



# Inventory of allometric equations for estimating tree biomass

A database for China

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**UN-REDD PROGRAMME**

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## Table of Contents

Executive Summary .....	iii
Foreword .....	v
1. Introduction.....	1
1.1 Biomass assessment and National Forest Inventory of China.....	1
1.2 GlobAllomeTree web platform.....	1
1.3 Objective of the report.....	1
2. Database development and allometric equations in China .....	3
2.1 Data collection and data entry .....	3
2.1.1 Data collection.....	3
2.1.2 Database structure .....	3
2.2 Allometric equations in China .....	3
2.2.1 Geographic location.....	3
2.2.2 Global ecological zones.....	5
2.2.3 Input and output variables .....	6
2.2.4 Vegetation components.....	7
2.2.5 Species and taxonomy .....	8
3. Comparison of allometric equations using field inventory data: an example using R.....	9
4. Recommendations.....	11
5. Conclusion .....	12
6. References.....	13
Appendices .....	14
Appendix 1. References collected in the China database .....	14
Appendix 2. R script.....	16
Appendix 3. List of species in the database .....	17

## Executive Summary

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Under the support of the UN-REDD Programme, an inventory of volume and biomass tree allometric equations is being undertaken globally. This report introduces an allometric equation database developed specifically for China that complements the current database for Asian countries. The database was prepared following the tutorial given by Baldasso, Birigazzi *et al.* Equations were compiled according to different categories to provide an overview of the allometric equations available in the literature. A comparison of the equations using field inventory data was given using statistical software R to present the application of the allometric equations in the specific context. This database reflects decades of experience relevant to supporting countries in the Asia-Pacific region in National Forest Monitoring. Several recommendations were given to support forest biomass assessment and to promote knowledge exchange in the region.

In total, 830 allometric equations from 32 scientific articles have been collected and entered into the database. They have been developed at 46 locations in 17 province-level divisions. Heilongjiang is the single province that produced the most equations. It is located in Northeast China where the major forest industry and forest institutions are. According to the FAO global ecological zoning framework, six biome types (including temperate, subtropical and tropical) are involved in the database. Fifty percent of the equations belong to temperate continental forests. Only 3.4% of the equations are volume equations, and the remaining are biomass equations. The most frequently used predictive variable in single-variable models is diameter at breast height, and in two-variable models are diameter at breast height and tree height. Wood density and crown diameter are presented in more complicated models. Biomass equations cover a wide range of vegetation components, but volume equations apply to stem only. In terms of species and taxonomy, in total 98 species are recorded into the database. The most represented species is *Pinus massoniana*, and four out of the five most represented species are coniferous trees.

During the development of the database, several problems have been identified. The biggest issue concerns the quality of the equations and the reference articles. Information on material and methods is crucial but commonly not given in detail in the articles, therefore the accuracy of the equations is unknown. Primary sources of data should be carefully preserved and the accessibility to them should be increased. Publishing raw field data in open data repositories is an example of good practice. The improving remote sensing techniques gives potential to predict biomass from crown diameter, and therefore it is recommended to develop more equations with crown diameter as an input variable.

The allometric equation database for China contributes to the UN-REDD Programme in facilitating access to data for the preparation of forest biomass and carbon stock and stock change assessment for countries in Southeast Asia. The objective of knowledge exchange is promoted as multiple institutions are involved in collecting reference articles for the database, and the result is shared among these institutions. Moving forward requires promoting the usage of the database and increasing the accessibility of research results. With the China database integrated into the open web platform GlobAllomeTree, more stakeholders can benefit from it.

## Executive Summary (Chinese)

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### 对估算立木生物量的相对生长方程的清查——中国数据库

#### 提要

在 UN-REDD 项目的支持下，对立木材积和生物量的相对生长方程的清查正在全球范围内展开。

本篇报告介绍了专门针对中国开发的相对生长方程数据库，以此作为对亚洲国家现有数据的补充。该数据库依据由 Baldasso, Birigazzi 等编写的教程而准备，并将相对生长方程按照不同类别进行整理和分析，以提供在文献中可得的相对生长方程的概览。利用统计学软件 R，对相对生长方程在具体条件下的应用进行了对比。此数据库体现了多年的相关经验，可为亚太地区的国家进行森林监测提供支持。报告同时提出了若干有助于估算森林生物量和促进该地区知识交流的建议。

该数据库收集并录入了 32 篇科学论文中的共计 830 个相对生长方程，研究范围覆盖了 17 个省级单位的 46 个地点。位于中国东北部、拥有主要森林产业和众多研究机构的黑龙江省，是收集到最多相对生长方程的单一省份。依据联合国粮农组织（FAO）的全球生态区划框架的划分，该数据库涵盖了包括温带，亚热带和热带在内共 6 种生态区，数据库中 50% 的相对生长方程属于温带大陆性森林。材积方程仅占总数的 3.4%，其余均为生物量方程。单变量模型中最常用的预测变量是胸径，双变量模型中最常用的变量组合为胸径和树高，一些更为复杂的模型还采用到木材密度和树冠直径。数据库中的生物量方程覆盖了多种植被组分，而材积方程仅适用于树干。在物种和分类学方面，共计 98 个树种被录入库中，有关马尾松的相对生长方程数量最多。方程数量最多的五种树种中，四种是针叶材。

在开发数据库的过程中遇到了一些问题，最主要的问题有关于方程和引用的文献的质量。至关重要的研究材料和方法在参考文献中通常未给出足够详细的信息，这在一定程度上影响了方程的准确性。原始数据和资料应进行妥善保存，并提高其可得性，如在开放数据库发布原始数据则是一种良好的做法。日益进步的遥感技术为从树冠直径预测生物量提供了潜在可能，在未来可开发更多以树冠直径为预测变量的相对生长方程。

中国立木相对生长方程数据库将促进 UN-REDD 对东南亚国家进行森林生物量、碳储量和储量变化的估测提供帮助支持。在未来，应推动数据库的使用和研究成果的推广。伴随中国数据库在开放网络平台 GlobAllomeTree 的发布，更多的利益方将会从中受益。

## Foreword

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The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD) is a collaboration between FAO, UNDP and UNEP. Within the partnership, FAO supports countries on technical issues related to forestry and the development of cost effective, transparent, robust and reliable National Forest Monitoring Systems (NFMS) to improve the assessment of forest biomass and carbon stocks.

