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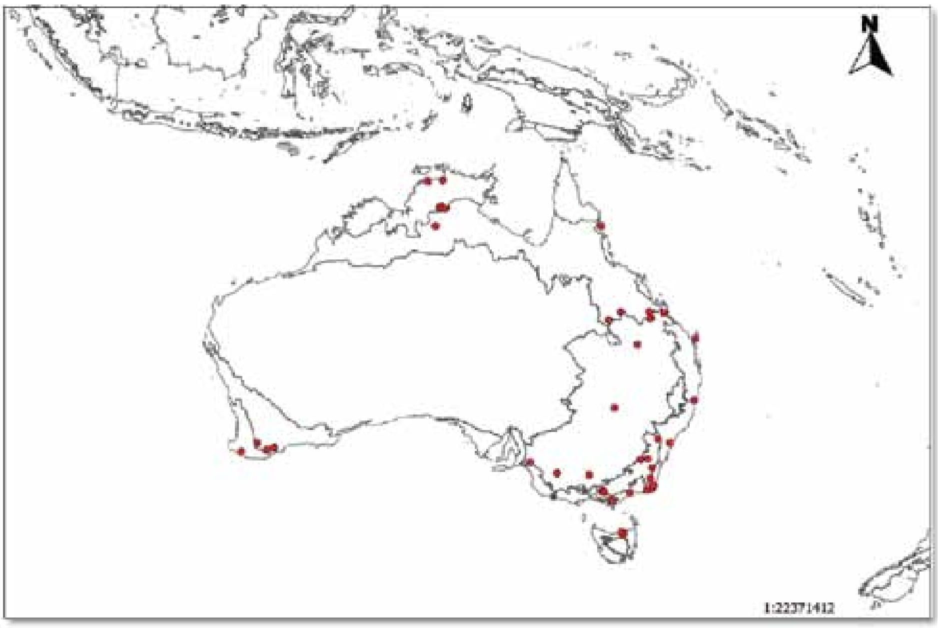

Inventory of Allometric Equations for Estimation of Above-ground tree biomass and volume in the Pacific

UN-REDD PROGRAMME

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The UN-REDD Programme, implemented by FAO, UNDP and UNEP, has two components: (i) assisting developing countries prepare and implement national REDD strategies and mechanisms; (ii) supporting the development of normative solutions and standardized approaches based on sound science for a REDD instrument linked with the UNFCCC. The programme helps empower countries to manage their REDD processes and will facilitate access to financial and technical assistance tailored to the specific needs of the countries.

The application of UNDP, UNEP and FAO rights-based and participatory approaches will also help ensure the rights of indigenous and forest-dwelling people are protected and the active involvement of local communities and relevant stakeholders and institutions in the design and implementation of REDD plans.

The programme is implemented through the UN Joint Programmes modalities, enabling rapid initiation of programme implementation and channeling of funds for REDD efforts, building on the in-country presence of UN agencies as a crucial support structure for countries. The UN-REDD Programme encourage coordinated and collaborative UN support to countries, thus maximizing efficiencies and effectiveness of the organizations' collective input, consistent with the "One UN" approach advocated by UN members.

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1. Introduction

Forest ecosystems are one of the most important carbon sinks of the terrestrial ecosystems. Forests play a critical role in the global carbon cycle as they have the potential to sequester a significant amount of carbon dioxide from the atmosphere through photosynthesis. However, forests can also act as a source of carbon dioxide when changes in forests areas occur due to deforestation and forest degradation. Therefore, it is extremely important to estimate forest carbon stocks and changes (Vashum and Jayakumar, 2012).

According to the United Nations Reducing Emissions from Deforestation and forest Degradation Programme (UN-REDD), the implementation of REDD projects can occur effectively if a “transparent, comparable, coherent, complete and accurate measurement, reporting and verification (MRV) national systems are developed and implemented”. The above-ground biomass can be estimated through field measurements, remote sensing and GIS methods (Vashum and Jayakumar, 2012). Forest biomass with field measurements can be estimated either directly with destructive method or indirectly with less destructive methods based on allometry (Cutini, A., F. Chianucci, et al. 2013).

The direct destructive method involves harvesting of the tree and measuring the weight of the different tree components (branches, leaves, trunk etc). This is the most accurate method for estimating tree biomass. Nevertheless, this method is time and resource consuming, expensive and is limited to small-scale analysis (Vashum and Jayakumar, 2012). The indirect method allows the assessment of tree biomass or volume from tree variables that are easier to measure such as diameter at breast height, height and crown diameter (Cutini, A., F. Chianucci, et al. 2013). The use of allometric equations is also necessary in order to achieve more accurate biomass estimates (Tier III) and higher financial returns due to carbon storage and reduced emissions (Aalde et al. 2003, IPCC 2006).

Scientists have developed a large number of allometric equations to estimate tree biomass, volume and carbon stocks. Allometric equations can be applied to species-specific, mixed-species, site-specific and large-scale global areas (Vashum and Jayakumar, 2012). Forest biomass differs with forest age, site class and stand density. Hence, it is important to bear in mind the suitability of the allometric model for the site, forest type, tree species and validity range (Vashum and Jayakumar, 2012). Selection of a specific allometric equation is critical as it affects the accuracy of forest biomass estimates (Cutini, A., F. Chianucci, et al. 2013). Large differences can be observed in estimates of forest biomass between different equations and therefore model-selection is another source of uncertainty that needs to be considered (Melson, S., M. Harmon, et al. 2001).

