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Global and regional tree species diversity

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Abstract

Aims
Understanding tree species richness at a global scale and the origin and maintenance of patterns of tree species richness across the world is crucial to preserving tree species diversity. The recently published global tree database (i.e. GlobalTreeSearch) is the only source with tree lists at both global and national scales. However, our review and assessment show that many species included in GlobalTreeSearch are not tree species. In addition, several thousands of tree species in the botanical literature have not been included in GlobalTreeSearch. The exact number of tree species in the world remains unknown. This study aims to correct errors with GlobalTreeSearch and to estimate the number of tree species in the world based on a large number of regional floras.

Methods
We standardized nomenclature and spellings of the species names according to The Plant List. We used 62 floristic sources, along with plant growth form and height, to assess the GlobalTreeSearch species checklist and to determine the degree to which GlobalTreeSearch incorrectly treated non-tree species as tree species.

Important Findings
Based on our review on 60.8% of the species in the GlobalTreeSearch database and the number of additional tree species that we have found from 62 continental, national, regional and local floristic sources, we found that about 8.7% of the species included in GlobalTreeSearch are not tree species (they are herbs, shrubs or vines). We estimate that there would be about 61 000 tree species (including approximately 5500 species that are primarily shrubs but occasionally trees) in the world.

Keywords: GlobalTreeSearch, global tree species richness, plant checklist, national tree lists.

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INTRODUCTION

Trees are major components of forests, which are among the most important repositories of terrestrial biodiversity. Trees play an important role in supporting diversity of other groups of organisms (Aerts 2011). Tree species have been used as a model system to explore and understand patterns of species richness variation across broad geographical scales (Currie and Paquin 1987; Latham and Ricklefs 1993a, 1993b; Wang *et al.* 2009), correlations between species richness and environment (Austin *et al.* 1996; Currie and Paquin 1987) and the effect of evolutionary history on community assembly (Qian *et al.* 2013). Despite the importance of trees and the great effort that has been made by botanists across the world in documenting tree species compositions at national and regional scales, we still don't know how many tree species there are in the world. Understanding tree species richness at a global scale and the origin and maintenance of patterns of tree species richness across the world is crucial not only to preserving tree species diversity *per se* but also to understanding patterns of species richness of many other groups of organisms that depend on trees.

In the past two decades, botanists have estimated tree species richness at global and 'semi-global' scales. At a global scale, estimates of the number of tree species vary substantially, ranging from 45 000 to 100 000 (Fine and Ree 2006; Oldfield *et al.* 1998; Savolainen 2000; Tudge 2006). At a semi-global scale, Slik *et al.* (2015) estimated there are 40 000–53 000 tree species in the tropics, while Hunt (1996) estimated there are 21 000 tree species in temperate regions. However, as Beech *et al.* (2017) pointed out, none of these estimates were derived based on an authoritative global list of trees.

Beech *et al.* (2017) have made a great effort in producing complete tree species lists for the globe as well as for each of the countries in the world. Their global tree database, called 'GlobalTreeSearch' (hereafter, GTS), has been recently published (Beech *et al.* 2017; also see http://www.bgci.org/globaltree_search.php). In GTS, a woody plant of ≥2 m tall or ≥5 cm in diameter at breast height (DBH) is defined as a tree. Specifically, they used the following tree definition to build the GTS database: 'a woody plant with usually a single stem growing to a height of at least two metres, or if multi-stemmed, then at least one vertical stem five centimetres in diameter at breast height.'

However, Beach *et al.*'s definition for trees differs substantially from commonly used definitions of trees. For example, essentially following Little (1979), Grandtner (2005) defines a tree as follows: 'A tree is defined as a woody plant, with a single, erect and persistent stem of at least 10 cm in diameter, measured at 1.3 m above the mean ground level, and with a total height of at least 5 m.' Similarly, Elias (1980) define trees and differentiate them from shrubs as follows: 'Trees are woody plants that usually grow at least 5m (16 ft) tall and have a single trunk. A shrub, by contrast, is typically a multiple-stemmed woody plant with more than one dominant stem, and shrubs are normally less than 5 m (16 ft) tall.' Woody plants of <5 m tall or <10 cm DBH at maturity are commonly not considered as trees (e.g. Elias 1980; Grandtner 2005; Little 1971–1978; Montoya *et al.* 2007; Slik *et al.* 2015). Because many woody plants of 2–5 m tall at maturity are typically shrubs, it is our concern that many non-tree species would have been included in GTS as tree species. If GTS indeed has included many shrub species and other non-tree species, results from any analyses using national or regional species lists derived from GTS would not be comparable with those using tree species defined appropriately. In particular, because trees and non-tree plants may function very differently (Ricklefs and Latham 1992), including their responses to environment (Wang *et al.* 2011), taking non-tree species as tree species in ecological and biogeographical analyses might substantially bias the conclusions of the analyses that are specifically for trees.