The UN-REDD Programme facilitates data-sharing, knowledge exchange and collaboration at both the global and regional level. Inventories of volume and biomass tree allometric equations are being undertaken in several continents, and country-specific databases of the equations are being developed and published on GlobAllomeTree, a web platform designed to enable access and optimized selection of the equations (Henry, Bombelli *et al.* 2013). Partnerships are established with international forestry institutions and universities to support knowledge exchange and dialogue.

This report introduces an allometric equation database developed specifically for China that complements the current database for Asian countries. Through the better archiving, harmonizing, and sharing data, regional collaboration in Asia can be further promoted.



# 1. Introduction

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## 1.1 Biomass assessment and National Forest Inventory of China

At regional and national scales, forest inventory data-based biomass models are widely used as a tool for biomass assessment (Zhao and Zhou 2004). Field ground data are collected and entered into database systems and analyzed using a variety of software and tools. Because the quality of biomass estimation and carbon stocks assessment at country level depends critically on the quality of the allometric equations applied to individual trees and the forest inventory data, it is therefore essential to ensure the quality of input data.

In China, a National Forest Inventory system was launched for the first time by the Ministry of Forestry in 1973, and afterwards at an interval of every five years. Since the 6<sup>th</sup> NFI (1999-2003), the State Forestry Administration (SFA) became the organizer. The objectives are to identify the status of forest resources at national and provincial levels. Up to 2014 eight NFIs have been conducted in China, with the most recent one covering the period from 2008 to 2013. The NFI system has been continuously improving in terms of technology and methodology. Remote sensing, GPS, modelling methods are widely applied to contribute to efficiency and accuracy (FAO 2007). Because the forest inventories do not include detailed forest biomass information directly, biomass expansion factors that convert merchantable timber volume to biomass of noncommercial components are used to calculate all forest biomass (Fang, Chen *et al.* 2001). Since the early 1980s, the method has been widely used at provincial and national level (Yu, Wang *et al.* 2014).

In order to improve national forest biomass assessment and support policy and measures related to REDD+ and climate change, the eighth NFI included biomass and carbon stock monitoring as an important component. According to this latest NFI, total forest area and total stock volume have increased from 195 to 208 million ha, and from 13.7 to 15.1 billion m<sup>3</sup>, respectively. Total forest biomass and carbon sink have reached 17 billion tons and 8.4 billion tons (SFA 2014). The national forest inventory reports are available on the SFA website: <http://www.forestry.gov.cn/>.

The Global Forest Resources Assessments (FRA) launched by FAO also provides country specific reports since FRA2005. Country reports of China are available on FAO website: <http://www.fao.org/forestry/fra/en/>.

## 1.2 GlobAllomeTree web platform

GlobAllomeTree is a web platform that aims to inventory existing allometric equations. In 2014 the platform contained more than 12,000 equations and has over 1,900 registered users. It provides free access to allometric equations for different species, tree components and biomes.

Before now, allometric equations from China were missing from the GlobAllomeTree platform for a number of reasons. First of all, the global database is still relatively new and is a work in progress. Secondly, existing allometric equations are mainly found in scientific articles, reports from private companies and hard copies in national libraries. The number of published literature that contains biomass models developed in China is limited, and many of them are written in Chinese. Therefore data accessibility is very restricted. Many documents written in Chinese are from forty years ago and are available only in hard copies. Some are badly preserved, if not missing. These factors all add to the difficulty in developing the Chinese database.

## 1.3 Objective of the report

The objectives of the report include: (a) to provide access to allometric equations developed in China over many years to support forest biomass assessment in Asia, (b) to provide an overview of the allometric equations available, (c) to present the application of the equations in the specific context,

and (d) to provide some recommendations to support forest biomass assessment and promote knowledge exchange in Southeast Asia.

The allometric equation database of China reflects decades of experience that is relevant to supporting countries in the Asia-Pacific region in National Forest Monitoring. These data could be beneficial to all countries in the region.

## 2. Database development and allometric equations in China

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### 2.1 Data collection and data entry

#### 2.1.1 Data collection

The allometric equations in the database were collected from 32 scientific articles published from 1984 to 2013. Thirteen were written in Chinese with English abstracts. The sources of these articles are listed below:

- a. Internet search through the Google scholar engine;
- b. Provided by Chinese directors from State Forestry Administration and Forestry Carbon Sequestration Accounting and Monitoring Center;
- c. Provided by Faculty of Forest Sciences and Forest Ecology Burckhardt-Institute of Georg-August-Universität Göttingen.

A reference library has been created to keep record of all the reference articles. In total 830 allometric equations have been recorded in the China database. All the equations and relevant metadata were entered according to the instructions given by the “Tutorial for tree allometric equation database development” (Baldasso, Birigazzi *et al.* 2012).

