

Brief Report

The Contributions of Neotropical Tree Families to the Structure of Common Amazon Forest-Types

Randall W. Myster

Biology Department, Oklahoma State University, Oklahoma City, OK 73107, USA; mysterrwm1@gmail.com

Abstract: In order to investigate how familial biodiversity structures forests in the critically important Amazon, I combined past plot samplings to investigate the contributions of tree families in those samplings to the structure of common Amazon forest types. I found that the families Arecaceae, Fabaceae, Clusiaceae, and Malvaceae had the most stems; Staphyleaceae, Caricaceae, and Anacardiaceae had the largest stems; Arecaceae, Fabaceae, Lecythidaceae, and Malvaceae had the largest basal area; Fabaceae, Malvaceae, and Sapotaceae had the most genera; Annonaceae, Euphorbiaceae, Fabaceae, Lauraceae, Malvaceae, Moraceae, and Sapotaceae had the most species, and the maximum Fisher's α diversity index was found for many families. Together, results suggest that Fabaceae and Malvaceae are the most important families structuring these forests, but also that Arecaceae and Sapotaceae may be important. Thus, conservationists and managers may help sustain structure in these forests by propagating and maintaining species in these families. Finally, correlations between total number of stems and basal area, and between total number of genera and total number of species, suggest a causal relationship between them as they structure these forests, but the lack of correlations with Fisher's α suggest it has little structural utility for these forests.

Keywords: Ecuador; igapó; LTER; palm; Peru; *terra firme*; várzea; white sand



Citation: Myster, R.W. The Contributions of Neotropical Tree Families to the Structure of Common Amazon Forest-Types. *Int. J. Plant Biol.* **2023**, *14*, 339–346. <https://doi.org/10.3390/ijpb14020028>

Academic Editor: Adriano Sofo

Received: 11 February 2023

Revised: 20 March 2023

Accepted: 21 March 2023

Published: 29 March 2023



Copyright: © 2023 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The effect of biodiversity on ecosystem structure and function is a central ecological research topic [1], as the global loss in biodiversity [2] may be leading to a decline in ecosystem-level processes [3]. For example, productivity may be reduced by a decrease in biodiversity because studies have shown a positive relationship between productivity and species richness [4,5]. Ecosystem stability—which can be defined as resistance to, or resilience to, perturbation—could also deteriorate because of a reduction in biodiversity [6]. However, perhaps most critically for our shared human future, loss of biodiversity might diminish key ecosystem “services” that we need, such as air and water purification and maintenance of soil fertility [7].

The Neotropics has long been known to be the most speciose place on Earth. It includes the very biodiverse Amazon [8,9], which has been an excellence place to investigate how biodiversity controls and affects the structure, function, and dynamics of ecosystems [10,11]. Surveys of Amazonian biodiversity have shown that there are at least 6727 tree species in lowland Amazon forested ecosystems (for trees at least 10 cm in diameter at breast height [12]) in at least 188 families, and the families with the most species are Fabaceae (1042 species), Lauraceae (400), Myrtaceae (393), Annonaceae (388), Rubiaceae (338), Melastomataceae (263), Chrysobalanaceae (256), Sapotaceae (244), Malvaceae (214), and Ochnaceae (166) [12–15]. Most of the sampling in these surveys has been in the most common Amazon forest types of *terra firme*, palm, white sand, várzea, and igapó, and has suggested that examining biodiversity at higher, more inclusive taxa levels than species (such as families) could facilitate ecological research on the effects of biodiversity on ecosystem structure and function [16].

Therefore, because of the importance of the Amazon and because it presents an exceptional opportunity to examine relationships between biodiversity and ecosystem

structure, function, and dynamics, I combined past samplings in one ha plots of the most common Amazon forest types to investigate these questions: (1) What are the families and most common species in these Amazon forested ecosystems? (2) How do these families individually contribute to the key structural parameters of total number of stems, mean stem size, total basal area, total number of genera, total number of species and Fisher's alpha (α) diversity index of these forests? and (3) What do correlations among those structural parameters reveal about how these forests are structured at the familial level?

