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Allometric Equations to Estimate the Aboveground Biomass of Seedling and Sapling Plants in 10 and 20 Years Old of Secondary Forests in Sarawak, Malaysia

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ABSTRACT

The seedlings and saplings plant stage determines the successional stages in the secondary forest establishment process. The estimation on aboveground biomass (AGB) of seedling and sapling plants is needed to describe undergrowth's contribution in the secondary forest. This study's objective was to develop allometric equations for accurate estimation of AGB for seedlings-saplings in 10 and 20 years old of secondary forests. The study was carried out at sites with two stages of the fallow period: lands with a fallow period of 10 and 20 years, respectively, in Sarawak, East Malaysia. The AGB data of all selected seedlings and saplings with the different species within 100 sample quadrates were used to develop allometric equations for seedlings and saplings in each study site. This study developed allometric equations to estimate AGB of seedlings-saplings (diameter at the ground surface of < 5 cm), particularly in 10 and 20 years of fallow ages.

Keywords: *Aboveground Biomass, Seedling, Sapling, Secondary Forest, Allometric Equation*

1. INTRODUCTION

Tree diversity is essential to predict tree carbon storage in hyperdiverse forests [1]. The total standing aboveground biomass (AGB) of woody vegetation elements is often one of the largest carbon pools. The AGB comprises all woody stems, branches, leaves of living trees, creepers, climbers, epiphytes, and herbaceous undergrowth [2]. AGB estimation is an essential aspect of carbon stocks studies and the effects of deforestation and carbon sequestration on the global carbon balance [3]. Because direct measurement of biomass cannot be made on an entire community or population, samples must be taken from a community or population [4]. Moreover, weighing tree biomass in the field is undoubtedly the most accurate method of estimating AGB. It is still an extraordinarily time-consuming and destructive method, generally limited to small areas and tree sample sizes [3].

An estimate of the vegetation biomass can provide information about the nutrients and carbon stored in the vegetation as a whole or the amount in specific fractions such as extractable wood [2]. Allometry is an effective method for accurately estimating trees' biomass, tree components, and stands [5]. It is hardly ever possible to measure all biomass on a sufficiently large sample area by destructive sample. Some form of allometry is used to estimate individuals' trees' biomass to an easily measured property such as its stem diameter [2]. Various dimensions and partial biomass of trees, such as bole wood, bark, branch, and foliage mass, are estimated from the diameter at breast height (DBH) by the allometric correlation method [6,7].

The allometric equation expresses the relationship between a tree's dimension or different parts of plants with the biomass [8,9]. Regression models are used to convert inventory data into an estimate of trees' biomass [9,10]. Once an allometric equation has been established for different classes of trees in vegetation, one only needs to measure DBH (or other parameters used as a basis for equation, such as height and total biomass or carbon content) to estimate the biomass of individual trees [2,8].

