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Data Descriptor

# Towards the Fulfillment of a Knowledge Gap: Wood Densities for Species of the Subtropical Atlantic Forest

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**Abstract:** Wood density ($\rho$) is a trait involved in forest biomass estimates, forest ecology, prediction of stand stability, wood science, and engineering. Regardless of its importance, data on $\rho$ are scarce for a substantial number of species of the vast Atlantic Forest phytogeographic domain. Given that, the present paper describes a dataset composed of three data tables: (i) determinations of $\rho$ (kg m$^{-3}$) for 153 species growing in three forest types within the subtropical Atlantic Forest, based on wood samples collected throughout the state of Santa Catarina, southern Brazil; (ii) a list of 719 tree/shrub species observed by a state-level forest inventory and a $\rho$ value assigned to each one of them based on local determinations and on a global database; (iii) the means and standard deviations of $\rho$ for 477 permanent sample plots located in the subtropical Atlantic Forest, covering ~95,000 km$^2$. The mean $\rho$ over the 153 sampled species is 538.6 kg m$^{-3}$ (standard deviation = 120.5 kg m$^{-3}$), and the mean $\rho$ per sample plot, considering the three forest types, is 525.0 kg m$^{-3}$ (standard error = 1.8 kg m$^{-3}$). The described dataset has potential to underpin studies on forest biomass, forest ecology, alternative uses of timber resources, as well as to enlarge the coverage of global datasets.

**Dataset:** Data tables are provided as Supplementary Materials.

**Dataset License:** CC0

**Keywords:** rainforest; wood specific gravity; aboveground biomass; functional traits

## 1. Introduction

Basic density or specific gravity ($\rho$) is a physical property of the wood consisting in the ratio between its oven-dry mass and fresh volume. The use of $\rho$ as a predictor variable in tree-level aboveground biomass (AGB) allometric models is being stimulated given the availability of global databases (e.g., Global Wood Density [1,2], GlobAllomeTree [3], and Try Plant Trait Database [4]) and regional studies. Indeed, it is an important variable in AGB estimation [5–7], and most of the available pantropical models embed it [7–9]; regional AGB models may also include it, aiming to generate more accurate predictions (e.g., [10–12]). As a functional trait, it may support studies on forest succession pathways, species growth and survival performance, among others [1,13,14]. Yet, data on $\rho$ are lacking for a substantial number of species growing in (sub)tropical forests, and the uncertainty of the existing data may be a limitation, as revealed by [15] using the example of the vast and species-rich Atlantic Forest phytogeographic domain.

Calculating mean $\rho$ values for the genus or botanical family is a workaround when information at the species level is missing [16,17]. This approach, however, may increase the uncertainty in AGB estimates in secondary forests or in studies on functional ecology if a certain species' $\rho$ was determined based on an older individual growing in a mature forest, which may have greater $\rho$ due to a larger volume of heartwood, for instance. The mean $\rho$ of 0.70 g cm$^{-3}$ reported by [16] (most likely) for mature Atlantic forests could be ∼30% greater than the mean $\rho$ of secondary forests in the same phytogeographic domain, as shown below.

Given the above, this paper describes a dataset that diminishes the knowledge gap on $\rho$ of a considerable amount of species of the subtropical Atlantic Forest, aiming to reduce the uncertainty in forest biomass estimates [18] and in studies on functional ecology [1,13,14], among other demands. The disclosed dataset is composed of three data tables. The first consists of determinations of $\rho$ for 153 tree species growing in three forest types within the subtropical Atlantic Forest. The second consists of a list of 719 tree/shrub species observed by the Forest and Floristic Inventory of Santa Catarina (IFFSC; http://iff.sc.gov.br/) and a $\rho$ value assigned to each one of them based on the first data table and on a global database. The third consists of the means and standard deviations of $\rho$ for 477 systematically-distributed permanent sample plots of the IFFSC, covering ∼95,000 km$^2$ and ∼23% of the Brazilian subtropical Atlantic Forest.