2. Materials and Methods

2.1. Study Sites

The first study site was the Estación Científica Yasuní (ECY: 0°41' S, 76°24' W), operated by the Pontificia Universidad Católica de Ecuador (PUCE) (www.puce.edu.ec, accessed on 11 February 2023) and located within the Yasuni National Park of eastern Ecuador [17]. The mean annual rainfall of ECY is 3081 mm and the wettest months are April to May and October to November, with August as the driest month. The mean monthly temperature varies between 22 °C and 35 °C. Soils in the National Park are clayey, low in most cations, but rich in aluminum and iron [18]. Most of the station is in *terra firme* forest but várzea forest—located next to the white-water Tiputini River, which floods for a few weeks every year to a maximum depth of 3 m—is also common. ECY is the site of a long-term 50 ha plot in *terra firme* forest, maintained by PUCE as part of the ForestGEO network (www.forestgeo.si.edu/sites/neotropics/yasuni, accessed on 11 February 2023).

The second study site was the Área de Conservación Regional Comunal de Tamshiyacu-Tahuayo (ACRCTT: 4°18' S, 73°13' W; www.perujungle.com, accessed on 11 February 2023), located in Loreto Province 130 km south of Iquitos Peru [19], and named for two white-water rivers—the Tamshiyacu and the Tahuayo—that form boundaries to the north and west. ACRCTT is part of one of the largest (270, 654 ha) protected areas in the Amazon where local black-water runoff creates igapó forests, and where *terra firme* forest and várzea forest are also common [20]. The precipitation ranges from 2400–3000 mm per year and the average temperature is relatively constant at 26 °C.

The third study site was the Sabalillo Forest Reserve (SFR: 3°20' S, 72°18' W) established in 2000 and operated by Project Amazonas (www.projectamazonas.org, accessed on 11 February 2023) [21]. SFR is located on both sides of the upper Rio Apayacu, 172 km east of Iquitos, Peru. The reserve is part of 25,000 hectares set aside over the last decade and consists of low, seasonally inundated river basins of the upper Amazon. Annual precipitation is 3297 mm per year and the rainy season is between November and April [22]. Within the reserve, *terra firme* forest, white sand forest, palm forest, and igapó forest are often found.

2.2. Setting Up and Sampling of the One Ha Plots

A one ha plot was sampled (1) in várzea forest (under water one month per year) at ECY in May 2010, (2) in igapó forest (under water two months per year) at ACRCTT in May 2011, (3) in *terra firme* forest, (4) in palm forest, and (5) in white sand forest at SFR in June 2013. Each of these plots were the same shape (200 m × 50 m) and used the same sampling protocols, including measuring the diameter at breast height (dbh) of all trees and palms at least 10 cm dbh at the nearest/lowest point when the stem was cylindrical, or just above the buttresses if the tree was buttressed. Trees and palms were also identified to family (using the familial taxonomic nomenclature found in [23]), to species, or in a few cases to genus if identification to species was not possible, using [24,25] as taxonomic sources. The Missouri Botanical Garden website (www.mobot.org, accessed on 11 February 2023), and herbaria at the Universidad Nacional de la Amazonia Peruana (UNAP) in Iquitos and at ECY, were also consulted. Voucher samples are kept at the UNAP and the ECY herbaria. The plot data from várzea forest and from igapó forest are archived at the Luquillo Experimental Forest in Puerto Rico (LTERDBAS#172) as part of its Long-term Ecological Research (LTER)

program (www.luq.lternet.edu, accessed on 11 February 2023) funded by the US National Science Foundation.

2.3. Data Analyses

The data for the plots were combined together to generate for each family found in any of the plots (1) the number of tree stems, (2) the average dbh (in cm) for those stems, (3) the sum of the basal areas of all individual tree stems in each family using the formula $\sum \pi r^2$; where r = the dbh of each individual stem/2, (4) the number of genera for those stems, (5) the number of species for those stems, and (6) Fisher's alpha (α) diversity index [26] using a Javascript algorithm based on Newton's method at (www.groundvegetationdb-web.com/ground_veg/home/diversity_index, accessed on 11 February 2023). Fisher's α uses both number of stems and number of species in its calculation [26]. The most common species were also compiled. Finally, a Pearson product moment correlation coefficient (PPMCC) [27,28] was computed between all 6 parameters taken pair-wise with the number of stems found in each family (i.e., the columns of Table 1), using the algorithm at (www.socscistatistics.com/tests/pearson/default2.aspx, accessed on 11 February 2023). The data from each of the one ha plots has been previously peer-reviewed and published [8,29–35] where the families and the ranges for their tree stem sizes were found to be similar and comparable to one ha plot samplings of the same forest types across the Amazon, as discussed and referenced in those published papers.