Our preliminary observation of some families in GTS that we are familiar with indeed has confirmed our concern. Our preliminary observation showed that GTS includes many non-tree species, including shrubs, lianas (woody vines) and herbs, some of which are less than 2 m tall. For example, *Rauvolfia tetraphylla* L. and *Medicago arborea* L., both of which can reach 2 m or taller, are typical shrub species (Wu *et al.* 1994–2013; also see http://www.efloras.org/flora_page.aspx?flora_id=2), but they were both included in GTS as tree species. Examples for liana and herbaceous species included in GTS are *Paederia foetida* L. and *Euphorbia atoto* G. Forst, respectively (Wu *et al.* 1994–2013; also see http://www.efloras.org/flora_page.aspx?flora_id=2). By including shrubs, lianas and herbs in GTS, the database cannot be considered as a database exclusively for trees. This bias of including non-tree species in the global checklist of GTS would translate into species lists of biomes, countries and regions derived from GTS. The bias with national and regional species lists is apparently shown when comparing some data reported in Beech *et al.* (2017) with related data published in the literature. For example, the tree flora of the Nearctic biome defined in Beech *et al.* (i.e. North America north of Mexico) has been well documented in the literature (e.g. Elias 1980; Little *et al.* 1971–1978). This tree flora has less than 680 native species (e.g. 679 species in Little *et al.* 1971–1978; 652 species in Elias 1980). In contrast, Beach *et al.* (2017) reported that the number of tree species for the Nearctic biome is 1 367 (their Fig. 5). This suggests that nearly half of the species assigned to the Nearctic biome in GTS are non-tree species. Similarly, the tree flora of China has been well known: it has 3 165 tree species, according to Wang *et al.* (2011). However, Beech *et al.* (2017) reported that GTS included 4 635 species for China (their Fig. 3), suggesting that GTS considered about 1 500 non-tree species as tree species for China. Furthermore, we noticed that many tree species known to science have not been included in the GTS database, and some tree known to occur in a particular country have not been included in GTS for the country (see below for examples). We predict that GTS will be broadly used in various research projects in future. We feel that there is an urgent need to independently review and evaluate the data with GTS before it is broadly used.

In this study, we checked the majority of the species included in GTS against over 60 continental, national, regional and local floras with well-documented information for plant growth form to assess the degree to which the global and national tree species lists derived from GTS might be biased. Based on our analysis of the GTS data and additional data, we offer a robust estimate for the number of tree species in the world.

MATERIALS AND METHODS

We downloaded the world species checklist of GlobalTreeSearch (i.e. global_tree_search_trees.csv) from http://www.bgci.org/global_tree_search.php on 16 April 2017. The checklist contained 60 451 species names. We standardized nomenclature and spellings of the species names according to The Plant List (version 1.1, http://www.theplantlist.org/).

We used 61 continental, national, regional or local plant checklists (see online Appendix S1) to evaluate the global species checklist of GTS. We standardized nomenclature and spellings of the species names according to The Plant List. Names of taxa below the species level (e.g. subspecies, variety) were lumped with binomial species-level names. All individuals of the species included in Yamada (1975), Hamann *et al.* (1999), Aiba *et al.* (2002), Culmsee and Pitopang (2009) and Culmsee *et al.* (2011) are 10 cm DBH or larger, which are commonly considered as trees (Slik *et al.* 2015); thus, we treated all species in these floristic sources as trees. Species included in Gentry forest plots (Phillips and Miller 2002) were classified as trees if an erect individual in any of the forest plots was 10 cm DBH or larger, as in Qian *et al.* (2017). The remaining floristic sources included information of plant growth form. These floristic sources have broadly covered Africa, Asia and North and South Americas. Australia, which was not included in the 60 floristic sources, is dominated by *Eucalyptus*. Accordingly, we manually checked each of the *Eucalyptus* species included in the GTS global species checklist on the Internet and relevant floristic books for growth form information. Finally, we linked each of the 62 floristic sources, along with plant growth form and height, to the GTS global species checklist.