#### 2.1.2 Database structure

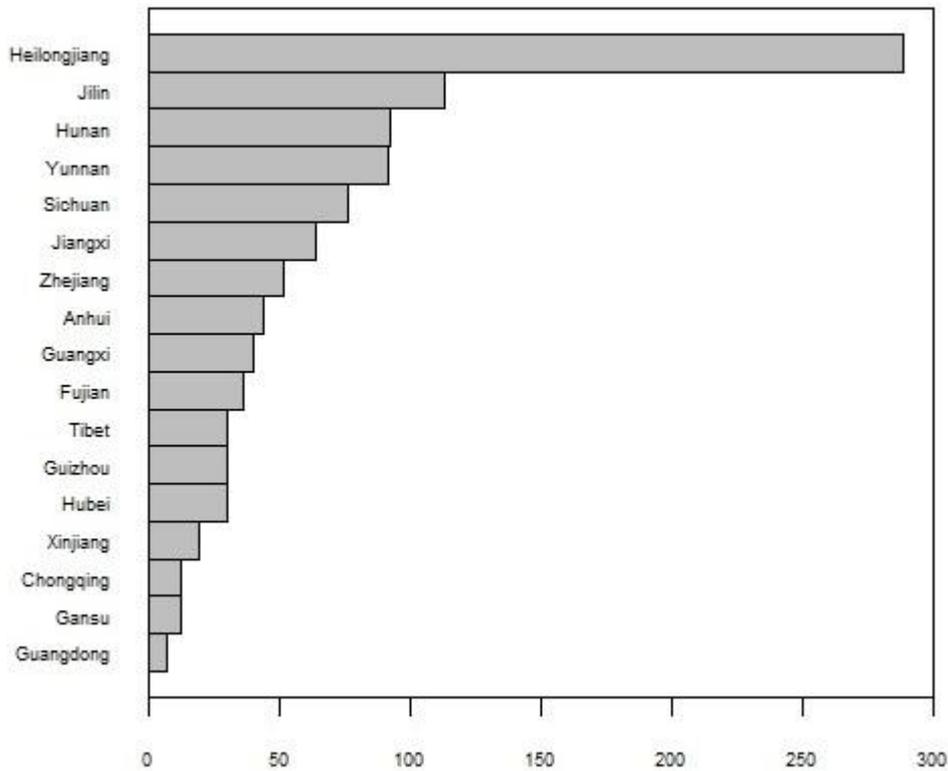
The allometric equation database for China was developed following the tutorial. The template used to prepare the database was structured as following:

- a. Location and ecology: Geographical information about the sites where allometric equations are developed.
- b. Global ecological zones: Biome information about the sites. GIS software such as QGIS, Arcview and Arcgis can be used to determine the biome types.
- c. Variables and vegetation components: Information on the input and output variables and units, and the corresponding vegetation components. By following the acronyms provided by the tutorial, data from different sources and times can be better harmonized and integrated into the platform.
- d. Species and taxonomy: Information on the names of the species in the binomial literature in the Latin grammatical form. The names shall contain no accents.
- e. Equation and references: This is the allometric equation and all information about the reference articles.
- f. Regression statistics and contributors: Statistical information on the coefficients of the parameters in the allometric equations. Usually they can be found in the references.

### 2.2 Allometric equations in China

#### 2.2.1 Geographic location

The allometric equation database for China contains a total of 830 equations for 98 species and 46 locations in 17 province-level divisions (Figure 1). Geographically, these provincial-level divisions cover northeast, northwest, southeast, and southwest China (Table 1).



**Figure 1.** Number of allometric equations by province-level divisions. No equations are recorded for the following province-level divisions: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Shanghai, Jiangsu, Shandong, Henan, Hainan, Shaanxi, Qinghai, Ningxia, Hong Kong, and Macau.

**Table 1.** Number of allometric equations by geographical location.

	Region	Number of AE	Provinces
1	Northeast	401	Heilongjiang, Jilin
2	Northwest	31	Gansu, Xinjiang
3	Southeast	324	Anhui, Fujian, Guangdong, Hubei, Hunan, Jiangxi, Zhejiang
4	Southwest	279	Chongqing, Guangxi, Guizhou, Tibet, Sichuan, Yunnan

Most of the study sites are located in southern China, but the province from which the most equations were developed is in northeast China. This is because the major forest industry and forest institutions are in the northeast region, where forests have been repeatedly studied, and therefore the number of allometric equations is the greatest. At the southwest border where the biodiversity is the highest, the number of equations is also large. Southeast China is the most populated area in the country, and northwest has few forests and is understudied. Figure 2 below shows the distribution of China's forests according to the sixth national forest inventory data.