Table 1. All families found in the five one ha plots sorted alphabetically with the total number (#) of tree stems sampled, mean stem dbh (in cm), basal area (in m² per 5 ha area), total number (#) of genera, total number (#) of species and Fisher's α index of diversity for each family (data taken from [8,29–35]). Calculations are truncated after two decimal places.

| Family | # Stems | Mean Stem dbh | Basal Area | # Genera | # Species | Fisher's α |
|------------------|---------|---------------|------------|----------|-----------|-------------------|
| Anacardiaceae | 5 | 37.82 | 0.56 | 3 | 3 | 3.16 |
| Annonaceae | 62 | 14.1 | 0.96 | 17 | 20 | 10.23 |
| Apocynaceae | 7 | 28.11 | 0.43 | 3 | 4 | 3.87 |
| Araliaceae | 2 | 14.85 | 0.03 | 2 | 2 | 999 |
| Arecaceae | 305 | 17.58 | 7.39 | 8 | 13 | 2.75 |
| Begoniaceae | 2 | 15.11 | 0.03 | 2 | 2 | 999 |
| Bixaceae | 18 | 12.21 | 0.21 | 10 | 15 | 42.29 |
| Boraginaceae | 4 | 26.83 | 0.22 | 1 | 4 | 999 |
| Burseraceae | 46 | 25.8 | 9.61 | 5 | 10 | 3.93 |
| Calophyllaceae | 8 | 12.75 | 0.1 | 1 | 1 | 0.3 |
| Capparaceae | 1 | 12.21 | 0.01 | 1 | 1 | 999 |
| Caricaceae | 3 | 41.23 | 0.4 | 1 | 1 | 0.52 |
| Cecropiaceae | 49 | 24.61 | 2.32 | 4 | 11 | 4.41 |
| Chrysobalanaceae | 24 | 16.35 | 0.5 | 5 | 13 | 11.57 |
| Clusiaceae | 240 | 14.01 | 3.69 | 9 | 21 | 2.65 |
| Combretaceae | 1 | 10 | 0.01 | 1 | 1 | 999 |
| Dichapetalaceae | 2 | 13.9 | 0.03 | 1 | 2 | 999 |
| Ehretiaceae | 1 | 10 | 0.01 | 1 | 1 | 999 |
| Elaeocarpaceae | 6 | 21.77 | 0.22 | 1 | 3 | 2.38 |
| Euphorbiaceae | 73 | 18.84 | 2.03 | 15 | 21 | 9.86 |
| Fabaceae | 293 | 22.92 | 12.08 | 31 | 57 | 21.11 |
| Humiriaceae | 15 | 12.22 | 0.17 | 4 | 5 | 2.62 |
| Icacinaeae | 7 | 15.15 | 0.12 | 3 | 5 | 7.81 |
| Lauraceae | 32 | 17.34 | 0.75 | 11 | 22 | 31.08 |
| Lecythidaceae | 98 | 29.36 | 6.63 | 4 | 16 | 5.42 |
| Malpighiaceae | 5 | 26.81 | 0.28 | 2 | 2 | 1.23 |
| Malvaceae | 196 | 20.52 | 6.47 | 26 | 37 | 13.49 |

Table 1. Cont.

| Family | # Stems | Mean Stem dbh | Basal Area | # Genera | # Species | Fisher's α |
|-----------------|---------|---------------|------------|----------|-----------|-------------------|
| Melastomataceae | 30 | 16.37 | 0.63 | 4 | 8 | 3.56 |
| Meliaceae | 68 | 20.52 | 2.24 | 5 | 10 | 3.23 |
| Memecylaceae | 1 | 11.6 | 0.01 | 1 | 1 | 999 |
| Moraceae | 57 | 24.74 | 2.73 | 13 | 23 | 14.33 |
| Myristicaceae | 76 | 21.94 | 2.87 | 6 | 16 | 6.18 |
| Myrtaceae | 71 | 14.36 | 1.14 | 5 | 9 | 2.73 |
| Nyctaginaceae | 24 | 25.14 | 1.19 | 2 | 4 | 1.37 |
| Ochnaceae | 1 | 22 | 0.03 | 1 | 1 | 999 |
| Oleaceae | 3 | 23.11 | 0.09 | 2 | 3 | 999 |
| Opiliaceae | 1 | 14 | 0.01 | 1 | 1 | 999 |
| Picramniaceae | 2 | 10.21 | 0.01 | 1 | 2 | 999 |
| Polygonaceae | 8 | 19.58 | 0.24 | 2 | 4 | 3.18 |
| Quiinaceae | 1 | 11.33 | 0.01 | 1 | 1 | 999 |
| Rhizophoraceae | 1 | 13.15 | 0.01 | 1 | 1 | 999 |
| Rubiaceae | 74 | 19.42 | 2.19 | 8 | 12 | 4.05 |
| Sabiaceae | 32 | 15.91 | 0.64 | 11 | 15 | 10.99 |
| Salicaceae | 24 | 12.33 | 0.28 | 7 | 10 | 6.42 |
| Sapindaceae | 23 | 16.65 | 0.5 | 7 | 12 | 10.12 |
| Sapotaceae | 64 | 23.01 | 2.66 | 20 | 28 | 18.98 |
| Simaroubaceae | 4 | 24.91 | 0.19 | 2 | 2 | 1.58 |
| Siparunaceae | 13 | 15.77 | 0.25 | 5 | 8 | 8.85 |
| Staphyleaceae | 1 | 42.31 | 0.14 | 1 | 1 | 999 |
| Ulmaceae | 7 | 29.92 | 0.49 | 4 | 6 | 20 |
| Urticaceae | 3 | 14.73 | 0.03 | 2 | 2 | 2.61 |
| Verbenaceae | 1 | 11.9 | 0.01 | 1 | 1 | 999 |
| Violaceae | 6 | 15.37 | 0.11 | 3 | 4 | 5.24 |
| Vochysiaceae | 21 | 20.51 | 0.69 | 12 | 15 | 23.46 |