The Food and Agricultural Organization of the United Nations (FAO) in collaboration with the French Research Center Cirad and the Tuscia University of Italy have developed a new online platform – GlobAllomeTree - with the aim to inventory all the existing biomass and volume allometric equations that have been developed at the global scale. Under the UN-REDD programme, inventories of volume and biomass tree allometric equation are being undertaken by a number of countries in Africa, Asia, Europe, North and South America.

The platform offers users free and easy access to various allometric equations for different tree species, tree components, ecosystems, and ecological zones that have been published over the years. The target users of the platform are scientists interested in calculating forest biomass and carbon stock, climate change project developers and foresters. Since its launch in 2012, GlobAllomeTree has had over 70, 000 page views, has over 1600 registered users and contains over 12, 000 equations which cover all forested continents. The platform contains a database of allometric equations that is constantly updated and enriched with new equations collected from different sources of literature.

1.1 The objectives of the report

The objectives of this report are (1) to make a survey of tree allometric equations that have been developed over the years for Australia and the Pacific Islands (Melanesia, Micronesia and Polynesia), (2) to create a database for this region on the GlobAllomeTree platform and (3) compile the data in a way that could be useful for identifying future research needs and potential existing gaps. It is important to note that this report represents only a relatively small portion of allometric equations that have been developed for Australia. Hence, there is a need to update the database in the future with allometric equations found in the existing literature that cover the Pacific islands.

1.2 Database Structure

The allometric equation database for this region has been developed following the "Tutorial for tree allometric equation database development" (Baldasso, Birigazzi et al. 2012). The database is freely available on the GlobAllomeTree platform and users have the possibility to easily access and download the data. This report will provide users with descriptive statistics of the collected data.

The database was structured in the following parts:

1.2.1 Location and Ecology:

This section of the database provides users with information regarding the tree population/s used in order to develop the equation, the ecosystem where the population/s belongs to, the continent where the equation was developed, the country and the specific location with latitude and longitude coordinates given in decimal degrees.

1.2.2 Global Ecological Zones:

There are five biome classification systems in the database. Each location indicates the site where the equation was developed and was classified based on the FAO classification system (FAO, 2001), Udvardy system (Udvardy, 1975), WWF system (Olson, Dinerstein et al. 2001), Bailey system (Bailey, 1989) and Holdridge system (Holdridge, 1967).

1.2.3 Variables and vegetation components:

This part of the database contains information regarding the number and the type of the independent variables of the equation, the units of measurements, the output of the equation, the age of the population and the tree components (Fig. 1) that were considered when developing the equation.

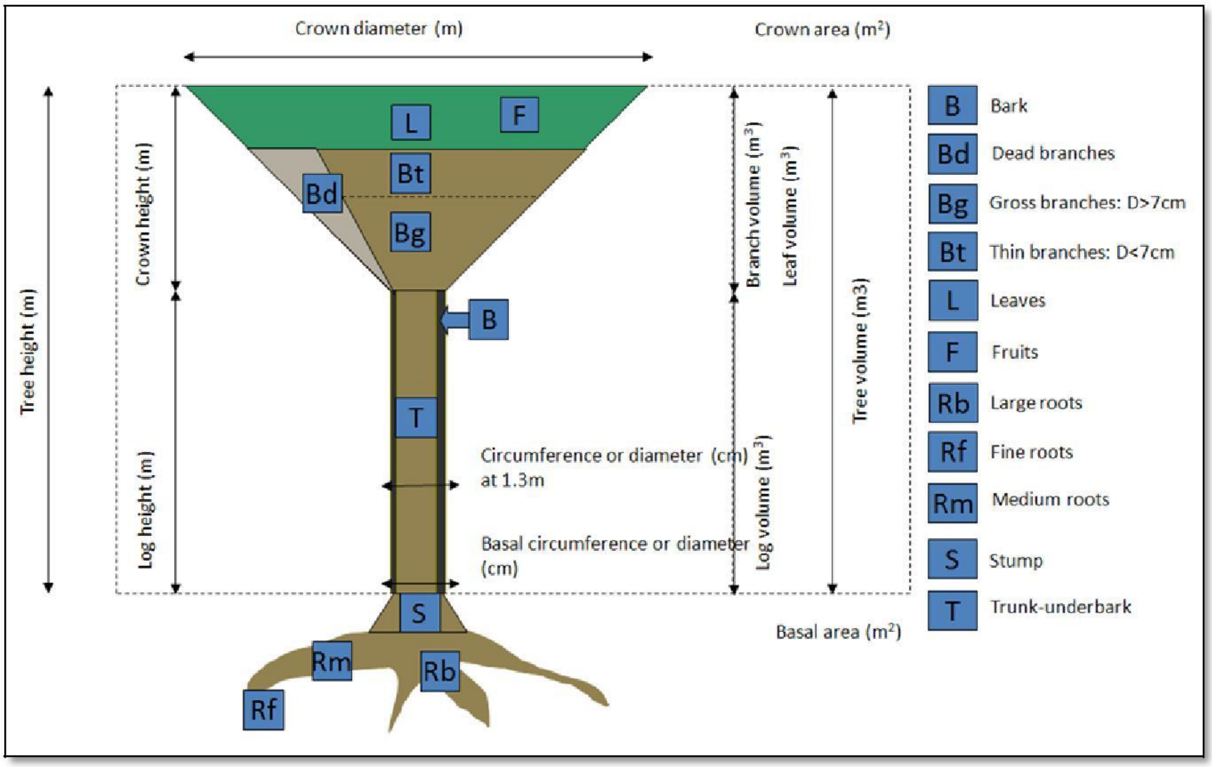


Figure 1. Representation of tree components considered in the description of allometric equations for Australia (source: Henry et al. 2011).

1.2.4 Species and Taxonomy:

This part of the database provides information on the scientific name of the tree species and the family that the species belongs to.