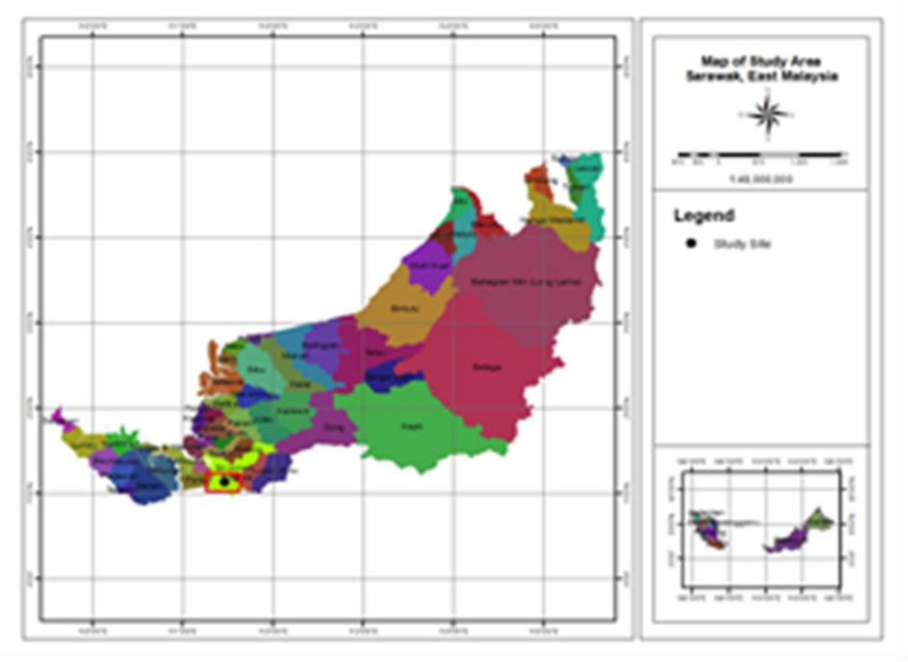

Figure 1 Map of the study area in Sabal, Sarawak, Malaysia

Because it is crucial to estimate AGB in different stage secondary forests accurately, suitable allometric equations are essential. This study's objective was to develop allometric equations for accurate estimation of AGB for seedlings-saplings in 10 and 20 years of fallow periods. Information on the study sites' dominant species and soil properties was reported by [11,12]. The specific selection seedlings-saplings samples were needed because mixed seedlings-saplings species characterize the secondary forests.

2. MATERIALS AND METHODS

2.1. Study Sites

The study was conducted in 10 and 20 years old of secondary forests in Sabal, Sri Aman, Sarawak, East Malaysia (figure 1). The geographic locations of these sites are 01°03'55.9"N 110°55'51.4"E and 01°03'59.3"N 110°53'34.4"E as reported for the previous studies by [11,12,13]. This study was carried out for a duration of 6 months from January 2013 to July 2013.

2.2. Data Collection

One hundred sample quadrates of 1 m × 1 m size were placed randomly in each study site for destructive sampling technique of all woody seedlings and saplings (diameter at the ground surface, Do of <5 cm). All seedlings and saplings within the sample quadrate were enumerated and identified. The different species of seedlings and saplings in every sample quadrate were selected for destructive samples. The AGB data of all selected seedlings and saplings with the other species within 100 sample quadrates were used to developed allometric equations for seedlings and saplings in each study site. Diameter at the ground surface (Do) and the total height of seedlings and saplings were measured using a digital micro caliper (Absolute Digimatic Mitutoyo) and tape, respectively. All parts of seedlings-saplings plants such as leaf and twig, branch, and stem samples were separated and weighed.

2.3. Data Analysis

2.3.1.Analysis of Dry-weight in the Laboratory

The total oven-dry weight of each seedling-sapling part was determined using the following formula [2,9,14]:

$$dw = (sdw \times fw) / sfw$$

where: dw = total dry weight (kg); sdw = dry weight of the sample (g); fw = total fresh weight (kg); sfw = fresh weight of the sample (g).

2.3.2. Tested Allometric Equations

In the first stage of developing allometric equations for estimated AGB in the study sites, the five selected allometric equations of AGB were tested:

$$y = a + b\,x \tag{1}$$

$$y = ax^{b} \tag{2}$$

$$y = a + b\,(\ln x) \tag{3}$$

$$(\ln y) = a + b\,x \tag{4}$$

$$(\ln y) = a + b\,(\ln x) \tag{5}$$

where:

y = total dry weight or biomass of each seedling-sapling plant part, such as stem, branch, leaf, and total aboveground biomass (TAGB) (kg)

x = diameter at the ground surface (Do, cm), full height (H, meter), and (Do2×H) (cm2 m)

'a' and 'b' = coefficients estimated by regression

2.3.3.Testing the Reliability of Model

The allometric equation's reliability was tested based on the significant parameters (P-value) and the determination coefficient value (adjusted R2). The best regression was selected based on the goodness of fit, focusing on the suitable scatter plot, good P-value, and the high value of adjusted R2 among all tested regressions.