3. Results

There were 57 plant families found in the plots and Arecaceae, Fabaceae, Clusiaceae and Euphorbiaceae were the only families present in all of them. The (common) families with more than 100 stems were Arecaceae (305 stems), Fabaceae (283 stems), Clusiaceae (240 stems), and Malvaceae (196 stems: Table 1), and the (rare) families with only one stem were Capparaceae, Combretaceae, Ehretiaceae, Memecylaceae, Ochnaceae, Opiliaceae, Quiinaceae, Rhizophoraceae, Staphyleaceae, and Verbenaceae. The families with an average stem size over 30 cm dbh were Staphyleaceae (42.31 cm), Caricaceae (41.23 cm), and Anacardiaceae (37.82 cm), and the families with an average stem size under 12 cm dbh were Verbenaceae (11.90 cm), Memecylaceae (11.60 cm), and Quiinaceae (11.33 cm). The families with a basal area over 5 m² were Fabaceae (12.08 m²), Burseraceae (9.61 m²), Arecaceae (7.39 m²), Lecythidaceae (6.63 m²), and Malvaceae (6.47 m²), and the families with a basal area of 0.01 m² were Capparaceae, Combretaceae, Ehretiaceae, Memecylaceae, Opiliaceae, Picramniaceae, Quiinaceae, Rhizophoraceae, and Verbenaceae.

The families with 20 or more genera were Fabaceae (31), Malvaceae (26), and Sapotaceae (20), and the families with only one genus were Boraginaceae, Calophyllaceae, Capparaceae, Caricaceae, Combretaceae, Dichapetalaceae, Ehretiaceae, Elaeocarpaceae, Memecylaceae, Ochnaceae, Opiliaceae, Picramniaceae, Quiinaceae, Rhizophoraceae, Staphyleaceae, and Verbenaceae. The families with 20 or more species were Fabaceae (57), Malvaceae (37), Sapotaceae (28), Moraceae (23), Lauraceae (22), Euphorbiaceae (21), and Annonaceae (20), and the families with only one species were Calophyllaceae, Capparaceae, Caricaceae, Combretaceae, Ehretiaceae, Memecylaceae, Ochnaceae, Opiliaceae, Quiinaceae, Rhizophoraceae, Staphyleaceae, and Verbenaceae. The maximum Fisher's α was found for the families Araliaceae, Boraginaceae, Capparaceae, Combretaceae, Dichapetalaceae, Ehretiaceae, Memecylaceae, Ochnaceae, Oleaceae, Opiliaceae, Picramniaceae, Quiinaceae,

and Rhizophoraceae, and the families with a Fisher's α less than one were Calophyllaceae and Caricaceae.

The (common) species with at least 15 stems sampled in the plots were in the families Arecaceae (*Astrocaryum murumuru*, *Iriartea deltoidea*, *Lepidocaryum tenue*, *Oenocarpus bataua*, *Socratea exorrhiza*), Fabaceae (*Crudia glaberrima*, *Inga oerstediana*, *Inga spectabilis*, *Macrolobium augustifolium*), Clusaceae (*Caraipa tereticaulis*), and Malvaceae (*Matisia malacocalyx*, *Pachira brevipes*), and may have significantly contributed to the contribution of these four families to the structure of the plots. All the genera with more than one species had either two species (*Astrocaryum*, *Matisia*, *Caraipa*, *Macrolobium*, *Pseudolmedia* and *Otoba*) or three species (*Inga*). The only PPMCC over 90% were between number of stems and basal area (PPMCC = +0.9010) and between number of genera and number of species (PPMCC = +0.9559).