1.2.5 Equation and References:

The allometric equation and other information related to the development of the allometric equation such as sample size or stump height. Moreover, the reference of the document where the equation was found is also mentioned.

1.2.6 Regression statistics and contributors:

Statistical data related to the model performance such as coefficient of determination (R^2), Adjusted R^2 and Root Mean Square Error (RMSE).

2. Data collection

The data of the database was collected from 9 scientific articles. Despite the small number of articles used to create the database, a number of 511 allometric equations comprise the database for Australia. The scientific articles were classified and organized into a bibliographic reference collection. All the equations found in the scientific articles as well as the relevant information related to their application were entered into the database.

3. Data compilation and description

In total 511 allometric equations are included in the database for 139 tree and shrub species and 40 locations. The compilation of the data was carried out following the structure of the database and the results of the compilation are presented below.

3.1.1 The compilation of the location and ecology data

The data for biomass and volume allometric models were collected and georeferenced from 40 study sites (Fig. 2). Most of the equations found in the existing database cover the eastern part of Australia.

In total 124 tree species and 15 shrub species are including in the database. Most of them are *Eucalyptus* and *Acacia* species. According to the FAO ecological zone classification system, most of the sample trees and shrubs species to subtropical steppe followed by temperate mountain system, temperate oceanic forest, subtropical dry forest, tropical dry forest, tropical shrubland and subtropical humid forest and tropical rainforest (Fig 3).

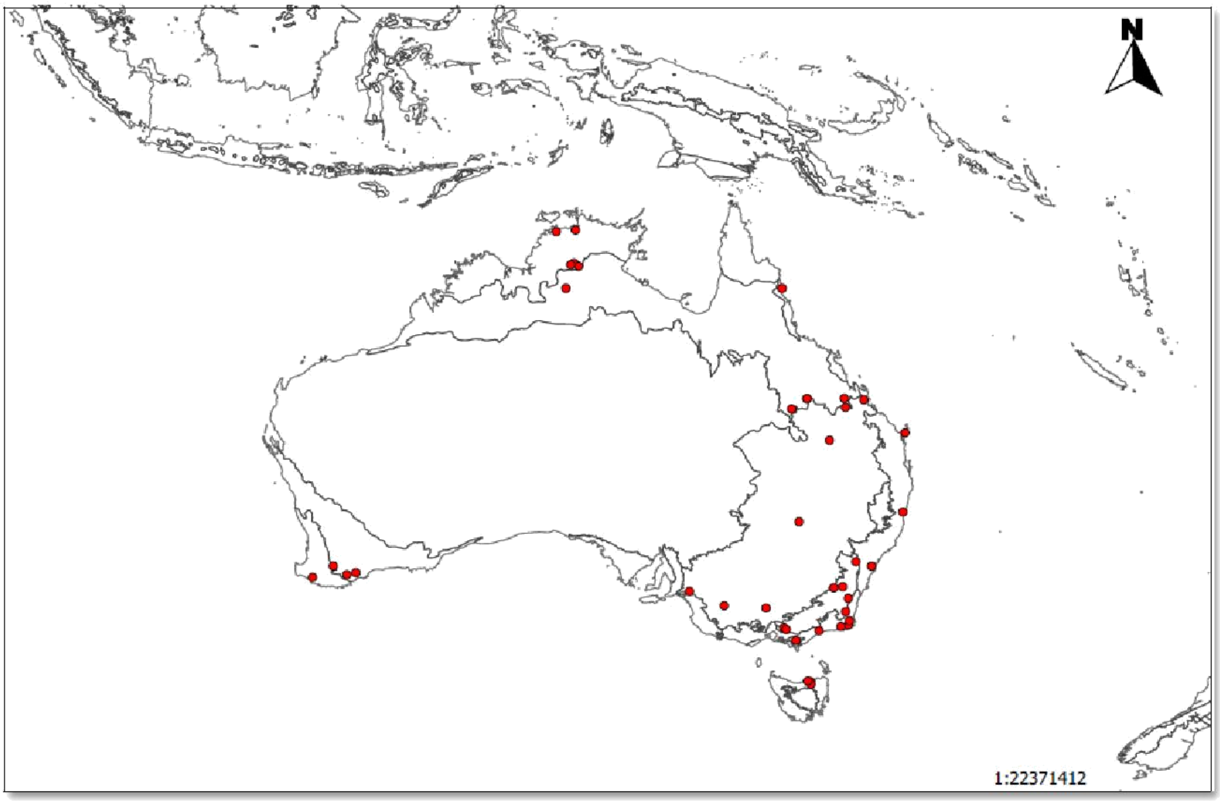


Figure 2. Geographical distribution of the study sites in Australia. The red dots indicate the locations where trees and shrubs were sampled to develop the allometric equation