For each of those species in the GTS global species checklist that appeared in any of our 62 floristic sources with growth form information, we assigned one of the following six growth forms to it, based on original descriptions on growth form in these floristic sources: (i) tree, T; (ii) primarily tree but occasionally shrub, T(S); (iii) primarily shrub but occasionally tree, S(T); (iv) shrub, S; (v) liana (woody vine), L and (vi) herb, H. For those species whose growth forms are not consistent among the 62 floristic sources, we assigned a single 'consensus growth form' to each species. Specifically, for a species where >2/3 of the floristic sources with growth form information of the species agreed on a single growth form, this growth form was assigned to the species as the consensus growth form, as in Engemann *et al.* (2016). For each of those species with <2/3 of the floristic sources agreed on a single growth form, we checked on the Internet and floristic books for detailed descriptions on growth form and plant height in order to determine an appropriate growth form for the species.

GTS provides with a search tool to generate national and regional checklists of tree species. To assess the degree to which national and regional species lists derived from GTS might be incomplete, we linked six national or regional species lists of vascular plants obtained from the literature (see online Appendix S2) to their respective species lists derived from the GTS global species checklist after standardizing plant names in these species lists according to The Plant List. The six species lists are for the floras of Ecuador, the Korean Peninsula, Japan, Mexico, Singapore and Taiwan (see online Appendix S2). We downloaded the GTS lists of the six countries or regions on 3 May 2017.

RESULTS AND DISCUSSION

The global tree flora

Of the 60 451 species names in the GTS global species checklist, 59 421 (98.3%) were found in The Plant List (www.theplantlist.org). Four hundred and sixty-five of these species names are synonyms of those that have been already included in the GTS global species checklist. For example, *Chalybea kirkbridei* (Wurdack) M. E. Morales & Penneys, *C. macrocarpa* (L. Uribe) M. E. Morales & Penneys, *C. minor* (L. Uribe) M.E. Morales & Penneys, *C. mutisiana* (L. Uribe) M.E. Morales & Penneys, *C. occidentalis* (Lozano & N. Ruiz-R.) M. E. Morales & Penneys, *C. penduliflora* (Wurdack) M. E. Morales & Penneys are homotypic synonyms of, respectively, *Huilaea kirkbridei* Wurdack, *H. macrocarpa* L. Uribe, *H. minor* (L. Uribe) Lozano & N. Ruiz, *H. mutisiana* L. Uribe, *H. occidentalis* Lozano & N. Ruiz, and *H. penduliflora* Wurdack but GTS treated them as 12 different species, rather than 6 species. Thus, GTS counted these 465 species twice. After correcting these errors and standardizing the nomenclature of the species names in the GTS global species checklist according to The Plant List, GTS contained 59 984 species.

Of the 59 984 species in the corrected and standardized version of the GTS global species checklist, 36 490 (60.8%) were found in the 62 continental, national, regional or local floristic sources with information of growth form or DBH. In other words, the 62 floristic sources included the majority of the species in GTS. Thus, it would be reasonable to consider the 36 490 species as a robust sample of the species in GTS.

We found that of the 36 490 species, 8.7% are non-tree species [0.3% are herbaceous plants (H), 7.4% are shrubs (S), 1.0% are lianas (L); see online Appendix S3 for examples of species present in GTS in these categories] and 82.2% are tree species [including categories T and T(S) in Fig. 1]. The remaining 9.1% of the species are primarily shrubs but occasionally trees [i.e. species in category S(T)], which were considered as tree species in GTS (Beech *et al.* 2017). When taking a relaxed definition for tree by considering those species in category S(T) as tree species along with species in categories T and T(S), 91.3% of the examined species are tree species. We consider the 36 490 examined species an unbiased sample of the 59 984 species in GTS; accordingly, the number of tree species in GTS for the world tree flora would be 54 765 (i.e. 59 984 multiplied by 91.3%).