3. RESULTS AND DISCUSSION

3.1.Selected Sample Seedlings and Saplings

The harvested seedlings and saplings varied from 0.2 to 4.8 cm in Do and from 0.5 to 5.4 m in height in 10 years old secondary forest. The Do ranged 0.4-4.4 cm, and height ranged 0.6-4.8 m for selective sample seedlings and saplings in 20 years old secondary forest. All data sets used to develop allometric equations in 10 and 20 years old of secondary forests were shown in Tables 1 and 2.

Table 1. All data sets for develop allometric equations in 10 years old secondary forest.

No.	Family	Species	Do (cm)	H (m)	Leaf (kg)	Branch (kg)	Stem (kg)	TAGB (kg)
1	Ampelidaceae	*Leea indica* (Burm.f.) Merr.	1.6	0.8	0.001		0.003	0.004
2	Annonaceae	*Goniothalamus malayanus* Hook. f. & Thomson	0.7	0.9	0.005		0.006	0.011
3	Annonaceae	*Polyalthia glauca* Boerl.	0.7	1.2	0.006		0.007	0.013
4	Apocynaceae	*Alstonia pneumatophora* Backer ex Den Berger	0.4	0.5	0.001		0.001	0.002
5	Apocynaceae	*Alstonia scholaris* (L.) R. Br.	1.9	1.4	0.005	0.009	0.033	0.047
6	Apocynaceae	*Alstonia spatulata* Blume	3.8	5.4	0.113	0.154	0.391	0.658
7	Apocynaceae	*Tabernaemontana* sp.	0.7	0.5	0.013		0.004	0.016
8	Asteraceae	*Vernonia arborea* Buch. Ham.	0.6	0.8	0.003		0.003	0.006
9	Burseraceae	*Dacryodes rostrata* (Blume) H.J. Lam	0.9	1.0	0.013	0.006	0.010	0.030
10	Burseraceae	*Santiria rubiginosa* Blume	1.0	1.8	0.012	0.014	0.036	0.062
11	Burseraceae	*Santiria tomentosa* Blume	0.5	0.7	0.004		0.003	0.007
12	Clusiaceae	*Cratoxylum glaucum* Korth.	1.0	1.4	0.019	0.008	0.017	0.045
13	Dilleniaceae	*Dillenia excelsa* Martelli	1.4	2.9	0.027		0.044	0.072
14	Dilleniaceae	*Dillenia pulchella* Gilg	1.4	2.4	0.012		0.086	0.098
15	Dilleniaceae	*Dillenia suffruticosa* Martelli	1.4	1.3	0.023		0.025	0.047
16	Dipterocarpaceae	*Hopea beccariana* Burck	0.5	0.9	0.006		0.006	0.011
17	Dipterocarpaceae	*Shorea macrophylla* (de Vriese) P.S. Ashton	1.5	1.6	0.054	0.012	0.031	0.097
18	Dipterocarpaceae	*Shorea palembanica* Miq.	1.3	1.6	0.030	0.011	0.025	0.066
19	Dipterocarpaceae	*Shorea parvifolia* Dyer	0.5	0.6	0.001		0.001	0.003
20	Dipterocarpaceae	*Shorea* sp.	0.4	0.5	0.002		0.002	0.004
21	Elaeocarpaceae	*Elaeocarpus beccarii* Aug. DC.	2.0	2.7	0.019	0.027	0.089	0.136
22	Elaeocarpaceae	*Elaeocarpus stipularis* Blume	1.9	1.2	0.022	0.007	0.013	0.043
23	Euphorbiaceae	*Agrostistachys longifolia* Benth. *ex* Hook. f.	0.7	1.0	0.014		0.008	0.022
24	Euphorbiaceae	*Antidesma neurocarpum* Miq.	1.3	2.1	0.002	0.019	0.052	0.072
25	Euphorbiaceae	*Aporosa* sp.	1.4	1.3	0.023	0.016	0.032	0.071
26	Euphorbiaceae	*Baccaurea macrocarpa* Mull. Arg.	1.5	1.5	0.030	0.013	0.031	0.073
27	Euphorbiaceae	*Cleistanthus* sp.	1.4	1.3	0.013		0.020	0.033
28	Euphorbiaceae	*Endospermum diadenum* (Miq.) Airy Shaw	0.5	0.6	0.002		0.003	0.005