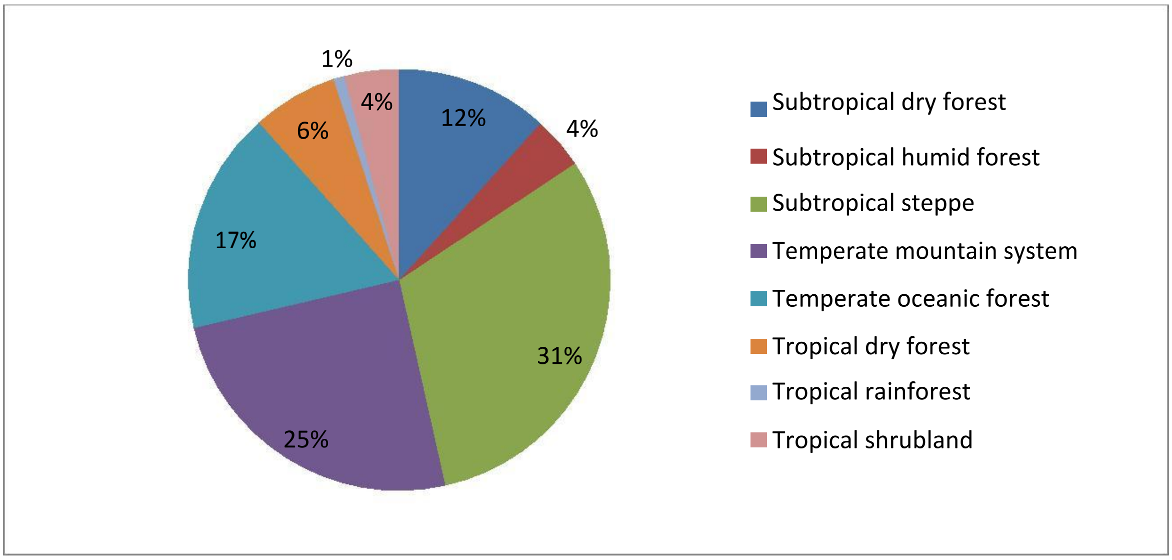


Figure 3. Number of allometric equation expressed in percentage (%) for the 8 different ecological classification zone of FAO (FAO, 2001).

3.1.2 The compilation of the Global Ecological Zones

In total the 40 study sites belong to 8 different ecological zones according to the FAO classification system (Fig. 4). More specifically the ecological zones that were classified were: subtropical dry forest (102 equations), subtropical humid forest (5 equations), subtropical steppe (269 equations), temperate mountain system (177 equations), temperate oceanic forest (149), tropical dry forest (57 equations), tropical rainforest (7 equations) and tropical shrubland (37 equations).

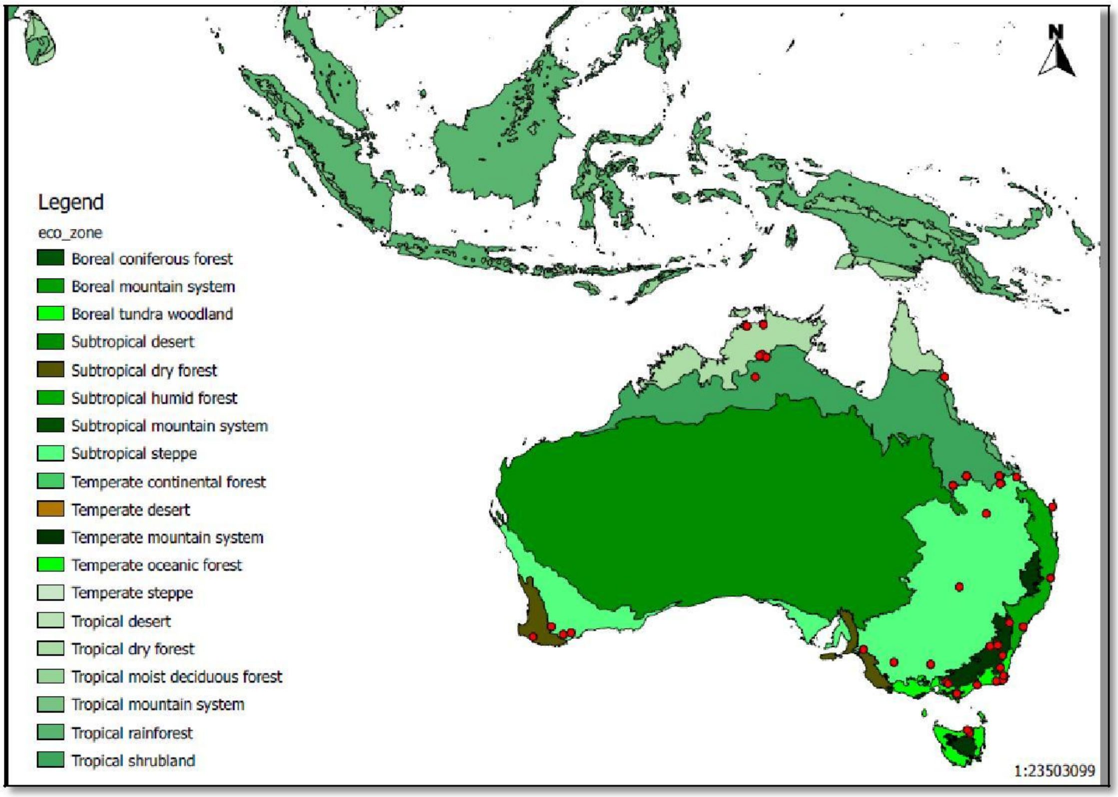


Figure 4. The geographical distribution of the study sites based on the FAO ecological zone classification (FAO, 2001).