4. Discussion

Three of the four most common families (Arecaceae, Fabaceae, Malvaceae) had the highest basal area, but none of the most common families had the biggest stems or the largest Fishers α , and only Fabaceae and Malvaceae had the most genera and the most species. Among the rare families, Staphyleaceae had the largest stem size and many of the rare families had a large Fisher α . Among the six structural parameters, Fabaceae and Malvaceae were among the families that had the largest values in four of them, and Arecaceae and Sapotaceae were among the families that had the largest values in just two of them. All other families had the largest values in at most one of the structural parameters. Among the genera with more than one species, only *Inga* was common in other Amazon samplings [12,13,36–38]. When we combined families that had large basal areas (which has been used as a key to structural dominance elsewhere [39]) with these familial results, the families Fabaceae and Malvaceae were implicated as most important in structuring common Amazon forests, but Arecaceae and Sapotaceae may also be important. Therefore, conservationists and managers may want to focus on the preservation and propagation of tree species in these families in order to best maintain the structure (which enables function) of common Amazon forests. The families found here were also found in past Amazon tree surveys [12–15] and in past Amazon palm forest surveys [39–41], and are commonly found throughout the rest of the Neotropics as well [9,25]. Correlation analysis showed that as the number of stems increases (or decreases), basal area increases (or decreases), and that as number of genera increases (or decreases), the number of species increases (or decreases), which suggests causality between them as they structure Amazon forests. The lack of correlation between Fisher's α and any of the structural parameters, however, casted doubt on the necessity or meaning of computing Fisher's α [42] as a way to investigate structure.

Previous examinations of the five plots showed the common Amazon forest types had these three most common families: in *terra firme* Malvaceae, Fabaceae and Myristicaceae (49 families total), in palm Arecaceae, Clusiaceae, and Fabaceae (6), in white sand Clusiaceae, Malvaceae, and Myrtaceae (15), in várzea Cecropiaceae, Fabaceae and Meliaceae (41) and in igapó, Fabaceae, Moraceae and Sapotaceae (16), and that palm forests were dominated by just a few species [8,29–35]. Any common families and species between *terra firme* and várzea and between *terra firme* and igapó may be due, in part, to *terra firme* tree species establishing ecotypes in flooded forests [43] where the regularity of the flood pulse facilitates adaptation and speciation [29]. Additionally, in those previous examinations, all the forest types except white sand had these unique families: in *terra firme* Cappariaceae, Caricaceae, Malpighiaceae, Memecyle, Quiinaceae, Staphyleaceae, Malvaceae, Urticaceae and Verbenaceae, in palm Humiriaceae, in várzea Bixaceae, Ebenaceae, Ochnaceae, Opiliaceae, Pichramnaceae, and Vochysiaceae, and in igapó Salicaceae. These familial differences among forest types may be due, in part, to the unflooded forest types (*terra firme*, palm, white sand) having soil differences (which can explain up to 50% of floristic differences [44]) and different micro-topological relief, and to the flooded forest types (várzea, igapó) having different

water characteristics such as sediment load and ion concentrations, and differences in both maximum depth and duration of flooding.

In other plots across the Amazon, *terra firme* stems smaller than 10 cm dbh were sampled in the families Bombacaceae, Arecaceae, Lecythidaceae, Fabaceae, Violaceae, and Melastomataceae [17,45], palm stems were 12–31% of monocot species with Arecaceae, Clusiaceae, Fabaceae, Lecythidaceae, and Humiriaceae the most common families [46], white sand stems were sampled in the families Leguminosae, Clusiaceae, Malvaceae, Euphorbiaceae and Icacinaceae [46], várzea stems were sampled in the families Myrtaceae, Fabaceae, Euphorbiaceae, Arecaceae, Lecythidaceae, Rubiaceae, Moraceae [46,47], and igapó stems were sampled in the families Leguminosae, Annonaceae, Arecaceae, Moraceae, Sapotaceae, Euphorbiaceae, Lecythidaceae [46]. Permanent black-water swamp stems were sampled in the families Arecaceae, Euphorbiaceae, and Fabaceae [46,48,49]. Secondary várzea (i.e., after disturbance) stems were sampled in the families Fabaceae and Euphorbiaceae [48] with species found in both várzea and igapó in the families Euphorbiaceae, Sapota, Clusiaceae, Mimosa, and Fabaceae [50].