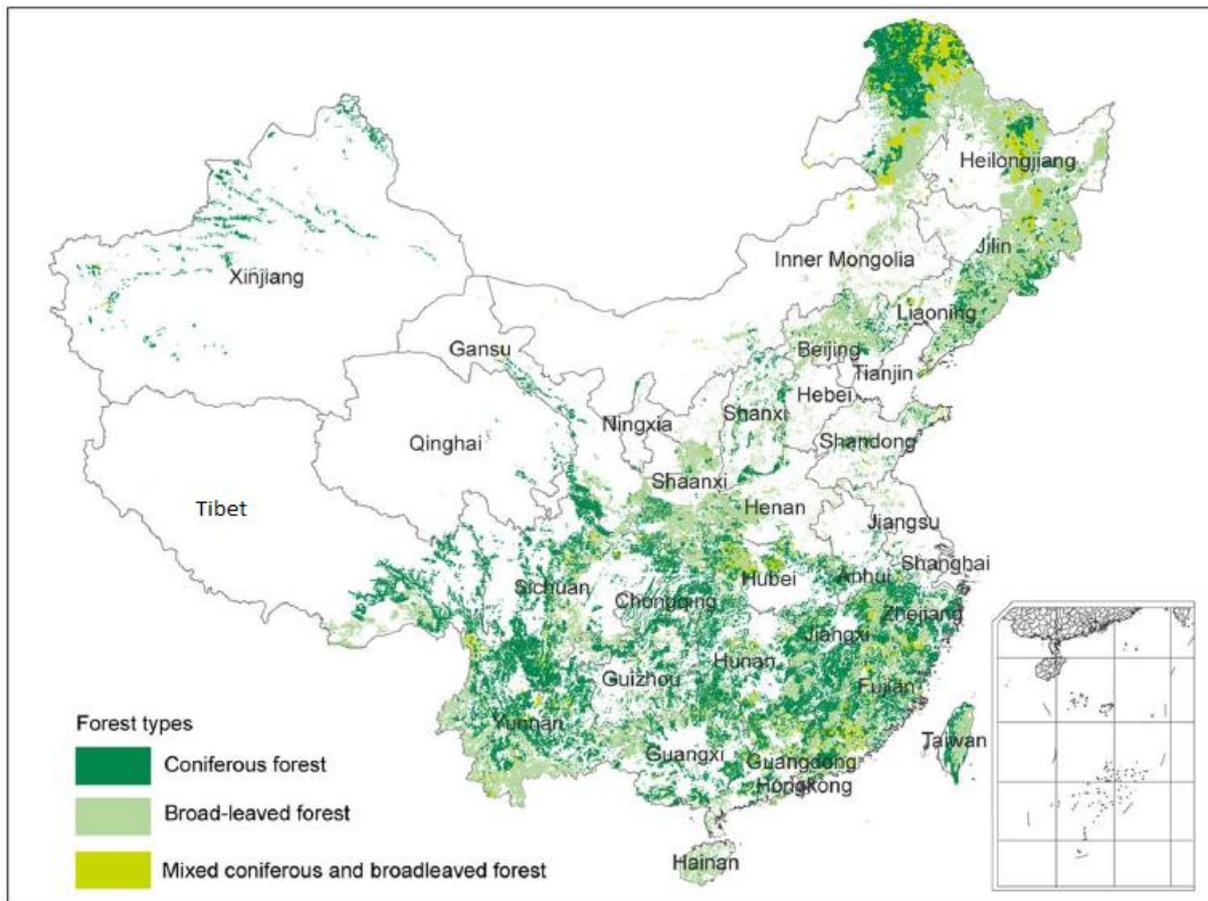


Figure 2. Forest distribution in China based on the sixth National Forest Inventory data (SFA 2005).

**2.2.2 Global ecological zones**

According to the FAO global ecological zoning framework for 2010 (FAO 2012), the equations collected cover six different biome types, from temperate to tropical systems. Fifty percent of the equations are developed in forests that belong to the temperate system, followed by subtropical system (46%) and tropical system (4%). The single biome that contains the most equations is temperate continental forests (50%). Figure 3 gives the number of equations expressed as a percentage (%).

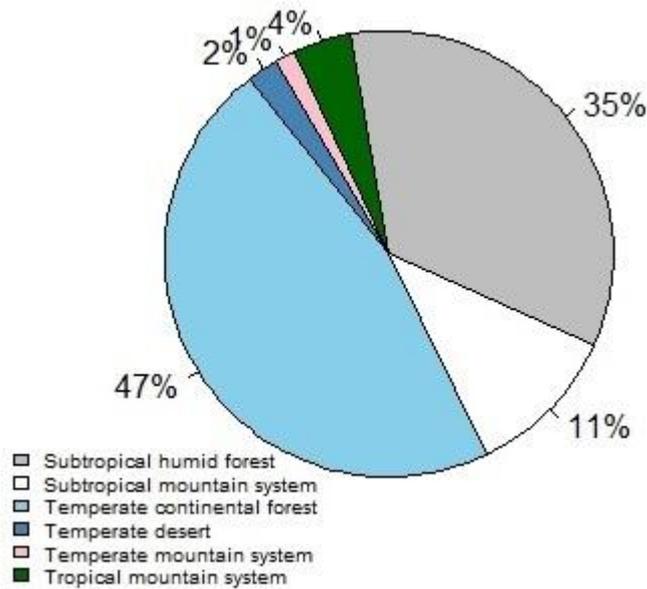


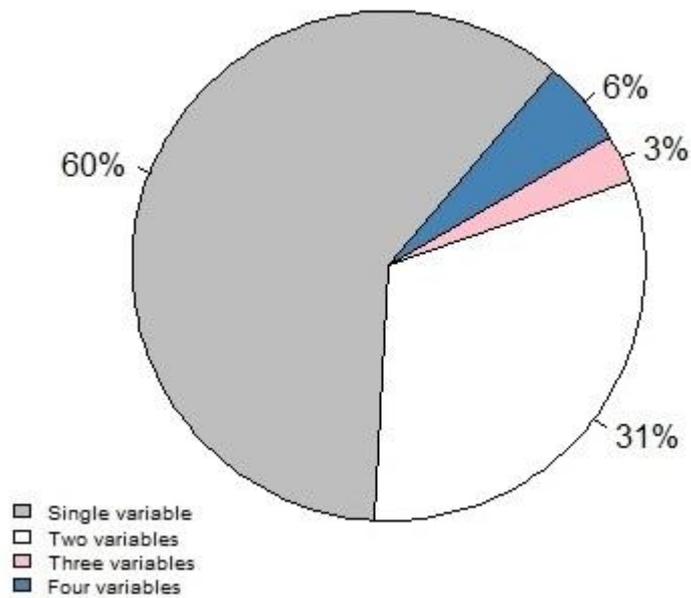
Figure 3. Number of allometric equations by FAO global ecological zones (FAO 2007; FAO 2012).