3.1.3 The compilation of the input variables and vegetation components

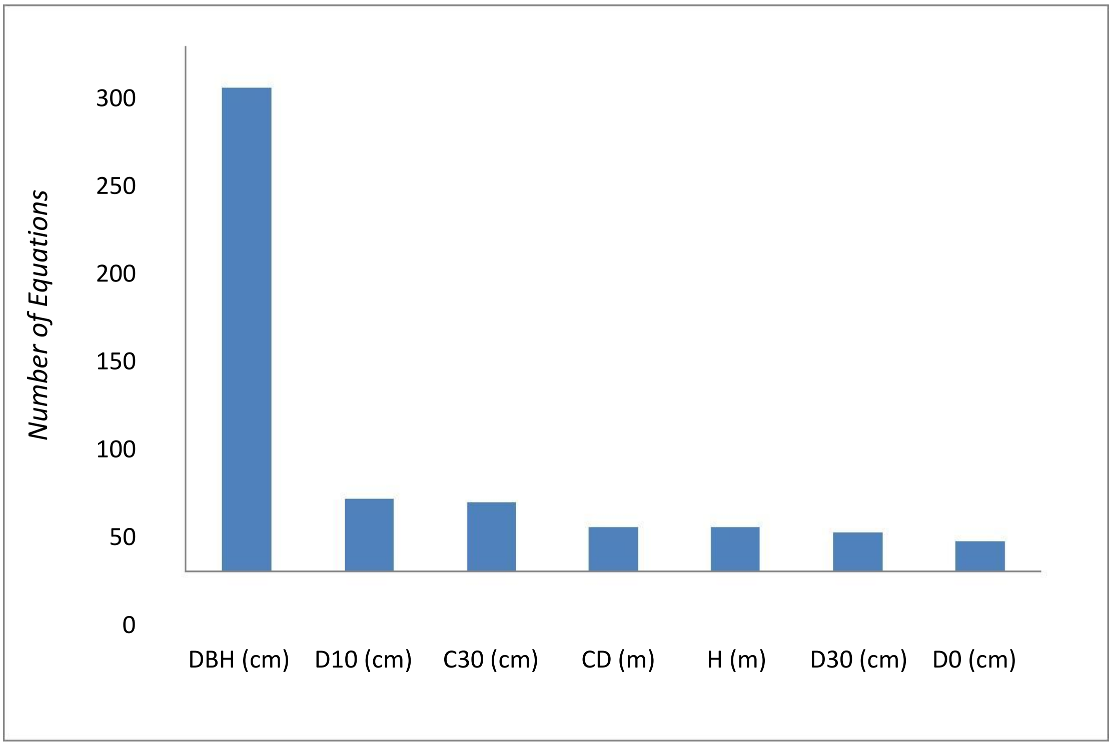
Allometric models including one independent variable

87% of the allometric models (445 equations) that were collected relate biomass to one independent variable. The following types of independent variables were observed:

- Tree circumference at 30 cm height (C30)
- Crown diameter in m (CD)
- Diameter at 0 cm (D0),
- Diameter at 10 cm (D10)
- Diameter at 30 cm (D30)
- Diameter at breast height (DBH) at 130 cm
- Tree height in m (H)

The diameter at breast height (DBH) was the most commonly used (276 equations) predictor variable for biomass estimation. DBH was followed by D10 with 41 equations, C30 with 39 equations, CD and H with 25 equations each and D0 with 17 equations (Fig. 5).

Figure 5. The number of allometric equations according to different input variables).



Allometric models including two independent variables

Out of a total of 511 equations, 66 estimated biomass as a function of two independent variables. The equations were found to relate biomass to:

- Diameter at breast height and height (DBH and H)
- Diameter at breast height and crown diameter (DBH and CD)
- Diameter at 30 cm and crown diameter (D30 and CD)

Based on the compilation of the data, it can be observed that most of the allometric models (49 equations) estimated biomass as a function of diameter at breast height and tree height followed by diameter at breast height and crown diameter (9 equations) and diameter at 30 cm and crown diameter (8 equations) (Fig. 6).

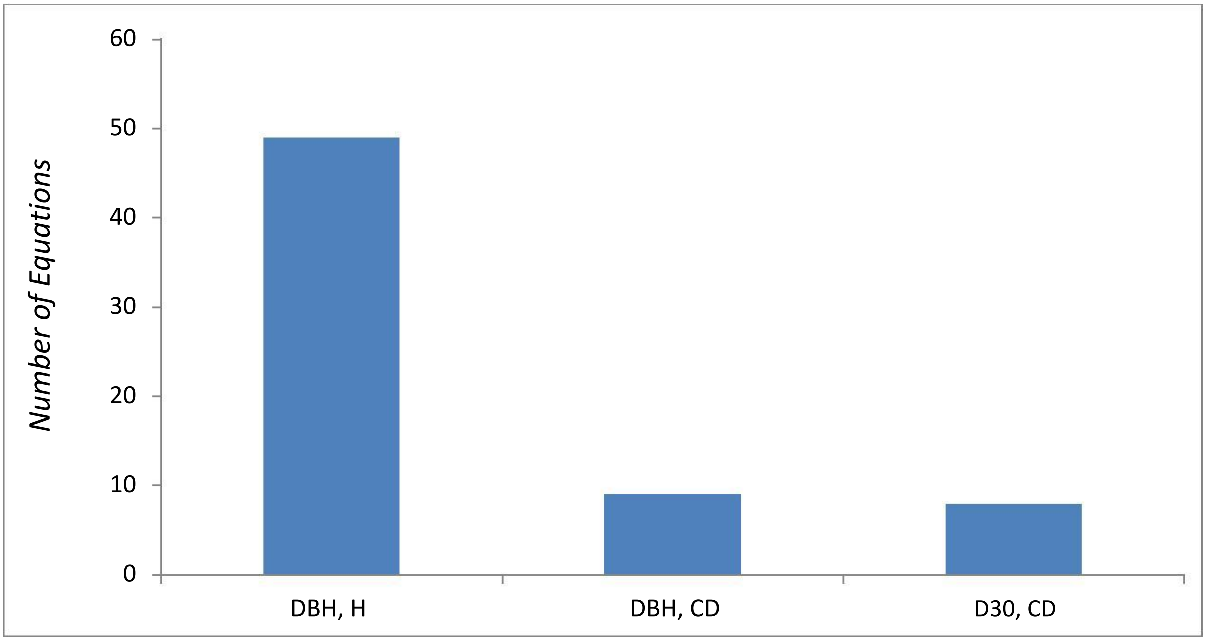


Figure 6. Number of allometric models based on the different combinations of input variables. Diameter at breast (DBH), height (H), crown diameter (CD) and diameter at 30cm (D30).