## 2. Data Description

The three data tables are described below. Table 1 describes the S1 file, which contains determinations of $\rho$ for 153 species growing in the Atlantic Forest based on wood samples collected throughout the state of Santa Catarina, southern Brazil (see Sections 3.2 and 3.3). It contains two exotic invasive tree species, namely *Hovenia dulcis* Thunb. and *Ligustrum lucidum* W.T.Ait.; the first is growing abundantly in the semi-deciduous forests of Santa Catarina [19] and the second at some sites in the *Araucaria* forest [20]. One species was not identified at the species level, but rather at the genus level, namely *Symplocos* sp. (a voucher can be consulted using the barcode FURB58775 at http://inct.splink.org.br/).

**Table 1.** Description of the S1 file.

| Header | Description | Unit |
|---|---|---|
| Species | Species' scientific name validated by [21] | - |
| Genus | Species' genus | - |
| Family | Species' botanical family following [22] | - |
| For. type (SC) | Forest type within the state of Santa Catarina in which the species was sampled | Evergreen rainforest<br>*Araucaria* forest<br>Semi-deciduous forest |
| No. of trees | Number of sampled individual trees | - |
| No. of discs | Number of discs used to determine the species' mean $\rho$ | - |
| Tree compart | Tree compartment from each the discs were taken | stem or large branch ($\varnothing \geq 5$ cm) |
| Mean $\rho$ (kg m$^{-3}$) | Mean wood basic density (determined according to Equation (1)) over the discs | kg m$^{-3}$ |
| SD (kg m$^{-3}$) | Standard deviation of $\rho$ among individual trees | kg m$^{-3}$ |
| CV% | Coefficient of variation of $\rho$ among individual trees | % |

A species may have more than one record in this data table because its $\rho$ may have been determined in more than one forest type or using wood samples taken from the stem or large branches (see Section 3.2).

Table 2 presents descriptive statistics of the data table described in Table 1, and Figure 1 illustrates the distribution of the species' $\rho$ in the respective forest type(s) in which they were sampled.

**Table 2.** Descriptive statistics of the data table containing determinations of $\rho$ for 153 species growing in three forest types within the subtropical Atlantic Forest in southern Brazil. ERF: evergreen rainforest; AF: *Araucaria* forest; SF: semi-deciduous forest.

| Forest Type | No. of Species | No. of Trees | No. of Discs | Mean $\rho$ (kg m$^{-3}$) | Standard Deviation [1] (kg m$^{-3}$) | Minimum $\rho$ (kg m$^{-3}$) | Maximum $\rho$ (kg m$^{-3}$) |
|---|---|---|---|---|---|---|---|
| ERF | 83 | 270 | 759 | 524.9a | 124.9 | 256.5 | 769.6 |
| AF | 46 | 79 | 236 | 550.8a | 118.1 | 303.6 | 790.9 |
| SF | 42 | 72 | 214 | 547.5a | 124.3 | 281.4 | 765.3 |
| All | 153 * | 421 | 1209 | 538.6 | 120.5 | 256.5 | 790.9 |

[1] Standard deviation of $\rho$ among species. * Total number of unreplicated species. Means followed by the same letter are not significantly different from each other according to Tukey–Kramer pairwise confidence intervals ($\alpha$ = 0.05). The three groups have equivalent variances according to Levine's test for homogeneity of variances ($\alpha$ = 0.05).