### 2.2.3 Input and output variables

Allometric equations in the database can be categorised into four groups based on the number of input variables in the regression models. Figure 4 is a summary of the four groups in terms of percentage. The following independent variables were observed in the database: diameter at breast height (DBH), diameter at 0 cm (D0), diameter at 10 cm (D10), tree height (H) and length (L) for woody liana, basal area (BA), basal area at 0.1 m (BA0.1), canopy area (CA), wood density (WD), crown length (CL), and volume (V).

The most commonly used predictive variable is DBH, which appears in 583 out of all 830 equations, either untransformed or log-transformed. Other diameter measures such as D0 and D10 are found in 111 equations in addition to DBH. In all the single-variable equations, diameter variables have a dominant proportion of 87.4%. In two-variable models, the most common treatment is a diameter variable (DBH, D0, or D10) and a height variable (H or L). Other combination includes canopy area plus height, and DBH plus wood density. More complicated models that contain three or four variables are found from the same article, and the combinations are uniform. Table 2 is a summary of number of equations compiled by input variables.

In terms of output variables, 28 out of the total 830 equations have volume as the output variable, which account for only 3.4%. The remaining equations are all biomass equations.



**Figure 4.** Proportion of allometric equations by number of input variables.

**Table 2.** Number of allometric equations by number of input variables.

	Number of equations	Variable names	Percentage
One variable	500	DBH, D0, D10	87%
		H	5%
		BA, BA0.1	4%
		CA	3%
		V	0%
Two variables	259	DBH+H, D0+H, D10+H	71%
		CA+H	28%
		DBH+WD	1%
Three variables	26	DBH+H+WD	100%
Four variables	45	DBH+H+WD+CL	100%

#### 2.2.4 Vegetation components

The equations recorded into the database cover a wide range of vegetation components (Figure 5); with equations for branches being the most frequent. Volume equations apply to stem only. ‘Other’ biomass includes woody tissue and shoots.

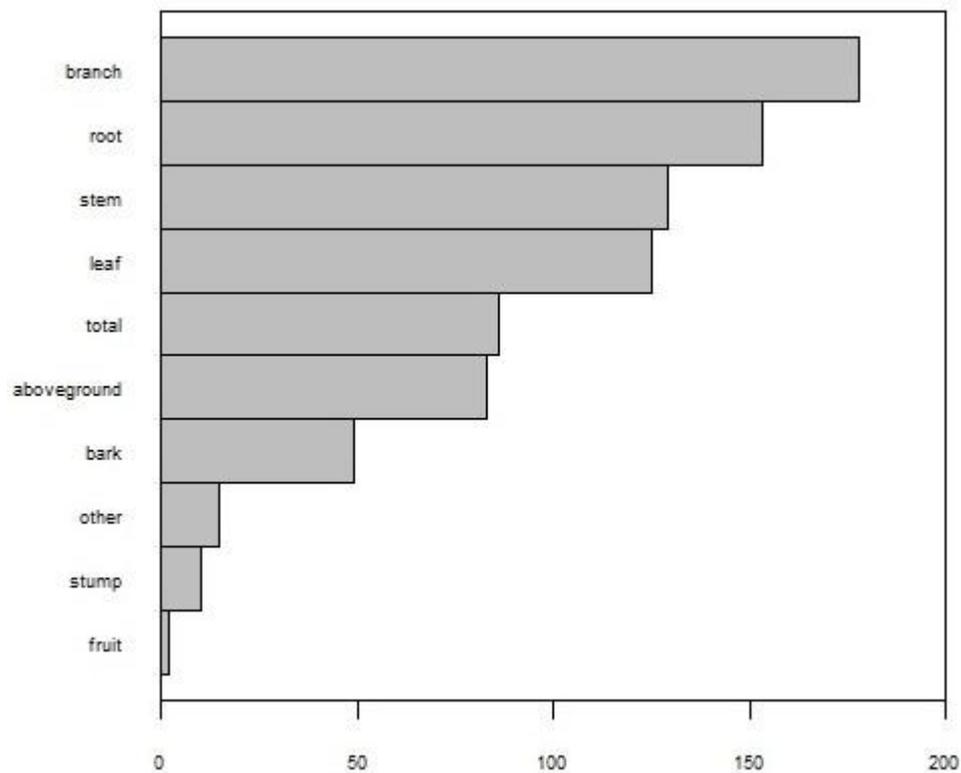


Figure 5. Number of allometric equations by vegetation component.

### 2.2.5 Species and taxonomy

In total 98 species are recorded in the database. The five most represented species are *Pinus massoniana* (80 equations), *Abies nephrolepis* (39 equations), *Cunninghamia lanceolata* (38 equations), *Pinus koraiensis* (36 equations), and *Cyclobalanopsis glauca* (36 equations). Except for *Cyclobalanopsis glauca*, these are all coniferous trees. The five most represented genera are *Pinus*, *Guercus*, *Abies*, *Castanopsis*, and *Acer*. A complete list of species in the database can be found in Appendix 4.

### 3. Comparison of allometric equations using field inventory data: an example using R

Field ground data are valuable for a number of reasons. First, they can be applied to new allometric equations to compare their quality. Second, when collecting raw data is not possible, existing data can be a good substitute. Because it is always time consuming and costly to collect new data, it is a good practice to inventory raw data. Multiple stakeholders can benefit from the increasing accessibility of data. Currently there are several open-access data repositories available online, for example Dryad: <http://datadryad.org/>.

In this part, the data used are taken from published literature; Xiang *et al.* (2011). 197 *P.massoniana* samples were measured with component biomass information recorded in the appendix of the original article. Twelve allometric equations that estimate stem biomass of the same species were selected from the database (Table 3). Eq. 10, 11, and 12, referred to as base models afterwards, were regressed from the raw data in Xiang *et al.* (2011), and the remaining from other literature. Six models use two input variables (DBH and height) and one model uses three (DBH, height and wood density).