29	Euphorbiaceae	*Macaranga beccariana* Merr.	4.8	3.6	0.111	0.056	0.319	0.487
30	Euphorbiaceae	*Macaranga caladifolia* Becc.	0.8	1.8	0.002		0.013	0.016
31	Euphorbiaceae	*Macaranga gigantea* Mull. Arg.	1.5	1.2	0.007		0.005	0.012
32	Euphorbiaceae	*Mallotus macrostachyus* Mull. Arg.	1.4	2.7	0.008		0.063	0.071
33	Fabaceae	*Sindora beccariana* Backer *ex* de Wit	1.0	1.4	0.009	0.008	0.024	0.041
34	Fabaceae	*Uraria crinita* Desv.	1.0	1.2	0.008	0.003	0.010	0.021
35	Fagaceae	*Lithocarpus* sp.	1.1	2.0	0.030	0.018	0.038	0.086
36	Lauraceae	*Beilschmiedia* sp.	1.7	3.4	0.061	0.039	0.134	0.233
37	Lauraceae	*Litsea costalis* (Nees) Kosterm. var. *nidularis* Gamble	0.2	1.6	0.015		0.013	0.028
38	Lauraceae	*Litsea elliptica* Blume	0.7	1.1	0.004		0.011	0.015
39	Loganiaceae	*Fagraea resinosa* Leenh.	2.3	3.2	0.102	0.131	0.162	0.395
40	Loganiaceae	*Norrisia malaccensis* Gardn.	1.1	1.4	0.002		0.032	0.034
41	Melastomataceae	*Blastus borneensis* Cogn. *ex* Boerl.	1.3	1.5	0.010		0.052	0.062
42	Melastomataceae	*Medinilla* sp.	0.8	1.4	0.024		0.016	0.040
43	Melastomataceae	*Pternandra multiflora* Cogn.	0.6	0.8	0.004		0.008	0.012
44	Moraceae	*Artocarpus kemando* Miq.	0.9	1.2	0.010	0.003	0.008	0.022
45	Moraceae	*Ficus aurata* Miq.	0.9	1.4	0.008		0.011	0.019
46	Moraceae	*Ficus condensa* King	0.4	0.6	0.002		0.002	0.004
47	Moraceae	*Ficus geocharis* Corner.	2.4	3.0	0.020	0.031	0.088	0.139
48	Moraceae	*Ficus* sp.	0.6	0.8	0.004		0.005	0.009
49	Myristicaceae	*Knema intermedia* Warb.	2.5	2.8	0.218	0.086	0.234	0.538
50	Myrsinaceae	*Ardisia* sp.	0.9	1.3	0.013		0.015	0.029
51	Myrtaceae	*Syzygium arcuatinervum* (Merr.) Craven & Briffin	0.3	0.8	0.001		0.002	0.003
52	Myrtaceae	*Whiteodendron moultonianum* (W.W.Sm.) Steenis	1.0	1.2	0.013	0.014	0.021	0.047
53	Polygalaceae	*Xanthophyllum flavescens* Roxb.	0.9	1.2	0.011		0.017	0.028
54	Rosaceae	*Prunus arborea* (Blume) Kalkman	1.2	1.7	0.054	0.024	0.035	0.113
55	Rosaceae	*Prunus beccarii* (Ridl.) Kalkman	1.4	1.2	0.010	0.015	0.103	0.128
56	Rubiaceae	*Canthium didymum* Gaertn.	1.9	3.1	0.076	0.042	0.164	0.282
57	Rubiaceae	*Gardenia resinifera* Korth.	0.7	0.8	0.007		0.009	0.016
58	Rubiaceae	*Nauclea subdita* Merr.	0.8	0.6	0.016		0.006	0.022
59	Rubiaceae	*Tarenna fragrans* Koord. & Valeton	1.0	1.2	0.012	0.009	0.013	0.034
60	Rutaceae	*Euodia glabra* (Bl.) Bl.	1.6	1.5	0.007	0.004	0.043	0.054
61	Verbenaceae	*Vitex pubescens* Vahl.	1.1	1.8	0.011		0.035	0.046
		Total	73.6	94.4	1.367	0.779	2.692	4.838
		Average	1.2	1.5	0.022	0.029	0.044	0.079
		Minimum	0.2	0.5	0.001	0.003	0.001	0.002
		Maximum	4.8	5.4	0.218	0.154	0.391	0.658