3.1.4 The output of the allometric models

Among the allometric models entered into the database, only one out of 511 equations was reported to estimate tree volume (m^3) while the rest of the equations were developed for estimates of tree biomass (kg $tree^{-1}$).

3.1.5 Tree vegetation component

The database has 213 allometric equations that predict the total above-ground biomass (kg $tree^{-1}$) of the tree. These allometric equations relate tree above-ground biomass to one explanatory variable that can be diameter at breast height, tree height, tree diameter at 0, 10, 30 cm, crown diameter and tree circumference. A lower number (67 equations) of allometric equations for estimates of the total tree biomass is also available in the database. Moreover, the database contains models for estimating the below ground biomass and for different tree components (leaf, branch, stem, lignotuber, fruit and dead wood) (Fig. 7).

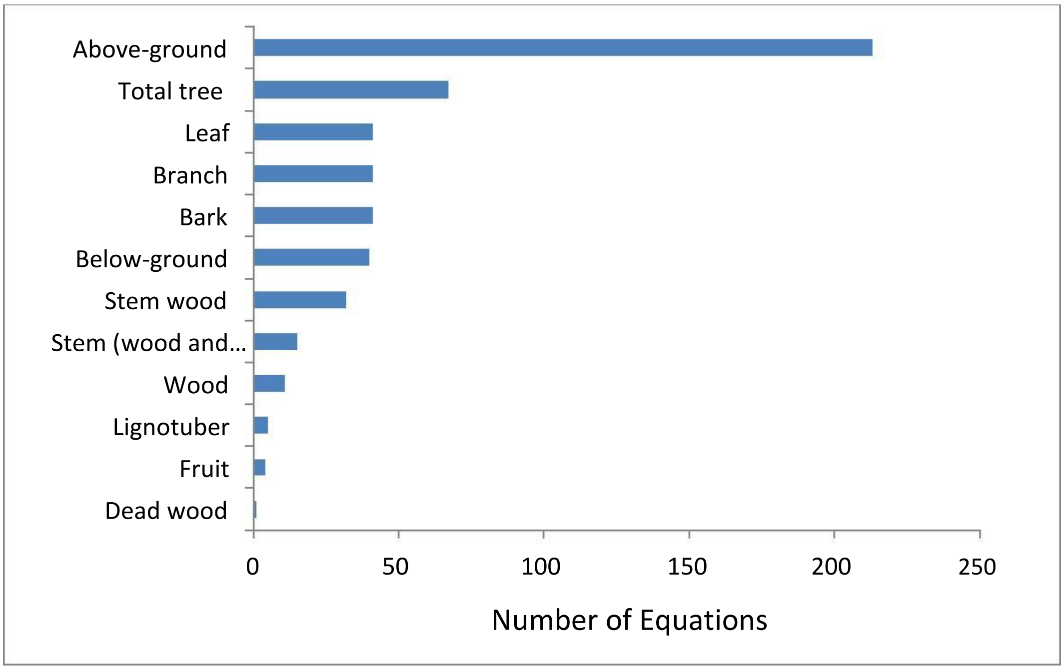


Figure 7. Number allometric equations available in the database for the different tree components

3.1.6 Compilation and description for Species and Taxonomy:

Most of the allometric models were developed for *Eucalyptus* species followed by *Acacia* species. However, the existing database for Australia contains equations that were developed from trees that belong to different genera (Fig 8).