We also found that 3 093 species in categories T (3 002 species) and T(S) (91 species) that were present in the 62 floristic sources and belong to the families considered in GTS were not included in the GTS global species checklist, including 251 tree species from China (Wu *et al.* 1994–2013). Examples of these missing Chinese tree species were shown in online Appendix S4. Interestingly, the tree floras of Americas by Grandtner (2005) and Grandtner and Chevrette (2014) are among the literature sources used in GTS, but 2 296 species that were included in Grandtner (2005) and Grandtner and Chevrette (2014) and belong to the families considered in GTS are absent from GTS. Considering that the 62 floristic sources that we examined covered nearly the entirety of the New World, whereas the vast majority of the Old World (particularly the palaeotropics) were not covered by the 62 floristic sources, we believe it is reasonable to estimate that GTS would have missed about 6 000 tree species in the global tree flora for the families that were considered in GTS.

GTS excluded cycads, tree ferns, Poaceae, Bromeliaceae and Musaceae from its global tree species checklist. Some plants in these groups can reach well over 20 m tall (e.g. many bamboo species such as *Dendrocalamus latiflorus* Munro,

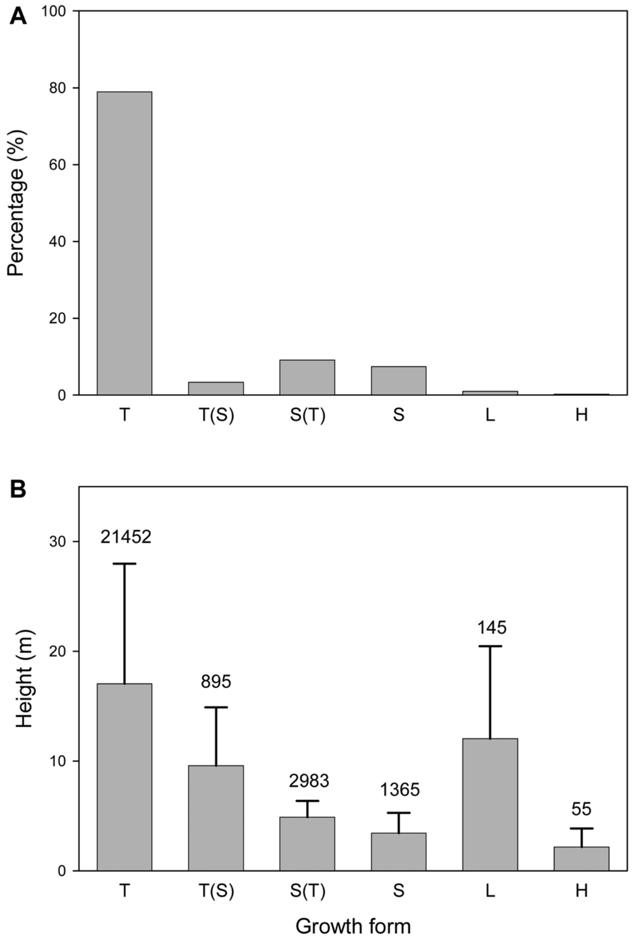

Figure 1: (A) percentages of the 36 490 species in the GTS global species checklist that were examined in this study for each of the six growth forms [tree, T; primarily tree but occasionally shrub, T(S); primarily shrub but occasionally treelet, S(T); shrub, S; liana, L; herb, H]. **(B)** Mean and SD of height of the 26 900 species in the GTS global species checklist for which height data are available in the 62 floristic sources used in this study. Value on a bar is the number of species used.

D. giganteus Munro, *D. sinicus* L.C. Chia & J.L. Sun, *D. tibeticus* Hsueh & T.P. Yi, and *D. yunnanicus* Hsueh & D.Z. Li) and are commonly considered as 'trees.' Bamboos are dominant canopy components of many forests in eastern Asia (Wu 1980). Thus, a tree species checklist without these taxonomic groups may not be considered as a complete checklist of global trees. The 62 floristic sources included about 257 tree or tree-like species in these taxonomic groups. Based on the 62 floristic sources that we examined, we estimate that there would be about 400 tree species in the taxonomic groups that have been excluded from GTS.

Approximately 26 900 species in the 62 national and regional floristic sources examined in this study that were present in the GTS global species checklist had information for plant height. On average, trees are 17.1 m tall at the global scale examined in this study (Fig. 1).