Note: Do=diameter at ground surface; H=total height; TAGB=total above ground biomass.

There were 61 species of 45 genera of 24 families selected in 10 years old secondary forest. The dry weight range was 0.001-0.218 kg for leaf, 0.003-0.154 kg for branch, 0.001-0.391 kg for the stem, and 0.002-0.658 kg for TAGB in this site. Out of 61 samples, 34 samples for both seedlings and saplings were without dry branch weight (Table 1). In 20 years of secondary forest, 65 species of seedlings and saplings belonged to 45 genera, and 30 families were encountered. The dry weight varied from 0.001 to 0.336 kg for leaf, 0.003 to 0.258 kg for branch, 0.002 to 0.537 kg for stem, and 0.007 to 0.979 kg for TAGB, respectively. Twenty-seven of 65 sample plants did not have a branch yet, as presented in Table 2.

Table 2. All data sets for develop allometric equations in 20 years old secondary forest.

No.	Family	Species	Do (cm)	H (m)	Leaf (kg)	Branch (kg)	Stem (kg)	TAGB (kg)
1	Ampelidaceae	*Leea indica* (Burm.f.) Merr.	0.4	0.8	0.005		0.002	0.007
2	Anisophylleaceae	*Anisophyllea disticha* Baill.	1.4	1.0	0.012	0.013	0.031	0.056
3	Annonaceae	*Goniothalamus velutinus* Airy Shaw	2.1	1.9	0.031	0.032	0.062	0.125
4	Annonaceae	*Monocarpia* sp.	1.7	1.7	0.026	0.032	0.051	0.110
5	Annonaceae	*Polyalthia* sp.	0.6	1.0	0.011		0.010	0.022
6	Apocynaceae	*Alstonia spatulata* Blume	0.6	1.0	0.001		0.008	0.009
7	Apocynaceae	*Tabernaemontana* sp.	1.7	2.1	0.041	0.025	0.066	0.132
8	Burseraceae	*Santiria rubiginosa* Blume	1.2	2.5	0.076	0.023	0.068	0.167
9	Celastraceae	*Bhesa paniculata* Arn.	1.4	1.3	0.008	0.006	0.054	0.067
10	Clusiaceae	*Cratoxylum arborescens* Blume.	1.9	2.3	0.015	0.024	0.115	0.153
11	Clusiaceae	*Cratoxylum formosum* Benth. & Hook. f. ex Dyer	0.7	1.0	0.005		0.004	0.010
12	Clusiaceae	*Garcinia* sp.	1.4	1.3	0.016	0.020	0.050	0.086
13	Dilleniaceae	*Dillenia suffruticosa* Martelli	2.4	2.7	0.109	0.054	0.175	0.339
14	Elaeocarpaceae	*Elaeocarpus beccarii* Aug. DC.	1.2	2.3	0.031	0.021	0.047	0.099