**Table 3.** Stem biomass equations selected to perform the comparison. (n-sample size)

ID	Model	n	R2	Reference
1	$0.0459 * ((DBH^2 * H)^{0.8867})$	5	0.9821	Ai, X., Shen, Z., <i>et al.</i> (1998)
2	$0.0236 * (((DBH^2 * H)^{0.9955})$	10	0.9896	Zhang, Z., Wang, Y., <i>et al.</i> (2006)
3	$0.0700 * (DBH^{2.5460})$	10	0.992	Zhang, Z., Wang, Y., <i>et al.</i> (2006)
4	$0.036 * (DBH^{2.609})$	10	0.987	Zhang, G., Li, X., <i>et al.</i> (2012)
5	$0.015 * (((DBH^2 * H)^{1.005})$	10	0.984	Zhang, G., Li, X., <i>et al.</i> (2012)
6	$0.017470 * (((DBH^2 * H)^{0.998299})$	10	0.9956	Xia, X. (2008)
7	$0.0590 * (DBH^{2.2906})$	8	0.9746	Zheng, H., Ouyang, Z., <i>et al.</i> (2008)
8	$\exp(-4.044 + 1.416 * \ln(DBH) + 1.544 * \ln(H))$	108	NA	Zhang, L., Deng, X., <i>et al.</i> (2012)
9	$\exp(-9.425 + 1.391 * \ln(DBH) + 1.467 * \ln(H) + 0.906 * \ln(WD))$	108	NA	Zhang, L., Deng, X., <i>et al.</i> (2012)
10	$\exp(-2.9928 + 2.5835 * \ln(DBH))$	197	0.9453	Xiang, W., S. Liu, <i>et al.</i> (2011)
11	$\exp(-2.9468 + 2.6207 * \ln(H))$	197	0.8793	Xiang, W., S. Liu, <i>et al.</i> (2011)
12	$\exp(-3.2145 + 0.9028 * \ln((DBH^2 * H)))$	197	0.9683	Xiang, W., S. Liu, <i>et al.</i> (2011)

Statistical software R was used to perform the analysis. Stem biomass of the twelve equations were plotted in the graph below (Figure 6). The scatter plots were the raw data from literature. Height data were converted according to the diameter-height relationship

$$\ln(H) = 0.9085 + 0.5944 \times \ln(DBH)$$

which was developed by Zhang *et al.* (2004), and the *P.massoniana* density value of  $0.431 \text{ gcm}^{-3}$  was taken from Liu *et al.* (2009). The highest estimates were given by Eq. 3 from Zhang *et al.* (2006).

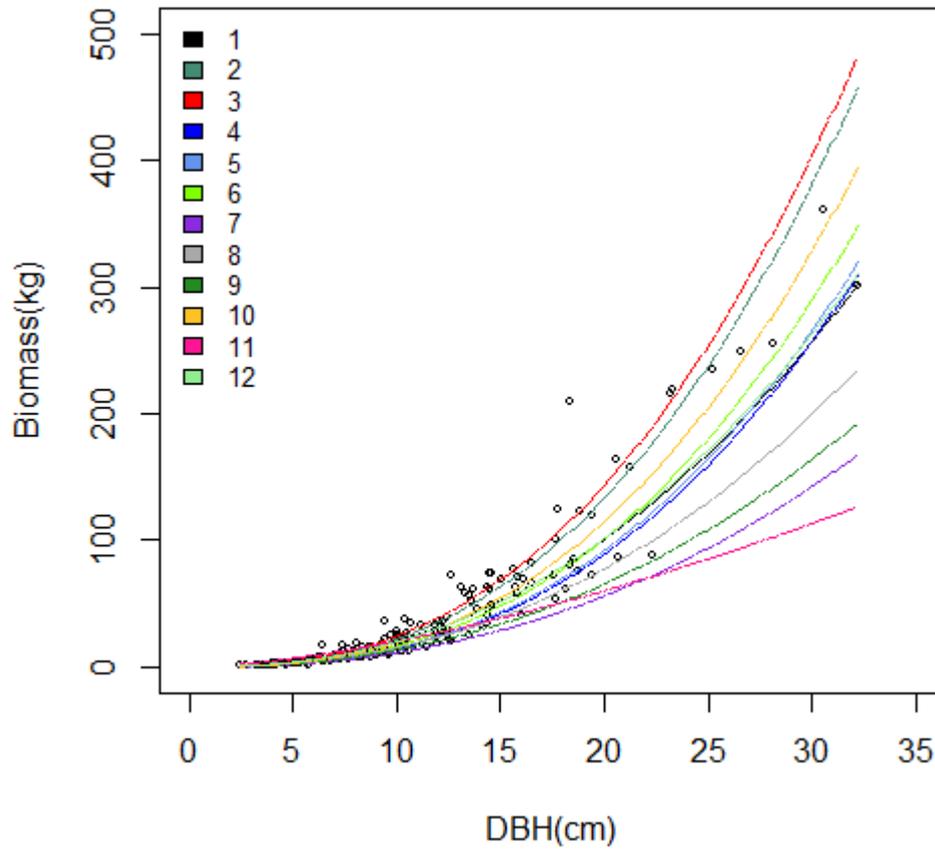


Figure 6. Comparison of stem biomass predicted by 12 equations from the database. Scatter plots are raw data.

In general, the nine stem biomass models (Eq. 1 to 9), are different in the following aspects compared with base models. First of all, the sample sizes are very different. The base models were developed from a sample size of 197 trees, while Eq. 1 to 7 were developed from five to ten trees, and Eq. 8 and 9 from 108 trees. Secondly, location varies. The base study involved twenty plots in Southeast China covering nine provinces. The sample sites used to develop Eq. 1 to 7 were also located in southern China, but each equation only involved one plot. Different climate and geographic conditions have thus impacted the growth of the trees. Thirdly, the age of sample trees differs. Last but not least, because of the lack of details in materials and methods of some literature, the precise vegetation component of the stem may differ.