National and regional tree species checklists with GTS

We found that the incompleteness of the national and regional species lists with GTS varied greatly, based on the six examined species lists (see online Appendix S2). For example, 1 051 native species of Singapore in Chong *et al.* (2009) were included in the GTS global species checklist but GTS indicated only 683 species for this country (see online Appendix S2). For the Korean Peninsula, 251 native species in Lee (1980) were included in the GTS global species checklist, but only 197 species were assigned to the Korean Peninsula in GTS (see online Appendix S2). A total of 793 native species in Huang (1993–2003) and Wu *et al.* (1994–2013) for Taiwan were included in the GTS global species checklist, but GTS assigned 631 species to Taiwan. Thus, species lists in GTS for these countries or regions are substantially incomplete. For the remaining three countries (i.e. Ecuador, Japan and Mexico) that we examined, discrepancies in species composition between GTS and the respective literature of the countries are small (see online Appendix S2), which may be due to the availability of recently published electronic lists of plants for these countries (i.e. Ecuador, http://www.tropicos.org/Project/CE; Japan, http://www.ecography.org/appendix/ecog-00981; Mexico, http://revista.ib.unam.mx/index.php/bio/article/viewFile/1638/1296), which were used by GTS when generating species lists for these countries.

In addition to comparing the six national and regional floras between GTS and the literature, we also checked many native tree species in various national floras published in the literature against species lists derived from GTS for these countries; we found that many tree species that appeared in the published flora of each particular country are not included in the species list derived from GTS for the country. For example, *Aglaia chittagonga* Miq., *Ardisia elliptica* Thunb., *Citrus hystrix* DC. and *Lepisanthes rubiginosa* (Roxb.) Leenh., which are native species in China (Wu *et al.* 1994–2013), were included in the GTS global species checklist but were not assigned to China in GTS. Several well-known Chinese tree species [e.g. *Chamaecyparis obtusa* (Siebold & Zucc.) Endl., *Cinnamomum camphora* (L.) J. Presl, *Cryptomeria japonica* (Thunb. ex L.f.) D. Don] were included in the GTS global species checklist but were not assigned to China in GTS. Interestingly, some species (e.g. *Calophyllum inophyllum* L. and *Garcinia subelliptica* Merr.) were assigned to Taiwan, a province of China, but were not assigned to China in GTS. Similarly, *Litsea glutinosa* (Lour.) C.B. Rob., *Mesua lepidota* T.Anderson, *Pinanga johorensis* C.K. Lim & Saw and *P. singaporensis* Ridl., which were included in the GTS global species checklist and are native to Malaysia, were not assigned to Malaysia in GTS. Such cases are numerous in GTS.

Furthermore, because national and regional tree species lists with GTS were compiled on the basis of the GTS global species checklist, which incorrectly considered many non-tree species as tree species, as noted above, national and regional tree species lists derived from GTS would naturally include many non-tree species as well, which would bias any analyses for trees based on the GTS data.

It is a great challenge to compile a global database that can generate reliable tree species lists at both global and regional scales. GTS has made a key step to this end. We suggest the followings to improve the global tree database with GTS.

1. GTS would include values of maximum height and DBH of each species. These values will allow a user to generate tree species lists from GTS based on the definition of tree preferred by the user. Data on height of tree species are generally available in the botanical literature and many online plant databases.
2. GTS would include a function that allows users to provide tree species from regional floras that are absent from GTS. Height and DBH values of the tree species, if available, may be provided as well. The data provided by the users are useful to improving the global and national tree species lists with GTS.
3. According to Beech *et al.* (2017), GTS records tree distributions at the state or province level for five geographically expansive countries but such data are not available online. Furthermore, Canada and Russia, which are the two largest countries in the world, are not included in these countries. State- or province-level distributions of plant species for Canada and Russia are available in the botanical literature and electronic databases (e.g. Kartesz 1999). In addition, many other relatively large countries have well-documented state- or province-level distributions of plant species (e.g. Argentina, Chile, and Mexico; Villaseñor 2016; Zuloaga *et al.* 2008), many of which have been digitized. We suggest GTS would organize distributions of tree species according to the hierarchical system of the World Geographical Scheme for Recording Plant Distributions (TDWG; Brummitt 2001), in which large countries are divided into states, provinces or equivalent areas at the 4th level of the TDWG system and make such data available online. Because many rare and endangered species have very narrow distributional ranges, making distribution data at the state or province level available online with GTS would substantially benefit biological conservation of tree species.
4. The current version of the global tree species database with GTS does not include cycads, tree ferns, Poaceae, Bromeliaceae and Musaceae. Without including these plant groups, GTS cannot generate complete tree species lists for the globe and many countries. We suggest the next version of the GTS database would include these missing plant groups.