15	Elaeocarpaceae	*Elaeocarpus stipularis* Blume	0.6	1.0	0.005		0.005	0.011
16	Euphorbiaceae	*Antidesma neurocarpum* Miq.	1.1	1.2	0.011	0.003	0.025	0.040
17	Euphorbiaceae	*Endospermum diadenum* (Miq.) Airy Shaw	0.8	1.2	0.003		0.011	0.013
18	Euphorbiaceae	*Macaranga beccariana* Merr.	2.2	3.0	0.070		0.103	0.173
19	Euphorbiaceae	*Macaranga gigantea* Mull. Arg.	3.2	4.8	0.115	0.258	0.278	0.651
20	Euphorbiaceae	*Mallotus macrostachyus* Mull. Arg.	1.1	1.5	0.017		0.023	0.040
21	Fabaceae	*Fordia* sp.	1.1	1.6	0.016	0.010	0.039	0.064
22	Fagaceae	*Lithocarpus* sp.	1.4	1.9	0.026	0.013	0.063	0.102
23	Ixonanthaceae	*Ixonanthes reticulata* Jack	0.7	1.0	0.012		0.010	0.022
24	Lauraceae	*Actinodaphne* sp.	1.1	1.5	0.007	0.016	0.023	0.045
25	Lauraceae	*Beilschmiedia endiandraefolia* Kosterm.	0.9	1.1	0.002		0.014	0.016
26	Lauraceae	*Litsea costalis* (Nees) Kosterm. *var. nidularis* Gamble	1.3	1.4	0.041	0.009	0.023	0.073
27	Lauraceae	*Litsea crassifolia* Boerl.	1.0	0.8	0.006	0.003	0.006	0.015
28	Lauraceae	*Litsea elliptica* Blume	2.6	3.2	0.144	0.084	0.263	0.491
29	Lauraceae	*Litsea nidularis* Gamble	0.8	1.3	0.015		0.019	0.033
30	Lauraceae	*Litsea oppositifolia* (Bl.) Vill.	0.9	0.9	0.008		0.007	0.015
31	Loganiaceae	*Norrisia malaccensis* Gardn.	2.6	2.7	0.063	0.056	0.121	0.240
32	Melastomataceae	*Pternandra coerulescens* Jack	1.7	3.6	0.063	0.049	0.121	0.233
33	Moraceae	*Artocarpus dadak* Miq.	1.4	1.8	0.033	0.029	0.035	0.097
34	Moraceae	*Artocarpus elasticus* Reinw.	0.7	1.2	0.008		0.006	0.015
35	Moraceae	*Artocarpus integer* (Thunb.) Merr.	0.8	1.6	0.007		0.018	0.025
36	Moraceae	*Artocarpus kemando* Miq.	0.9	0.9	0.001		0.009	0.010
37	Moraceae	*Artocarpus nitidus* Trecul	1.5	3.0	0.047	0.030	0.053	0.130
38	Moraceae	*Artocarpus odoratissimus* Blanco	0.8	1.7	0.013		0.015	0.028
39	Moraceae	*Ficus aurata* Miq.	4.4	4.3	0.153	0.192	0.396	0.741
40	Moraceae	*Ficus condensa* King	0.8	0.8	0.003		0.015	0.018
41	Moraceae	*Ficus geocharis* Corner	2.5	3.3	0.121	0.095	0.285	0.501