## 4. Recommendations

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China is vast in area and diverse in both biome and vegetation types. The majority of the country is located in temperate and subtropical climate, and the southwest border adjacent to Southeast Asia has a tropical climate. In this area, biome and forest types are similar to northern Laos and Vietnam, and forest research with similar objectives has been done by different institutions. With improved knowledge sharing and exchange practices, multiple stakeholders can benefit from research results.

During the development of the China database several problems were identified. In order to promote the harmonization of existing allometric equations and improve the quality of databases, the following practices are recommended.

Some AEs are taken from secondary sources where primary sources are old and hard-copy, difficult if not impossible to access. As a result, the accuracy of these equations is unknown. Therefore it is always important to preserve primary sources of data, and regularly check the availability. Increasing the accessibility of scientific articles and constantly updating the reference libraries is also recommended.

Information on material and methods is crucial but commonly not given in detail in the articles, especially when they are written in Chinese. Without such information, it is very difficult to determine vegetation components. The regression models also need be clearly specified in the methods; some articles provide regression parameters but do not specify the model. About 15% of the equations in the database give unreliable predictions that are either too big or too small. There may be multiple reasons, including typing errors. Contacting original authors can take an extremely long time and a lot of effort. When there is uncertainty about the equations, the operator is responsible for making a good judgement on the equations. To improve the accuracy of the equations, the material and methods should be as detailed as possible, including the valid range of measurement and regression models used. Local names of species should be recorded in databases if possible. Publishing or submitting raw field data in open data repositories is also recommended.

There is no standardized translation of forestry terminology in Chinese. Consequently when searching for scientific articles using keywords in Chinese, it takes more time and effort. It is therefore a good initiative to standardize terminology in multiple languages. The International Union of Forest Research Organizations (IUFRO) has a SilvaVoc terminology project that aims to inventory forest terminology in multiple languages, but the current database does not contain Chinese or Southeast Asian languages. Information regarding the project can be found at IUFRO's website: <http://www.iufro.org/science/special/silvavoc/silvaterm/>

Wood density is incorporated in some equations as an input variable. Also there is potential of developing allometric models that use crown diameter to predict biomass. The improving remote sensing techniques may greatly increase the efficiency in forest monitoring and measurement (Holmgren, Masakha *et al.* 1994). Thus it is recommended to develop more equations with crown diameter as an input variable.

## 5. Conclusion

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The allometric equation database for China contributes to the UN-REDD Programme in facilitating access to data for the preparation of forest biomass and carbon stock and stock change assessment for countries in Southeast Asia. Currently the database contains a relatively small number of equations, and therefore requires continuous collating and harmonizing of existing data spread across the literature. However, because the majority of collected articles are published after the year 2000, there is a need to increase the accessibility of earlier articles. The objective of knowledge exchange is promoted when multiple institutions are involved in collecting reference articles for the database, and the result is shared among these institutions.

According to the results from the compilation of data, forests in northwest China and in the tropical region are understudied. Wood density is presented as an input variable in some equations and appears to be a promising variable to include in future research, as it has been proven that wood density is the second most important predictor of aboveground biomass in tropical forests (Chave, Andalo *et al.* 2005).

During the development of the database, the biggest issue is the quality of the allometric equations. Typing errors are often observed, and when the regression parameters contain errors, they give unrealistic predictions. Substantial effort is required to verify the equations and control the quality. These problems are rather general and not specific to any country, and therefore special attention needs to be drawn for similar activities in the future.

Moving forward requires promoting the usage of the database and increasing the accessibility of research results. The UN-REDD Programme is establishing partnerships across the globe. With the China database integrated into the open web platform GlobAllomeTree, more stakeholders can benefit from it.

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## Appendices

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### Appendix 1. References collected in the China database

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## Appendix 2. R script

This script will read equations in excel spreadsheets and plot them in one graph. Currently it works only on simple database with single-variable equations that have given maximum and minimum values of the predictive variable.

```
#Read equations in excel and use them in a plot example
eqfile <- read.csv("C:/Users/chengz/Desktop/example.csv", stringsAsFactors = FALSE)
eqfile<-subset(eqfile,X=="DBH" & Z=="None")

#Draw equations with ranges
#Determine overall x range for the plot
#xseq[which(eqfile$Max_X=="None")]<-seq(0,50,0.1)
eqfile$Equation<-gsub("X","x", eqfile$Equation)
eqfile$Equation<-gsub("log","logb", eqfile$Equation)

##if ("None" %in% eqfile$Max_X) {
# xseq<-seq(0,10,0.1)
#} else {
# xseq<-seq(0,max(eqfile$Max_X),0.1)#draw ticks every 0.1 units of X until the maximum X in the file
#}

#Evaluate all equations to determine the range of y's for the plot
#evaleq<-function(xseq)
# try(eval(parse(text=xseq)),silent=FALSE)

#ylimmax<-max(unlist(lapply(eqfile$Equation,FUN=evaleq)))
xlimmax<-50
ylimmax<-2000

#Labels in plot
xlab<-paste(eqfile$X[1], " (",eqfile$Unit_X[1],")")
ylab<-paste(eqfile$Output[1], " (",eqfile$Unit_Y[1],")")

#Rename variables and operators so the system can evaluate them
#curveqs<-eqfile$Equation

#Create empty plot
#plot(1, type="n", xlab=xlab, ylab=ylab, xlim=c(0, max(eqfile$Max_X)), ylim=c(0, ylimmax))
plot(1, type="n", xlab=xlab, ylab=ylab, xlim=c(0, xlimmax), ylim=c(0, ylimmax))

#Initialize vectors with colors and line widths for different components
colCompon=rainbow(dim(eqfile)[1])
lwdComp<-rep(1,dim(eqfile)[1])
#Draw curves
for (i in 1:dim(eqfile)[1]){
  #define range for each component
  if ("None" %in% eqfile$Max_X[i]) {
    xrang<-seq(0,1,0.1)
  } else {
    xrang<-seq(as.numeric(eqfile$Min_X[i]),as.numeric(eqfile$Max_X[i]),0.1)#draw ticks every 0.1 units of x until the maximum x in the file
  }
  #define line width for each component
  if(eqfile$Veg_Component[i]=="above ground biomass") {
    lwdComp[i]=2}
  else if (eqfile$Veg_Component[i]=="total biomass"){
    lwdComp[i]=3}
  lines(x,eval(parse(text=eqfile$Equation[i])),lwd=lwdComp[i],col=colCompon[i])
}
#Draw legend
legend(0, ylimmax, eqfile$Veg_Component[1:dim(eqfile)[1]], cex=0.8, col=colCompon, lwd=lwdComp, title="Tree components")
```