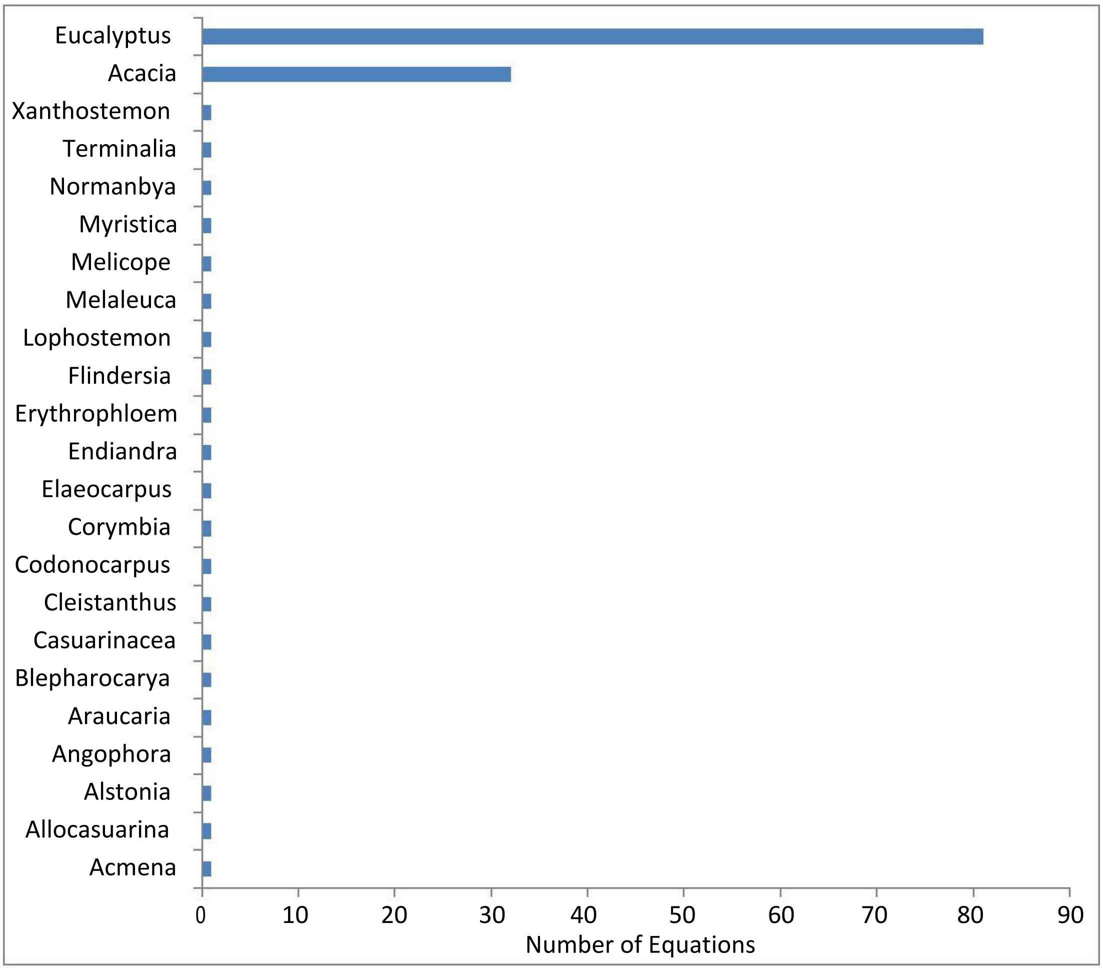


Figure 8. The number of allometric models based on the different types of genus

4. An example of comparing allometric equations for Australia using Fantallometrik software

The first module “Comparison of allometric equations” of the Fantallometrik software was used in order to compare the allometric equations that were developed for Australia. The first module allows the comparison of different allometric equations based on the selection of different filters (tree component, species, location etc) and provides the users with the opportunity to select the best module based on their criteria.

Following the software tutorial (Trotta, Henry, et al 2013), three files were imported: the input file with the variables, the wood density database and the allometric equation database. The comparison was carried out based on the selection of the trunk component. To make the comparison more specific we further limited the comparison to all the *Eucalyptus* species (7 species) found in different locations (7 sites) which belong to the same ecological zone (Temperate mountain system) as classified by FAO. A number of 22 equations were found to meet the above criteria. Each equation gave different biomass estimates for the trunk of the *Eucalyptus* species (Fig. 9).

The highest biomass estimates was given by the equation -5.097+2.3log*(DBH), from Burrows, W. H., M. B. Hoffmann, et al. (2000). The equation was developed in woodland ecosystems for *Eucalyptus melanophloia* in eastern Australia. A number of 43 trees were measured in order to develop the model giving a coefficient of determination (R^2) of 0.960. The allometric equation exp(-3.772+0.960*log(DBH^2H)) gave the smallest estimates of biomass, from Bi, H., J. Turner, et al. (2004). The model was developed in “open-forest” ecosystems for *Eucalyptus muelleriana.* The sample size of the trees was 13 trees and R^2 was 0.965. Unfortunately, there is no information regarding the applicability range of diameter at breast height (DBH) and height (H).

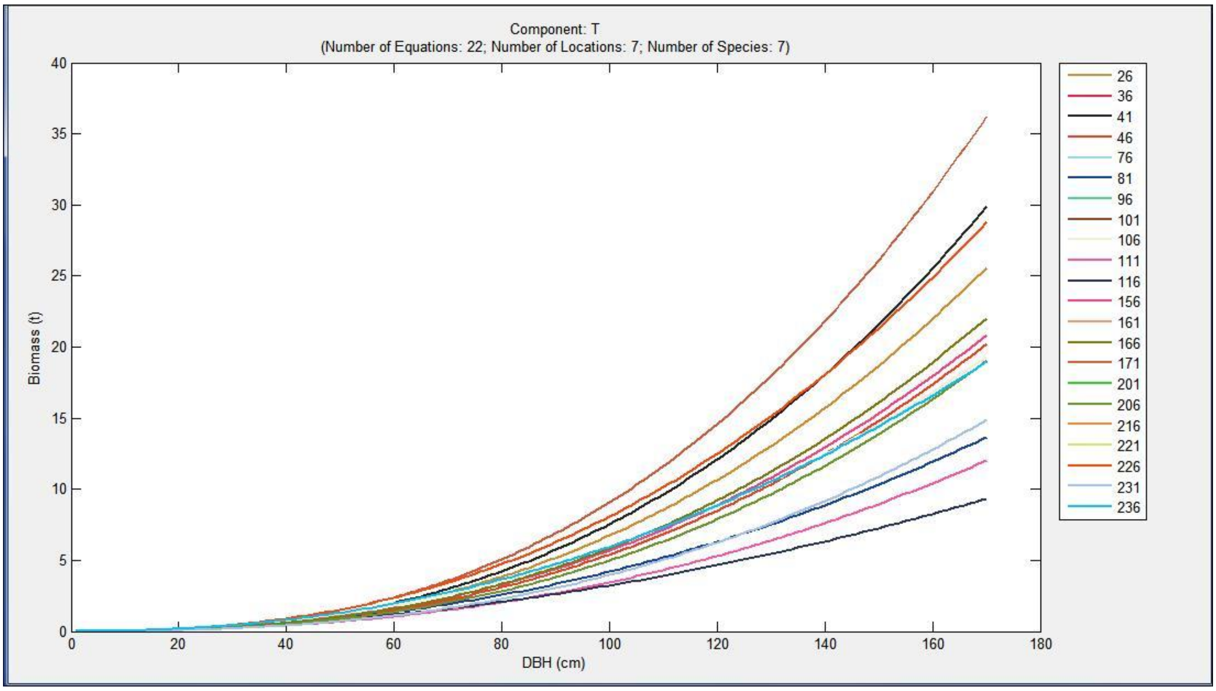


Figure 9. Comparison of biomass estivates given by 22 allometric equations. The values are estimating the biomass of the trunk of 7 Eucalyptus species found in 7 locations in Australia which belong to the same ecological zone

5. Conclusion

As it was mentioned in the introduction the existing database for Australia and the Pacific was developed from 9 scientific articles. Therefore, the database has a relatively small number of allometric equations that were developed to estimate the biomass of different tree components. It is important to enrich and constantly update the database with new allometric equations that will estimate not only the biomass but also the volume of the trees. Moreover, the database needs more information for the validity range of the allometric models and also models that will cover the whole of Australasia.