5. Conclusions

Two of the four common families Fabaceae and Malvaceae dominated the structural parameters of number of stems, basal area, number of genera and number of species, but not stem size or Fishers α . Another common family Arecaceae and the family Sapotaceae were also implicated in affecting structure. In addition, families in the plots were commonly found in other Amazon samplings, but few genera were in common. While there were large correlations between the number of stems and basal area and between the number of genera and number of species, which suggested that there was a causal relationship between these parameters as they structure these forests at the familial level, correlation results casted doubt on the necessity and meaning of computing Fisher's α as a way to investigate structure. Finally, more sampling is needed to make these conclusions more robust for these Amazon forest types.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data analyzed in this study are available at: www.luq.lternet.edu.

Acknowledgments: Acknowledgements for the original samplings are found in those papers.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Srivastava, D.S.; Vellend, M. Biodiversity-ecosystem function research: Is It Relevant to Conservation? *Annu. Rev. Ecol. Evol. Syst.* **2005**, *36*, 267–294. [CrossRef]
2. Naeem, S. Ecosystem consequences of biodiversity loss: The evolution of a paradigm. *Ecology* **2002**, *83*, 1537–1552. [CrossRef]
3. Schulze, E.D.; Mooney, H.A. *Biodiversity and Ecosystem Function*; Springer: Berlin/Heidelberg, Germany, 1993.
4. Stubbendieck, J.; Friisoe, G.Y.; Bolick, M.R. *Weeds of Nebraska and the Great Plains*; Nebraska Department of Agriculture, Bureau of Plant Industry: Lincoln, NE, USA, 1994.
5. Myer, R.W. Are productivity and richness related consistently after different crops in the Neotropics? *Botany* **2009**, *87*, 357–362. [CrossRef]
6. Loreau, M.; De Mazancourt, C. Biodiversity and ecosystem stability: A synthesis of underlying mechanisms. *Ecol. Lett.* **2013**, *16*, 106–115. [CrossRef]
7. Daily, G. Introduction: What are ecosystem services? In *Nature's Services: Societal Dependence on Natural Ecosystems*; Mooney, H., Ed.; Academia Press: Cambridge, MA, USA, 1997; pp. 1–10.
8. Myer, R.W. *Forest Structure, Function and Dynamics in Western Amazonia*; Wiley-Blackwell: Oxford, UK, 2016.
9. Antonelli, A.; Zizka, A.; Carvalho, F.A.; Condamine, F.L. Amazonia is the primary source of Neotropical biodiversity. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 6034–6039. [CrossRef]
10. Sakschewski, B.; von Bloh, W.; Boit, A.; Poorter, L.; Pena-Claros, M.; Heinke, J.; Joshi, J.; Thonicke, K. Resilience of Amazon forests emerges from plant trait diversity. *Nat. Clim. Chang.* **2016**, *6*, 1032–1036. [CrossRef]