42	Moraceae	*Ficus beccarii* King.	2.6	4.0	0.054	0.083	0.332	0.469
43	Moraceae	*Ficus* sp.	1.2	2.5	0.015	0.020	0.032	0.067
44	Myristicaceae	*Horsfieldia grandis* Warb.	1.1	1.0	0.013		0.012	0.024
45	Myrtaceae	*Syzygium polyanthum* Walp.	1.0	0.9	0.008		0.008	0.016
46	Polygalaceae	*Xanthophyllum affine* Korth. ex Miq.	1.0	1.2	0.008	0.005	0.012	0.025
47	Polygalaceae	*Xantophyllum ferrugineum* Van der Meijden	1.0	1.5	0.013		0.019	0.032
48	Polygalaceae	*Xantophyllum flavescens* Roxb.	1.1	1.5	0.011	0.006	0.018	0.035
49	Proteaceae	*Heliciopsis percoriacea* R.C.K. Chung	2.2	2.5	0.071	0.043	0.152	0.266
50	Rosaceae	*Prunus arborea* (Blume) Kalkman	0.6	0.7	0.003		0.006	0.008
51	Rubiaceae	*Gardenia resinifera* Korth.	1.5	1.2	0.041		0.033	0.073
52	Rubiaceae	*Nauclea subdita* Merr.	1.6	0.7	0.045	0.023	0.049	0.117
53	Rubiaceae	*Tarenna fragrans* Koord. & Valeton	1.0	1.2	0.013		0.023	0.036
54	Sapindaceae	*Lepisanthes* sp.	1.4	1.4	0.007		0.093	0.099
55	Sapindaceae	*Nephelium cuspidatum* Blume	1.2	0.7	0.002		0.008	0.010
56	Sapotaceae	*Palaquium decurrens* H.J. Lam	2.3	3.1	0.130	0.060	0.210	0.400
57	Sapotaceae	*Palaquium gutta* Burck	1.3	1.7	0.067	0.021	0.039	0.128
58	Sterculiaceae	*Commersonia bartramia* (L.) Merr.	0.8	1.1	0.006		0.004	0.010
59	Theaceae	*Adinandra dumosa* Jack	0.5	0.6	0.006		0.011	0.017
60	Thymelaeaceae	*Gonystylus costalis* Airy Shaw	1.4	1.4	0.012	0.005	0.025	0.041
61	Thymelaeaceae	*Gonystylus* sp.	3.0	4.2	0.336	0.105	0.537	0.979
62	Tiliaceae	*Brownlowia havilandii* Stapf	1.4	1.0	0.013	0.010	0.012	0.034
63	Tiliaceae	*Grewia laevigata* Vahl	2.0	1.6	0.018	0.016	0.023	0.058
64	Tiliaceae	*Pentace* sp.	1.1	1.5	0.023	0.011	0.017	0.051
65	Ulmaceae	*Gironniera nervosa* Planch.	0.8	1.3	0.011	0.004	0.014	0.030
		Total	91.4	113.7	2.322	1.511	4.418	8.251
		Average	1.4	1.7	0.036	0.040	0.068	0.127
		Minimum	0.4	0.6	0.001	0.003	0.002	0.007
		Maximum	4.4	4.8	0.336	0.258	0.537	0.979

Note: Do=diameter at ground surface; H=total height; TAGB=total above-ground biomass

3.2.The Best Selected Allometric Equations for Above Ground Biomass (AGB) of Seedlings-Saplings

The regression analysis results for predicting plant part biomass of subject seedlings and saplings from diameter at the ground surface (Do) and total height (H) using all studied individuals' data are shown in Table 3. From all tested regression, the best selected allometric equations to estimate seedlings and saplings were dominated by the log-linear model (ln y=a+b ln x)" (8 and 10 proposed equations in 10 and 20 years old secondary forests). These equations were the best-fitting model to relate dependent variables (leaf, branch, stem, and AGB) and independent variables (Do, (Do2×H), and H) for the seedlings-saplings stage. However, the result did not propose the best equations for the relationship between dry leaf biomass of seedling-saplings and plant dimensions in 10 years old secondary forest. Among all five tested allometric equations, only two allometric equations were proposed following exponential models (y = a x b). After shifting cultivation, the allometric equations for different ages of secondary forests in fallow lands, such as 10 and 20 years fallow periods, are still rare available. Several allometric equations of secondary forests were reported by [3,15] [16,17,18]. When no specific allometric equations estimate AGB of seedlings-saplings at a different age, secondary forests are available. These proposed equations may be used to estimate AGB at different stages of fallow periods. In addition, most previous reported allometric equations were for the trees stage. This study proposed allometric equations to estimate AGB of seedlings-saplings (Do of < 5 cm), particularly in 10 and 20 years of fallow ages. The developed allometric equations were suitable for 10 and 20 years of secondary forests because the selected samples in the destructive method were based on the representative species.