It is also important to enrich the database with allometric equations coming from different countries in the Pacific (New Zealand, Vanuatu, Tonga, Tuvalu, Papua New Guinea, Palau, etc..) that belong to different ecological zones. The future inventory on allometric equations for the Pacific should be focused on models that relate tree biomass and volume to different tree components. For instance, the diameter at breast height (DBH) is the most common tree component for tree biomass assessment and only a small number of equations were observed for other tree components such as tree height and crown diameter. There is also a need to develop and research equations for the assessment of dead wood and belowground biomass. Furthermore, the existing databases lack allometric equations for a variety of tree genera as most of the equations have been developed for *Eucalyptus* and *Acacia.* The future inventory on allometric equations should be carried out taking into consideration different sources of literature that might not be published in scientific journals.

A more complete database of allometric equations for the Pacific will result in a better and more accurate assessment of tree and forest volume and biomass and in the long term will contribute to the improvement of forest management and planning.

6. References

Aalde, H., Abdelgadir, J.Penman, M. Gytarsky and T. Hiraishi. 2003. Forest land. Good practice guidance for land use, land-use change and forestry. Institute for Global Environmental Strategies (IGES) for the IPCC, Kanagawa, Japan.

Bailey, R.G.. 1989. Explanatory supplement to Ecoregions map of the continents. Environmental Conservation 16: 307-309.

Baldasso,M., Birigazzi L., Trotta, C. Henry, M.. 2012. Tutorial for tree allometric equation databse development.

Bi, H., J. Turner, et al. 2004. Additive biomass equations for native eucalypt forest trees of temperate Australia. Trees 18(4): 467-479.

Burrows, W. H., M. B. Hoffmann, et al. 2000. Allometric relationships and community biomass estimates for some dominant eucalypts in Central Queensland woodlands. Australian Journal of Botany 48(6): 707-714.

Cutini, A., F. Chianucci, et al. 2013. Allometric relationships for volume and biomass for stone pine (Pinus pinea L.) in Italian coastal stands. iForest - Biogeosciences and Forestry 6(6): 331-335.

Trotta, C., Henry, M 2012. Fantallometrik [software]. Available from www.globallometree.org/software

FAO, 2001. Global ecological zoning for the global forest resources assessment 2000 The Forest Resources Assessment Programme: Rome.

Forrester, D. I., J. Bauhus, et al. 2004. Growth dynamics in a mixed-species plantation of Eucalyptus globulus and Acacia mearnsii. Forest Ecology and Management 193(1–2): 81-95.

Holdridge, L.R., 1967. Life zone ecology. San José, Costa Rica, Tropical Science Center.

IPPC. 2006. Guidelines for national greenhouse gas inventories. Prepared by the National Greenhouse Gas Inventories Programme. Technical report. The Intergovernmental Panel on Climate Change, IPCC/IGES, Kanagawa, Japan.

Jonson, J. H. and D. Freudenberger 2011. Restore and sequester: Estimating biomass in native Australian woodland ecosystems for their carbon-funded restoration. Australian Journal of Botany 59(7): 639-652.

Liddell, M. J., N. Nieullet, et al. 2007. Assessing the above-ground biomass of a complex tropical rainforest using a canopy crane. Austral Ecology 32(1): 43-58.

Melson, S., M. Harmon, et al. 2011. Estimates of live-tree carbon stores in the Pacific Northwest are sensitive to model selection. Carbon Balance and Management 6(1): 1-16.

O'Grady, A. P., X. Chen, et al. 2000. Composition, leaf area index and standing biomass of eucalypt open forests near Darwin in the Northern Territory, Australia. Australian Journal of Botany 48(5): 629-638.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, V.N., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., Kassem, K.R. 2001. Terrestrial ecoregions of the world: A new map of life on Earth. BioScience 51(11) 933-938.

Paul, K. I., S. H. Roxburgh, et al. 2013. Development and testing of allometric equations for estimating above-ground biomass of mixed-species environmental plantings. Forest Ecology and Management 310(0): 483-494.

Trotta, C., Henry, M, Baldasso, M. Birigazzi, L. Sola, G**.** 2013. Tutorial for the Fantallometrik software. 40 pp.

Udvardy, M.D.F. 1975. A classification of the biogeographical provinces of the world. Occasional paper 18. World Conservation Union. Morges, Switzerland.

Vashum KT, Jayakumar S. 2012, Methods to estimate above-ground biomass and carbon stock in natural forests – A review. J Ecosyst Ecogr 2:116. doi:1.4172/2157-7625.1000116.

Werner, P. A. and P. G. Murphy 2001. Size-specific biomass allocation and water content of above- and below-ground components of three Eucalyptus species in a northern Australian savanna. Australian Journal of Botany 49(2): 155-167.

Williams, R. J., A. Zerihun, et al. 2005. Allometry for estimating aboveground tree biomass in tropical and subtropical eucalypt woodlands: towards general predictive equations. Australian Journal of Botany 53(7): 607-619.