11. Fearnside, P.M. The intrinsic value of Amazon biodiversity. *Biodivers. Conserv.* **2021**, *30*, 1199–1202. [[CrossRef](#)]
12. Cardoso, D.; Sarkinen, T.; Alexander, S.; Amorim, A.M.; Bittrich, V.; Celis, M.; Daly, D.C.; Fiaschi, P.; Funk, V.A.; Giacomini, L.L.; et al. Amazon plant diversity revealed by a taxonomically verified species list. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 10695–10700. [[CrossRef](#)]
13. ter Steege, H.; Pitman, N.C.A.; Sabatier, D.; Baraloto, C.; Salomão, R.P.; Guevara, J.E.; Phillips, O.L.; Castilho, C.V.; Magnusson, W.E.; Molino, J.; et al. Hyperdominance in the Amazonian tree flora. *Science* **2013**, *342*, 1243092. [[CrossRef](#)]
14. ter Steege, H.; Vaessen, R.W.; Cardenas-Lopez, D.; Sabatier, D.; Antonelli, A.; de Oliveira, S.M.; Pitman, N.C.A.; Jorgensen, P.M.; Salomao, R.P. The discovery of the Amazonian tree flora with an updated checklist of all known tree taxa. *Sci. Rep.* **2016**, *6*, 29549. [[CrossRef](#)] [[PubMed](#)]
15. Gentry, A. Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Annu. Mo. Bot. Gard.* **1988**, *75*, 1–34. [[CrossRef](#)]
16. Luize, B.G.; Venticini, E.M.; Silva, T.S.F.; Novo, E.M.L. A floristic survey of angiosperm species occurring at three landscapes of the Central Amazon várzea, Brazil. *Check List* **2015**, *11*, 1789. [[CrossRef](#)]
17. Duivenvoorden, J.F.; Balslev, H.; Caveillier, J.; Grandez, C.; Tuomisto, H.; Valencia, R. *Evaluacion de Recursos Vegetales no Maderables en la Amazonia Noroccidental*; Institute for Biodiversity and Ecosystem Dynamics, Universiteit van Amsterdam: Amsterdam, The Netherlands, 2001.
18. Tuomisto, H.; Ruokolainen, K.; Yli-Halla, M. Dispersal, environment, and floristic variation of western Amazonian forests. *Science* **2003**, *299*, 241–244. [[CrossRef](#)]
19. Gottdenker, N.; Bodmer, R.E. Reproduction and productivity of white-lipped and collared peccaries in the Peruvian Amazon. *J. Zool.* **1998**, *245*, 423–430. [[CrossRef](#)]
20. Daly, D.G.; Prance, G.T. Brazilian Amazon. In *Floristic Inventory of Tropical Countries*; Campbell, D.G., Hammond, H.D., Eds.; New York Botanical Garden: Bronx, NY, USA, 1989; pp. 401–426.
21. Moreau, C.S. Unraveling the evolutionary history of the hyperdiverse ant genus *Pheidole* (hymenoptera: Formicidae). *Molecular Physiol. Evol.* **2008**, *48*, 224–239. [[CrossRef](#)]
22. Choo, J.P.S.; Martinez, R.V.; Stiles, E.W. Diversity and abundance of plants with flowers and fruits from October 2001 to September 2002 in Paucarillo reserve, Northeastern Amazon, Peru. *Revisita Peru Biol.* **2007**, *14*, 25–31. [[CrossRef](#)]
23. Chase, M.W.; Christenhusz, M.J.M.; Fay, M.F.; Byng, J.W.; Judd, W.S.; Soltis, D.E.; Mabberley, D.J.; Sennikov, A.N.; Soltis, P.S.; Stevens, P.F. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Bot. J. Linn. Soc.* **2016**, *181*, 1–20.
24. Romoleroux, K.; Foster, R.; Valencia, R.; Condit, R.; Balslev, H.; Losos, E. Especies lenosas (dap \geq 1 cm) encontradas en dos hectareas de un bosque de la Amazonia ecuatoriana. In *Estudios Sobre Diversidad y Ecología de Plantas*; Valencia, R., Balslev, H., Eds.; Pontificia Universidad Católica del Ecuador: Quito, Ecuador, 1997; pp. 189–215.
25. Gentry, A. *A Field Guide to Woody Plants of Northwest South America (Colombia, Ecuador, Peru)*; Conservation International: Washington, DC, USA, 1993.
26. Fisher, R.A.; Corbet, A.S.; Williams, C.B. The relation between the number of species and the number of individuals in a random sample of an animal population. *J. Anim. Ecol.* **1943**, *12*, 42–58. [[CrossRef](#)]
27. SAS. *User's Guide: Statistics, Version 5*; SAS Institute Inc.: Cary, NC, USA, 1985.
28. Myster, R.W.; Thomlinson, J.R.; Larsen, M.C. Predicting landslide vegetation in patches on landscape gradients in Puerto Rico. *Landsc. Ecol.* **1997**, *12*, 299–307. [[CrossRef](#)]
29. Myster, R.W. Varzea forest vs. terra firme forest floristics and physical structure in the Ecuadorean Amazon. *Ecotropica* **2015**, *20*, 35–44.
30. Myster, R.W. Black-water forests (igapo) vs. white-water forests (varzea) in the Amazon: Floristics and physical structure. *Biologist (Lima)* **2016**, *13*, 391–406.
31. Myster, R.W. The physical structure of forests in the Amazon basin: A review. *Bot. Rev.* **2016**, *82*, 407–427. [[CrossRef](#)]
32. Myster, R.W. What we know about the composition and structure of Igapo forests in the Amazon basin. *Bot. Rev.* **2018**, *84*, 394–410. [[CrossRef](#)]
33. Myster, R.W. *Igapó (Black-Water Flooded Forests) in the Amazon Basin*; Springer: Berlin/Heidelberg, Germany, 2018.
34. Myster, R.W. Effects of soil type on floristics and stand structure in Amazon unflooded forests. *J. Plant Stud.* **2018**, *7*, 20–28. [[CrossRef](#)]
35. Myster, R.W. Primary and Secondary Igapó Forests in the Peruvian Amazon: Floristics, Physical Structure and the Predictive Value of Soil Bulk Density. *J. Plant Stud.* **2019**, *8*, 20–29. [[CrossRef](#)]
36. Hopkins, M.J.G. Flora da Reserva Ducke, Amazonas, Brasil. *Rodriguésia* **2005**, *56*, 9–25. [[CrossRef](#)]
37. Valencia, R.; Balslev, H.; Paz, G.; Miño, C. High tree alpha-diversity in Amazonian Ecuador. *Biodivers. Conserv.* **1994**, *3*, 21–28. [[CrossRef](#)]
38. ter Steege, H.; Pitman, N.C.A.; Phillips, O.L.; Chave, J.; Sabatier, D.; Duque, A.; Molino, J.; Prévost, M.; Spichiger, R.; Castellanos, H.; et al. Continental-scale patterns of canopy tree composition and function across Amazonia. *Nature* **2006**, *443*, 444–447. [[CrossRef](#)]
39. Prickett, R.M.; Honorio, E.N.; Baba, Y.; Baden, H.M.; Alvez, C.M.; Quesada, C.A. Floristic inventory of one hectare of palm-dominated creek forest in Jenaro Herrera, Peru. *Edinb. J. Bot.* **2012**, *69*, 259–280. [[CrossRef](#)]