### Appendix 3. List of species in the database

Species	No.- of equations	Species	No. of equations
<i>Pinus massoniana</i>	80	<i>Lonicera maackii</i>	10
<i>Abies nephrolepis</i>	39	<i>Spiraea ussuriensis</i>	10
<i>Cunninghamia lanceolata</i>	38	<i>Viburnum burejaeticum</i>	10
<i>Pinus koraiensis</i>	36	<i>Elaeocarpus varunua</i>	10
<i>Cyclobalanopsis glauca</i>	36	<i>Semecarpus reticulata</i>	10
<i>Fraxinus mandshurica</i>	35	<i>Cleidion brevipetiolatum</i>	10
<i>Pometia tomentosa</i>	35	<i>Lithocarpus leucostachyus</i>	10
<i>Gironniera subaequalis</i>	33	<i>Litsea rangi</i>	10
<i>Castanopsis eyrei</i>	30	<i>Pterospermum lanceaefolium</i>	10
<i>Quercus aquifolioides</i>	30	<i>Pittosporopsis kerrii</i>	10
<i>Terminalia myriocarpa</i>	25	<i>Goniothalamus griffithii</i>	10
<i>Barringtonia macrostachya</i>	25	<i>Populus euphratica</i>	9
<i>Chisocheton siamensis</i>	25	<i>Betula costata</i>	9
<i>Mezzettiopsis creaghii</i>	25	<i>Pinus elliottii</i>	9
<i>Millettia laptobotrya</i>	25	<i>Camellia oleifera</i>	9
<i>Larix gmelinii</i>	24	<i>Castanopsis sclerophylla</i>	8
<i>Quercus mongolica</i>	24	<i>Liquidambar formosana</i>	8
<i>Betula platyphylla</i>	24	<i>Picea brachytyla</i>	8
<i>Phellodendron amurense</i>	24	<i>Abies fabri</i>	8
<i>Juglans mandshurica</i>	24	<i>Mitrephora wangii</i>	8
<i>Tilia amurensis</i>	24	<i>Knema cinerea</i>	8
<i>Populus davidiana</i>	23	<i>Lasiococca comberi</i>	8
<i>Acer mono</i>	23	<i>Baccaurea ramiflora</i>	8
<i>Garuga floribunda</i>	23	<i>Sonneratia apetala</i>	7
<i>Myristica yunnanensis</i>	23	<i>Uimus davidiana</i>	7
<i>Philadelphus schrenkii</i>	21	<i>Larix olgensis</i>	7
<i>Acer ginnala</i>	20	<i>Pinus densata</i>	6
<i>Padus asiatica</i>	20	<i>Picea crassifolia</i>	6
<i>Euonymus verrucosoides</i>	20	<i>Sabina przewalskii</i>	6
<i>Corylus mandshurica</i>	20	<i>Machilus viridis</i>	5
<i>Deutzia parviflora</i>	20	<i>Lithocarpus xylocarpus</i>	5
<i>Rhamnus davuricus</i>	19	<i>Castanopsis wattii</i>	5
<i>Sorbaria sorbifolia</i>	19	<i>Abies salauensis</i>	5
<i>Syringa reticulata</i>	18	<i>Schima noronhae</i>	5
<i>Euonymus alatus</i>	18	<i>Manglietia insignis</i>	5
<i>Rhamnus yoshinoi</i>	18	<i>Picea purpurea</i>	5
<i>Viburnum sargentii</i>	18	<i>Castanopsis hystrix</i>	5
<i>Schima superba</i>	17	<i>Michelia macclurei</i>	5
<i>Loropetalum chinense</i>	16	<i>Calligonum caputmedusae</i>	4
<i>Quercus fabri</i>	16	<i>Tamarix ramosissima</i>	4
<i>Vitex negundo</i>	16	<i>Picea likiangensis</i>	3
<i>Gardenia jasminoides</i>	16	<i>Alhagi sparsifolia</i>	2
<i>Acanthopanax senticosus</i>	16	<i>Byttneria grandifolia</i>	2
<i>Beilschmeidia brachythyrsa</i>	15	<i>Strychnos nitida</i>	2
<i>Garcinia cowa</i>	15	<i>Strychnos wallichiana</i>	1
<i>Drypetes indica</i>	15	<i>Strychnos cathayensis</i>	1
<i>Lithocarpus glaber</i>	14	<i>Tetrastigma planicaulum</i>	1
<i>Cinnamomum camphora</i>	12	<i>Combretum yunnanensis</i>	1
<i>Picea koraiensis</i>	11	<i>Bousigonia mekongensis</i>	1
Not specified	20		