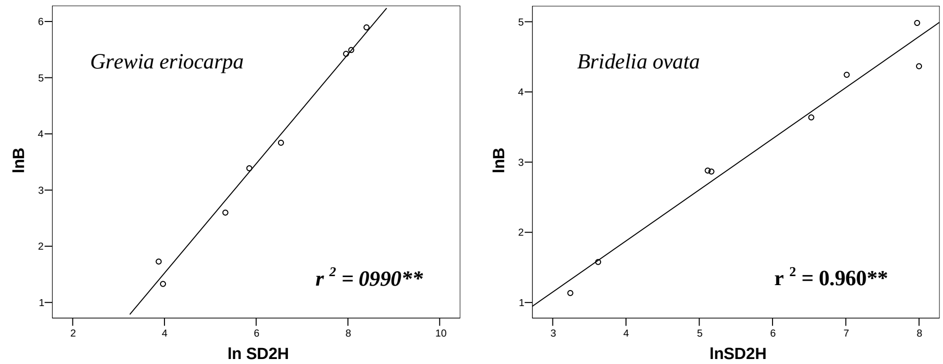

Figure 3 (cont.) Relations between ln*B* and ln ρD^2H fitted by linear regressions of for *Grewia eriocarpa* (n = 8) and *Bridelia ovata* (n = 8).
** highly significant

Table 3 Comparing linear regressions for *Sterculia pexa, Millettia brandisiana, Grewia eriocarpa* and *Bridelia ovata,* where ρD^2H is the independent variable, tree size classes at 2-5cm, >5-10 cm, >10-20 cm and >20 cm.

Regression model	Coefficient symbol	Coefficient value	Standard error	r^2	Average unsigned deviation (%)	Significance level of t-value
Model 3: $\ln(B) = c + \beta \ln(\rho D^2 H)$						
Sterculia pexa	*c*	-3.039	.241	0.989	2.66	< 0.0001
	β	1.018	.041			< 0.0001
Millettia brandisiana	*c*	-1.035	.303	0.973	1.27	0.014
	β	.728	.050			< 0.0001
Grewia eriocarpa	*c*	-2.371	.258	0.990	0.09	< 0.0001
	β	.973	.040			< 0.0001
Bridelia ovata	*c*	-1.586	.445	0.960	1.16	0.012
	β	.818	.069			< 0.0001

Research findings revealed that the coefficient of determination for *Sterculia pexa, Millettia brandisiana, Grewia eriocarpa* and *Bridelia ovata* as shown in Table 3 were 98.9%, 97.3%, 99% and 96%. The average unsigned deviation of the estimates for *Sterculia pexa, Millettia brandisiana, Grewia eriocarpa* and *Bridelia ovata* were 2.66%, 1.27%, 0.09% and 1.16%, respectively. For comparing the slopes of these equations, there were significantly different among these slopes. It was also found that significant differences were revealed on the equation lines between *Sterculia pexa* and *Millettia brandisiana, Sterculia pexa* and *Bridelia ovata* additional *Millettia brandisiana* and *Grewia eriocarpa*.

4. Discussions

Based on the findings of this study the following discussion was developed. By using the average deviation, it was found that the model with variable D is the most appropriate models. It also indicated that the biomass estimation model using ρD^2H is better than the equation using only D^2H. Moreover, in consideration with model of D^2H, some species are found not to be classified. And the accuracy of the biomass estimation by using the variable D in the equation comparing to the equation using the variable ρD^2H is not dramatically different. Hence, it seems more appropriate to use biomass equation with one variable D because of the simplest model. In addition, the measurement of dry weight biomass, wood specific gravity was needed for converting tree volume to dry weight biomass. So, it depends on user's considerations in practice. However, the researcher was unable to draw any conclusions regarding the applications of equation. Finally, we found that the difference of the coefficient of four species in linear regression depended on whether single or complex variable are applied.

5. Conclusions

The pressures brought about by climate change have made biomass assessment essential to measure the forest's potential as a carbon sink and source. Much attention is given to precisely measuring how much biomass exists in the forest. Since approaches to biomass assessment involve predictive modeling, it is important to maximize the accuracy of these models. This study involved the formulation of precision models and an examination of the relationships among model variables for assessing biomass in tropical forests, for four species of trees.

Conclusions of this study, based on the finding were that the best regression models for estimating biomass had two forms, namely $\ln(B) = c + \alpha \ln(D)$ and $\ln(B) = c + \alpha \ln(\rho D^2 H)$. Dry weight of an individual tree was estimated in the regression model using $\rho D^2 H$ with an average error in the range of 0.09-2.66%. This was just as suitable as using only D, in which an average error of estimation was in the range of 0.28-1.77%. Therefore, adding H and ρ as additional input variables does not improve accuracy for specific species regression, but it is needed to avoid species bias. However, when calculating dry weight from volume, wood specific gravity becomes an important variable in a model, so it is appropriate to use $\rho D^2 H$ as an independent variable. One can conclude, therefore, it is most appropriate to use $\rho D^2 H$ as an independent variable in a model. Linear regression results indicate differences among the four species, which suggests that it is not possible to use only one linear regression for all four tree species. There is sufficient evidence to suggest that the formulation of species-specific regression models is important for tracking biomass and carbon in mixed-deciduous degraded forest, and perhaps in any forest.

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