40. Cintra, R.; de Carvalho, A.; Fábio, X.; Gondim, R.; Kropf, M.S. Forest spatial heterogeneity and palm richness, abundance and community composition in *terra firme* forest, Central Amazon. *Braz. J. Bot.* **2005**, *28*, 75–84. [[CrossRef](#)]
41. Goodman, R.C.; Phillips, O.L.; Del Castillo, M.; Torres, D.; Freitas, L.; Cortese, S.T.; Monteagudo, A.; Baker, T.R. Amazon palm biomass and allometry. *For. Ecol. Manag.* **2013**, *310*, 994–1004. [[CrossRef](#)]
42. Stropp, J.; ter Steege, H.; Malhi, Y. Disentangling regional and local tree diversity in the Amazon. *Ecography* **2009**, *32*, 46–54. [[CrossRef](#)]
43. Wittmann, F.; Junk, W.J.; Oiedade, T.F. The varzea forests in Amazonia: Flooding and the highly dynamic geomorphology interactions with natural forest succession. *For. Ecol. Manag.* **2004**, *196*, 199–212. [[CrossRef](#)]
44. Ruokolainen, K.; Tuomisto, H.; Macia, M.J.; Higgins, M.A.; Yli-Halla, M. Are floristic and edaphic patterns in Amazonian rain forest congruent for trees, pteridophytes and Melastomataceae? *J. Trop. Ecol.* **2007**, *23*, 13–25. [[CrossRef](#)]
45. Leimbeck, R.M.; Balslev, H. Species richness and abundance of epiphtic Araceae on adjacent floodplain and upland forest in Amazonia Ecuador. *Biodivers. Conserv.* **2001**, *10*, 1579–1593. [[CrossRef](#)]
46. Honorio, E.N. Floristic Relationships of the Tree Flora of Jenaro Herrera, an Unusual Area of the Peruvian Amazon. Master's Thesis, University of Edinburgh, Edinburgh, UK, 2006.
47. Godoy, J.R.; Petts, G.; Salo, J. Riparian flooded forests of the Orinoco and Amazon basins: A comparative review. *Biodivers. Conserv.* **1999**, *8*, 551–586. [[CrossRef](#)]
48. Duivenvoorden, J.F.; Lips, J.M. *A Land-Ecological Study of Soils, Vegetation, and Plant Diversity in Colombian Amazonia*; The Tropenbos Foundation: Wageningen, The Netherlands, 1995.
49. Ferreira, L.V. Effects of flooding duration on species richness floristic composition and forest structure in river margin habitat in Amazonian black water floodplain forests: Implications for future design of protected areas. *Biodivers. Conserv.* **2000**, *9*, 1–14. [[CrossRef](#)]
50. Amaral, I.L.D.; Adis, J.; Prance, G.T. On the vegetation of a seasonal mixed water inundation forest near Manaus, Brazilian Amazonia. *Amazoniana* **1997**, *14*, 335–347.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.