CONCLUSIONS

The GTS database for global tree species has a potential to become a very useful source for both scientific research and biological conservation. We applaud the developers of the GTS database for their effort and accomplishment in compiling the data. However, in the current version of the GTS database, about 8.7% of the species are non-tree species on one hand, and about 6000 tree species across the world have not been included on the other hand. Because about 40% of the species included in GTS have not been examined for their growth forms (i.e. herb, shrub, liana or tree), the exact number of tree species in the world remains unknown. However, based on the 60.8% of the species in the GTS database that we have reviewed and the number of additional tree species found in the 62 floristic sources that we have examined, we estimate that there would be about 61 000 tree species (including about 5 500 species that are primarily shrubs but occasionally trees) in the world, which we consider a robust estimate for the tree species diversity at the global scale.

The national and regional tree species lists with GTS are biased at various degrees. In some cases, the majority of tree species in a national or regional flora are not included in the GTS database for the nation or region. Thus, one should not assume that the national and regional tree species lists in the current version of the GTS database are reliable, at least in some cases. Accordingly, tree species richness data for individual countries derived from GTS may not be used in analyses that explore variation in tree species richness across the world or the relationship between tree species richness and environment because such analyses require data derived from complete or nearly complete species lists. Similarly, national tree species lists derived from GTS may not be used to explore the relationships in tree species composition among countries (e.g. species turnover or beta diversity) until the GTS database has been substantially improved.

SUPPLEMENTARY DATA

Supplementary material is available at *Journal of Plant Ecology* online.

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REFERENCES

Aerts R, Honnay O (2011) Forest restoration, biodiversity and ecosystem functioning. *BMC Ecol* **11**:29.

Aiba SI, Kitayama K, Repin R (2002) Species composition and species-area relationships of trees in nine permanent plots in altitudinal sequences on different geological substrates of Mount Kinabalu. *Sabah Parks Nat J* **5**:7–69.

Austin MP, Pausas JG, Nicholls AO (1996) Patterns of tree species richness in relation to environment in southeastern New South Wales, Australia. *Austral Ecol* **21**:154–64.

Beech E, Rivers M, Oldfield S, *et al*. (2017) GlobalTreeSearch: the first complete global database of tree species and country distributions. *J Sustain For* **36**:454–89.

Brummitt RK (2001) *World Geographical Scheme for Recording Plant Distributions*, 2 edn. Pittsburgh: Hunt Institute for Botanical Documentation, Carnegie Mellon University.

Chong KY, Tan HTW, Corlett RT (2009) A checklist of the total vascular plant flora of Singapore: native, naturalised and cultivated species. Singapore: Raffles Museum of Biodiversity Research National University of Singapore.

Culmsee H, Pitopang R (2009) Tree diversity in submontane and lower montane primary rain forests in Central Sulawesi. *Blumea* **54**:119–23.

Culmsee H, Pitopang R, Mangopo H, *et al*. (2011) Tree diversity and phytogeographical patterns of tropical high mountain rain forests in Central Sulawesi, Indonesia. *Biodivers Conserv* **20**:1103–23.

Currie DJ, Paquin V (1987) Large-scale biogeographical patterns of species richness of trees. *Nature* **329**:326–7.

Elias TS (1980) *The Complete Trees of North America. Field Guide and Natural History*. Newyork (NY): Times Mirror Magazines.

Engemann K, Sandel B, Boyle B, *et al*. (2016) A plant growth form dataset for the New World. *Ecology* **97**:3243.

Fine PV, Ree RH (2006) Evidence for a time-integrated species-area effect on the latitudinal gradient in tree diversity. *Am Nat* **168**:796–804.

Grandtner MM (2005) *Elsevier's Dictionary of Trees*. **Vol. 1**. Amsterdam, North America: Elsevier Science.

Grandtner MM, Chevrette J (2014) *Elsevier's Dictionary of Trees*. **Vol. 2**. Cambridge, MA: Academic Press.

Hamann A, Barbon EB, Curio E, *et al*. (1999) A botanical inventory of a submontane tropical rainforest on Negros Island, Philippines. *Biodivers Conserv* **8**:1017–31.

Hunt DR (1996) The genera of temperate broadleaved trees. *Broadleaves* **2**:4–5.