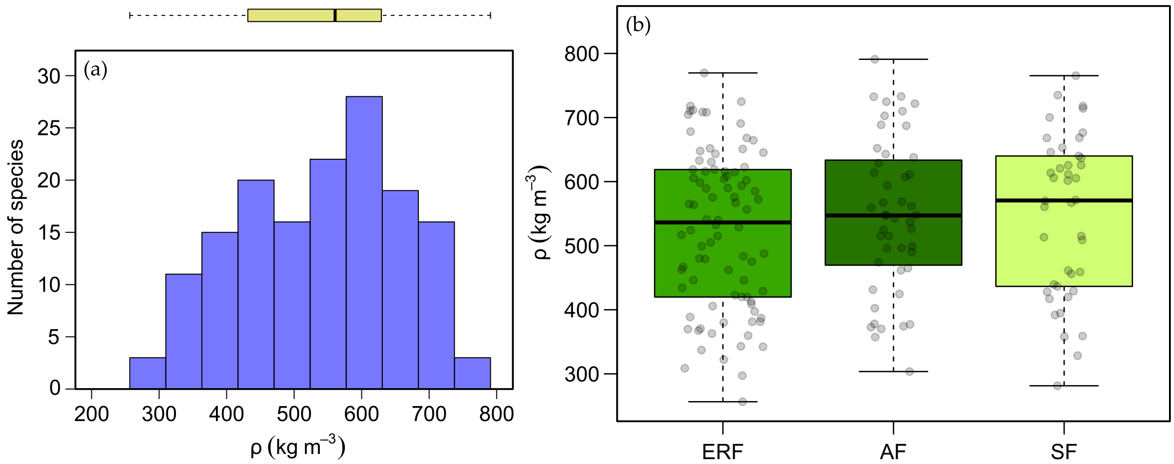


**Figure 1.** (**a**) Distribution of the 153 species' $\rho$; (**b**) distribution of the species' $\rho$ in the forest type in which they were sampled. ERF: evergreen rainforest; AF: *Araucaria* forest; SF: semi-deciduous forest.

Table 3 describes the S2 file containing a list of 719 tree/shrub species (including exotic species) observed in the field by the IFFSC and a $\rho$ value assigned to each one of them, based on the procedure described in Section 3.5, which used the data described in Table 1, as well as data from the Global Wood Density database (GWD).

**Table 3.** Description of the S2 file.

| Header | Description | Unit |
|---|---|---|
| Species | Species' scientific name validated by [21] | - |
| Genus | Species' genus | - |
| Family | Species' botanical family following [22] | - |
| $\rho$ (kg m$^{-3}$) | Wood basic density | kg m$^{-3}$ |

Table 4 describes the S3 file containing the arithmetic means and standard deviations of $\rho$ for 477 systematically-distributed sample plots located in three forest types within the Brazilian subtropical Atlantic Forest, as well as the means and standard deviations of $\rho$ for the 477 sample plots weighted by the species' basal area within each of them (see Section 3.5). The estimates considered only woody species, i.e., palm trees and tree ferns were not considered.

**Table 4.** Description of the S3 file.

| Header | Description | Unit |
|---|---|---|
| Sample plot | IFFSC sample plot ID | - |
| For. type | Forest type wherein the sample plot was located | Evergreen rainforest<br>*Araucaria* forest<br>Semi-deciduous forest |
| Long | Sample plot's longitude | Decimal degrees |
| Lat | Sample plot's latitude | Decimal degrees |
| Mean $\rho$ (kg m$^{-3}$) | Arithmetic mean wood basic density over the species within the sample plot | kg m$^{-3}$ |
| SD (kg m$^{-3}$) | Standard deviation of $\rho$ over the species within the sample plot | kg m$^{-3}$ |
| W. mean $\rho$ (kg m$^{-3}$) | Weighted mean $\rho$ based on the species' basal area in the sample plot | kg m$^{-3}$ |
| SDw (kg m$^{-3}$) | Weighted standard deviation of $\rho$ based on the species' basal area in the sample plot | kg m$^{-3}$ |

Table 5 and Figure 2 present estimates generated using the data described in Table 4. Because distinct portions of the population were sampled with different intensities (i.e., 10 × 10 km grid for the evergreen rainforest (ERF) and *Araucaria* forest (AF), and 5 × 5 km grid for the semi-deciduous forest (SF); see Section 3.1), the mean $\rho$ over all forest types and its standard error were calculated using stratified estimators [23]. These estimators take into account the proportion of each stratum (or portion) of the population in the estimation of its mean and variance, thus circumventing the greater weight the stratum sampled with greater intensity (i.e., SF) would have in the population estimates. Strata weights were calculated using the forest areas reported in Section 3.1.

**Table 5.** Stratified estimates using the dataset containing arithmetic and weighted means of $\rho$ for 477 systematically-distributed sample plots located in the Brazilian subtropical Atlantic Forest.

| Forest Type | Weight | No. of Sample Plots | Mean [1] $\rho$ (kg m$^{-3}$) | Standard Error (kg m$^{-3}$) | Mean [2] $\rho$ (kg m$^{-3}$) | Standard Error (kg m$^{-3}$) |
|---|---|---|---|---|---|---|
| ERF | 0.4796 | 206 | 532.7a | 1.7 | 524.9a | 3.0 |
| AF | 0.4677 | 181 | 523.3b | 1.7 | 517.9a | 3.1 |
| SF | 0.0475 | 90 | 521.0b | 2.4 | 489.9b | 5.0 |
| All | 1.0000 | 477 | 525.0 | 1.8 | 517.3 | 3.2 |

[1] Mean over the arithmetic means per sample plot. [2] Mean over the means per sample plot weighted by the species' basal area. Means followed by the same letter are not significantly different from each other according to Tukey–Kramer pairwise confidence intervals ($\alpha$ = 0.05). The three groups have equivalent variances according to Levine's test for homogeneity of variances ($\alpha$ = 0.05).