The amount of dry biomass was influenced by the number of individuals. At the early stage of secondary forests, the occurrence of seedlings and saplings was dominant and abundant. The seedlings and saplings stage was abundant as far as the gap was available. When forests reached maturity and big trees began dominating, light availability was limited in the forest floor, caused the seedlings and saplings to decrease while increasing the forest. As [11] and [19] reported, the number of plant seedlings and saplings decreased in secondary forests with increasing fallow periods. The late pioneer and secondary species were dominant in the ten and 20-year-old secondary forests [13]. Seedling height and biomass growth varied significantly amongst the species [20]. Significant changes occur when many dominant trees senesce at the same time, creating significant gaps and giving an opening to species found at the earlier stages of succession. Replacement of canopy dominants in different age species will occur without substantial disruption of the forests' structure and biomass [21].

4. CONCLUSION

We conclude that the best selected allometric equations to estimate seedlings and saplings were dominated by the log-linear model (ln y = a + b ln x). This study's findings propose an allometric equation of AGB in 10 and 20 years old of secondary forests under similar parent materials and land-use history (slash and burn after shifting cultivation).

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Table 3. The best selected allometric equations for predicting plant part biomass of subject seedlings-saplings (Do of < 5 cm) in the study sites.

Dependent variable (y)	Independent variable (x)	Equation	*P*-value	Adjusted R^2
Ten years old secondary forest				
Branch dry biomass (kg)	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.6720 \times \ln (x) - 5.060$	<0.001	0.67
	H (m)	$\ln (y) = 2.0164 \times \ln (x) - 5.314$	<0.001	0.76
Stem dry biomass (kg)	Do (cm)	$\ln (y) = 1.8545 \times \ln (x) - 4.067$	<0.001	0.64
	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.7532 \times \ln (x) - 4.280$	<0.001	0.80
	H (m)	$\ln (y) = 2.3739 \times \ln (x) - 4.727$	<0.001	0.85
Aboveground biomass (kg)	Do (cm)	$\ln (y) = 1.7911 \times \ln (x) - 3.425$	<0.001	0.64
	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.7206 \times \ln (x) - 3.628$	<0.001	0.77
	H (m)	$\ln (y) = 2.2275 \times \ln (x) - 4.043$	<0.001	0.80
20 years old secondary forest				
Leaf dry biomass (kg)	Do (cm)	$\ln (y) = 2.0957 \times \ln (x) - 4.559$	<0.001	0.63
	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.7598 \times \ln (x) - 4.752$	<0.001	0.70
	H (m)	$\ln (y) = 1.9968 \times \ln (x) - 4.939$	<0.001	0.64
Branch dry biomass (kg)	Do (cm)	$\ln (y) = 2.5308 \times \ln (x) - 5.047$	<0.001	0.77
	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.8783 \times \ln (x) - 5.254$	<0.001	0.86
	H (m)	$y = 0.003 (x)^{0.9181}$	<0.001	0.75
Stem dry biomass (kg)	Do (cm)	$\ln (y) = 2.3751 \times \ln (x) - 4.039$	<0.001	0.82
	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.8450 \times \ln (x) - 4.244$	<0.001	0.88
	H (m)	$\ln (y) = 2.1410 \times \ln (x) - 4.419$	<0.001	0.75
Aboveground biomass (kg)	Do (cm)	$\ln (y) = 2.4014 \times \ln (x) - 3.411$	<0.001	0.83
	$(Do^2 \times H)$ (cm^2m)	$\ln (y) = 0.8571 \times \ln (x) - 3.621$	<0.001	0.90
	H (m)	$y = 0.008 (x)^{1.1279}$	<0.001	0.77

Note: *P* values of the regression analysis are shown. Adjusted R^2 denotes multiple coefficients of determination.

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