Huang TC (1993–2003) Flora of Taiwan, 2 edn. Editorial Committee of the Flora of Taiwan, Taipei.

Kartesz JT (1999) A synonymized checklist and atlas with biological attributes for the vascular flora of the United States, Canada, and Greenland. 1st edn. In Kartesz JT, Meacham CA (eds). *Synthesis of the North American Flora, Version 1.0*. Chapel Hill: North Carolina Botanical Garden.

Latham RE, Ricklefs RE (1993a) Continental comparisons of temperate-zone tree species diversity. In Ricklefs RE, Schluter D (eds). *Species Diversity in Ecological Communities*. Chicago: University of Chicago Press, pp. 294–314.

Latham RE, Ricklefs RE (1993b) Global patterns of tree species richness in moist forests: energy-diversity theory does not account for variation in species richness. *Oikos* **67**:325–33.

Lee TB (1980) Illustrated Flora of Korea. Hyangmunsa, Seoul, South Korea.

Little EL Jr (1971–1978) *Atlas of United States Trees*. **Vols. 1, 3, 4, and 5**. Washington (DC): U.S. Department of Agriculture Miscellaneous Publication.

Little EL Jr (1979) *Checklist of United States Trees (Native and Naturalized). Agriculture Handbook No. 541, Forest Service*, Washington: United States Department of Agriculture.

Montoya D, Rodríguez MA, Zavala MA, *et al*. (2007) Contemporary richness of holarctic trees and the historical pattern of glacial retreat. *Ecography* **30**:173–82.

Oldfield S, Lusty C, MacKinven A (1998) *The World List of Threatened Trees*. Cambridge (UK): Cambridge: World Conservation Press, UNEP-WCMC.

Phillips O, Miller JS (2002) *Global Patterns of Plant Diversity*: Alwyn H. Gentry's Forest Transect Data Set. Missouri Botanical Garden Press.

Qian H, Jin Y, Ricklefs RE (2017) Patterns of phylogenetic relatedness of angiosperm woody plants across biomes and life-history stages. *J Biogeogr* **44**:1383–92.

Qian H, Zhang Y, Zhang J, *et al*. (2013) Latitudinal gradients in phylogenetic relatedness of angiosperm trees in North America. *Global Ecol Biogeogr* **22**:1183–91.

Ricklefs RE, Latham RE (1992) Intercontinental correlation of geographic ranges suggests stasis in ecological traits of relict genera of temperate perennial herbs. *Am Nat* **139**:1305–21.

Savolainen O (2000) Developing criteria and indicators for genetically sustainable forestry. In J. Turok and T. Gerubek (eds). *International Collaboration on Forest Genetic Resources: The Role of Europe*. Proceedings of the Second EUFORGEN Steering Committee meeting. Vienna, Austria, Rome. ISBN: 978-92-9043-448-1.

Slik JWF, Arroyo-Rodríguez V, Aiba SI, *et al*. (2015) An estimate of the number of tropical tree species. *Proc Natl Acad Sci USA* **112**:7472–7.

Tudge C (2006) *The Tree: A Natural History of What Trees Are*. New York (NY): Crown Publishers.

Villaseñor JL (2016) Checklist of the native vascular plants of Mexico. *Rev Mex Biodivers* **87**:559–902.

Wang Z, Brown JH, Tang Z, *et al*. (2009) Temperature dependence, spatial scale, and tree species diversity in eastern Asia and North America. *Proc Natl Acad Sci USA* **106**:13388–92.

Wang Z, Fang J, Tang Z, *et al*. (2011) Patterns, determinants and models of woody plant diversity in China. *Proc R Soc B* **278**:2122–32.

Wu CY (1980) *The Vegetation of China*. Beijing: Science Press.

Wu CY, Raven PH, Hong DY, *et al*. (1994–2013) *Flora of China*, **Vols. 2–25**. St. Louis: Science Press, Beijing and Missouri Botanical Garden Press.

Yamada I (1975) Forest ecological studies of the montane forest of Mt. Pangrango, West Java. 1. Stratification and floristic composition of the montane rain forest near Cibodas. *J Southeast Asian Stud* **13**:402–26.

Zuloaga F, Morrone O (2008) *Catálogo De Las Plantas Vasculares Del ono Sur. Monographs in Systematic Botany 107*. St. Louis: Missouri Botanical Garden Press.