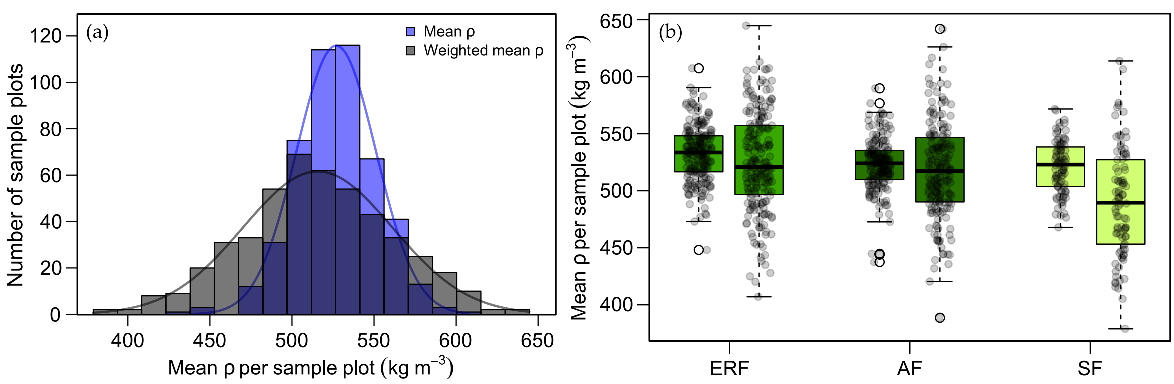


**Figure 2.** (**a**) Distribution of all the IFFSC sample plots' mean $\rho$; (**b**) distribution of sample plots' mean $\rho$ in the three main forest types in the state; the first box in each group refers to arithmetic means and the second to means weighted by the species' basal area. ERF: evergreen rainforest; AF: *Araucaria* forest; SF: semi-deciduous forest.

## 3. Methods

### *3.1. Study Area*

The study area was defined as the state of Santa Catarina, southern Brazil, with an area of 95,346 km$^2$ (Figure 1), of which ∼28% is covered by native forests [24]. The state's three main forest types are [25]: evergreen rainforest (ERF), with an area of 31,281 km$^2$, of which 40.4% is forest land; *Araucaria* forest (AF), with an area of 56,395 km$^2$, of which 21.8% is forest land; and semi-deciduous forest (SF), with an area of 7671 km$^2$, of which 16.3% is forest land [24]. According to the Köppen–Geiger climate classification, the study area is influenced by two climatic types: Cfa, fully-humid temperate climate with a warm summer, and Cfb, fully-humid temperate climate with a cool summer [26]. The annual average temperature ranges from 10–22 °C, and the annual average precipitation ranges from 1100–2900 mm and is well distributed all year-round [27].

### *3.2. Data Collection for Determining Wood Basic Densities*

Between the years of 2014 and 2016, trees selected to be felled in a forest management plan prepared for a secondary ERF in the municipality of Guaramirim, Santa Catarina, Brazil (Figure 3), were sampled, totaling 255 felled trees. An average of three wood discs per stem were collected from each tree, one at its base, one at its middle, and another at its upper end. The felled individuals belonged to 76 species, 64 genera, and 35 families. Their diameter at breast height (dbh) and total height ranged from 5.4–71.8 cm and 4.5–27.9 m, respectively.

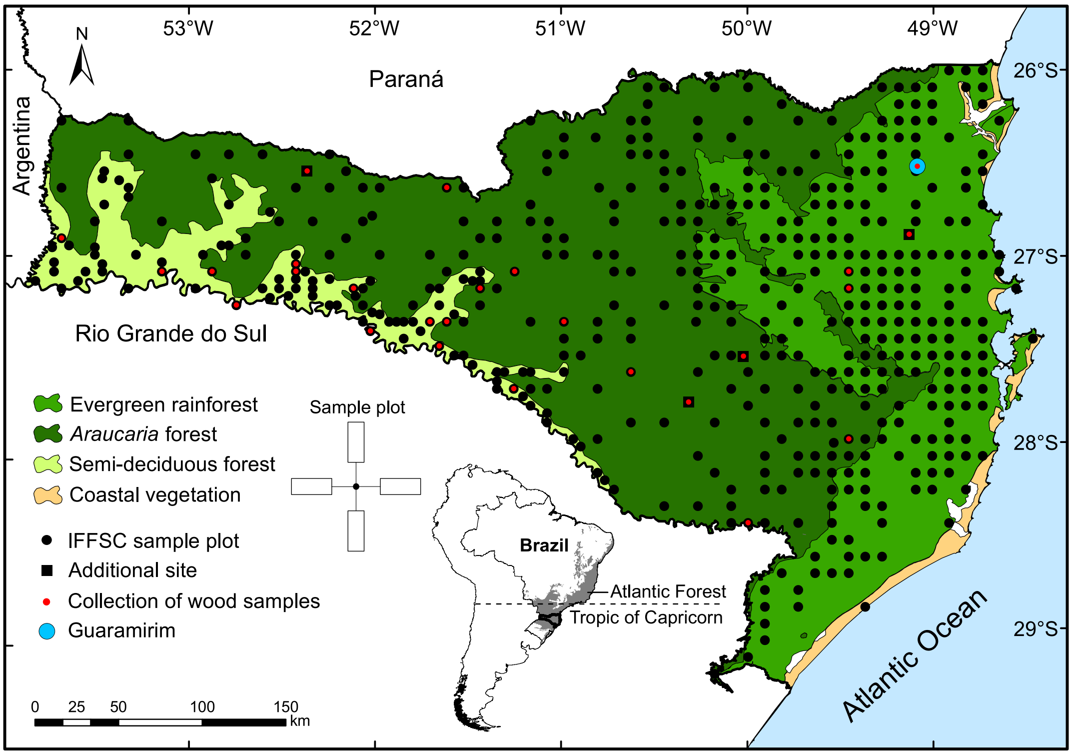


**Figure 3.** The study area and its main forest types, the IFFSC's sample plots, and sites wherein wood samples were collected.

Additionally, within the systematically-distributed 0.4 ha sample plots of the IFFSC (see Section 3.4) (Figure 3), between the years of 2018 and 2019, segments of ∼40 cm were collected from large branches (with diameter (⌀) ≥5 cm) (Figure 4a) of individual trees using a pruning saw coupled to an extension pole of 4 m. Epicormic branches were avoided because they usually occur on trees growing under stressful environmental conditions or with reduced cambial activity [28]; thus, due to their accelerated primary growth, their $\rho$ may be substantially smaller than that of regular large branches. Based on tree community data gathered by the IFFSC (see Section 3.4), species lists were formerly built for giving priority to the collection of branches of species with greater basal area in the three forest types. Large branches, or eventually stems, were also collected in private properties outside the IFFSC sampling grids (Figure 3). In total, 166 individual trees belonging to 86 species, 68 genera and 34 families were sampled within the IFFSC sample plots and in private properties. At the laboratory, three wood discs were taken per segment (Figure 4b).

(a) (b)

**Figure 4.** (**a**) Example of collected branches with ⌀ ≥ 5 cm and (**b**) discs taken from a branch.

### 3.3. Wood Basic Density Determination

The discs were submerged in water for at least 24 h for fiber saturation; their bark was removed, and their saturated volume ($vol_{sat}$) was determined through the difference between their weight in air and in water [29]. Then, the samples were dried in an oven with air circulation at 103 ± 2 °C until they reached a constant weight (sample anhydrous mass, $dm_0$). Thus, the $\rho$ was determined as the ratio between $dm_0$ and $vol_{sat}$:

$$\rho = \frac{dm_0}{vol_{sat}} \tag{1}$$

where $\rho$ = sample basic density (kg m$^{-3}$); $dm_0$ = sample anhydrous mass (kg); and $vol_{sat}$ = sample saturated volume (m$^3$). The $\rho$ of an individual tree was determined as the mean $\rho$ over the discs taken from it. In turn, the mean $\rho$ of a given species was calculated based on the mean over individuals.

### 3.4. Forest Community Data Collected by the IFFSC

The IFFSC collected data between 2007 and 2011 within permanent ground sample plots located at the intersections of a 10 × 10 km grid covering the state's territory. The greatly-fragmented SF required a 5 × 5 km grid to assure representativeness. The sample plots were located in native forests after a land-use pre-stratification based on maps drawn up from medium resolution multispectral satellite imagery [24]. Among 477 sample plots, 427 satisfied the following forestland definition: an area with continuous tree vegetation, with canopy height ≥ 10 m and basal area ≥ 10 m$^2$ ha$^{-1}$. Among the 477 sample plots, 206 were located in the ERF, 181 in the AF, and 90 in the SF. Each sample plot consisted of a cluster of four crosswise subplots with an area of 1000 m (20 × 50 m), distanced 30 m from the sample plot center (Figure 3).

Approximately 95% of the sampled forests were classified by the IFFSC as secondary, with ∼30–50 years of ecological succession. Inside the sample plots' limits, all living trees with dbh ≥10 cm were identified and measured (∼98,000 individuals). The sample plots' altitude ranges (m, a.s.l.) were 5–1195 m for the ERF, 514–1560 m for the AF, and 170–898 m for the SF.

Species identification was done by a network of taxonomists from Brazil and abroad; vouchers of all species were deposited at FURB Herbarium [30]. The species' names were verified using the "flora" R package [31], which consults data from [21] and checks for eventual misspellings or no longer valid species names.

### 3.5. Calculating the Mean ρ for the IFFSC Sample Plots

The first step in calculating the mean $\rho$ for the IFFSC sample plots consisted in assigning a $\rho$ value for each tree observation in the dataset. When $\rho$ for a given species was lacking, it received the mean of its genus, and if it was still lacking, it received the mean of its family, as suggested by [16]. This procedure was carried out using the data described in Table 1. If a species' $\rho$ was still missing, the GWD was consulted; if information at the species level was not available, it received the mean of its genus; if it was still not available, it received the mean of its family. Trees/shrubs identified at the genus level received the mean $\rho$ of its genus, and the ones identified at the family level received the mean of its family; in this procedure, the GWD was consulted only if the information was unavailable in the data table described in Table 1. The $\rho$ of exotic species was assigned following the same logic, but only the GWD was consulted, with the exception of *H. dulcis* and *L. lucidum*, which had their $\rho$ determined using samples collected by the IFFSC.

After this step, the arithmetic mean and standard deviation of $\rho$ were both calculated for each sample plot based on the tree/shrub species recorded within it. The weighted mean and weighted standard deviation of $\rho$ were calculated based on the sum of each species' basal area within the sample plot. Even though exotic species were included in the S2 file, they were excluded in the calculation of the mean $\rho$ per sample plot; unidentified species and the ones with unavailable information in both datasets (i.e., the local dataset and GWD) were also excluded. These procedures were conducted in R [32], with the aid of the packages "dplyr" [33] for data filtering and "SDMTools" [34] for calculating weighted means and standard deviations.

## 4. User Notes

The dataset will most likely be updated as new samples are collected on subsequent remeasurement cycles of the IFFSC's sample plots. Users can find information about updates at http://iff.sc.gov.br/ or by contacting the authors.

## 5. Conclusions

Legal constraints regarding the use and protection of Brazilian native forests may hinder the collection of wood samples from the stem of felled trees, even though, in theory, this would be permitted for scientific purposes. Therefore, collecting samples from large branches (with $\varnothing \geq 5$ cm) may stand as a feasible and low-budget approach to gather important data to generate more conservative biomass estimates and to support studies on functional ecology. Results of an unpublished study using 83 of the 236 felled trees in the ERF, which had both the $\rho$ of the stem and large branches determined, brought evidence that, in mean values, the $\rho$ of the two compartments are statistically equivalent.

The data described in this paper could be integrated into global datasets to improve their coverage; they could also be associated with forest inventory data gathered at other locations within the studied forest types under similar climate features and forest successional stage for studies on aboveground biomass estimates (e.g., [35,36]), topics related to uncertainty in large-area AGB estimates (e.g., [37]), and alternative uses of timber resources, among others (see [38]).

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2306-5729/4/3/104/s1: S1 file: iffsc_wd_153_species_jun-2019.xlsx; S2 file: iffsc_wd_719_species_jun-2019.xlsx; and S3 file: iffsc_mean_wd_sample_plots_jun-2019.xlsx.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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