# Carbon Stock Assessment and Modelling in Zambia
A UN-REDD programme study

2009

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by

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# Report outline



# List of acronyms

| | |
|---|---|
| COP | Conference of the Parties |
| FAO | Food and Agriculture Organisation of the United Nations |
| FRA | Forest Resources Assessment |
| GHG | Green House Gas |
| IPCC | Intergovernmental Panel on Climate Change |
| LULUCF | Land use, Land-use Change and Forestry |
| MRV | Measuring, Reporting and Verification |
| MTENR | Ministry of Tourism, Environment and Natural Resources |
| NFMA | National Forest Monitoring and Assessment |
| REDD | Reducing Emissions from Deforestation and Degradation |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNDP | United Nations Development Programme |
| UNEP | United Nations Environment Programme |
| ZFD | Zambian Forestry Department |

# 1. Introduction and background

Reducing Emissions from deforestation and forest degradation (REDD) may play a significant role in climate change mitigation and adaptation. Additionally, it has the potential to yield significant sustainable development benefits and generate a new financing stream for sustainable forest management in developing countries. The Bali Action Plan, adopted by the United Nations Framework Convention on Climate Change (UNFCCC) at the thirteenth session of its Conference of the Parties (COP-13) held in Bali in December 2007, mandates Parties to negotiate a post 2012 instrument, including possible financial incentives for forest-based climate change mitigation actions in developing countries. COP-13 also adopted a decision on “Reducing emissions from deforestation in developing countries: approaches to stimulate action”. This decision encourages parties to explore a range of actions, identify options and undertake efforts to address the drivers of deforestation and forest degradation (UN-REDD Programme 2008). The Bali Action Plan also highlighted the importance of “measurable, reportable and verifiable” (MRV) greenhouse gas mitigation actions and commitments (OECD and IEA 2009).

In response to the COP-13 decision, requests from countries, and encouragement from donors, FAO, UNDP and UNEP developed a collaborative REDD programme. A multi-donor trust fund was established that allows donors to pool resources and provides funding to activities towards this programme. During the pilot phase of this programme, country programmes are being developed under the UN Joint Programme Modality, and with strong linkages to related programmes and activities in the countries. Development of MRV systems plays a significant role in preparing countries for REDD readiness.

## 1.1. Purpose

The overall purpose of the study has been to establish a starting point for developing the elements of a MRV system required under a potential REDD scheme for the Republic of Zambia. Zambia has been selected as one of nine pilot countries for the UN-REDD programme. By analysing existing field data from the Integrated Land Use Assessment (ILUA) in Zambia, collected in the period from 2005 to 2007 and completed in 2008, in conjunction with ancillary information, the study had the following objectives:

- Provide national level carbon stock assessment by land use category and carbon pool, with statistical precision measures;
- Compare above findings with previous estimates and reports and analyse the differences;
- Make projections of potential carbon mitigation/sequestration in each land use category under different scenarios of land use developments;
- Evaluate current estimates and reports of emissions from deforestation against the above results;

The study also seeks to demonstrate how the selection of methods for estimating forest carbon stock will influence the final estimate and discuss in brief what this will imply for any future REDD payment scheme. In order to structure the report and guide the way of thinking, the following working questions were developed:

1. *Based on forest inventory data, how can national level carbon stock in Zambia be estimated for various land use categories and carbon pools and within what range are the estimates?*
2. *What data are available for estimating deforestation in Zambia and what is the estimated annual deforestation rate?*
3. *Based on historical data and carbon stock estimate derived from ILUA data, what has been the annual decrease in forest carbon stock from deforestation and degradation in Zambia?*
4. *What are the potential scenarios for REDD in terms of land-use development in Zambia?*

During the working process it was realised that not all working questions could be evenly well answered. Data base querying and data analysis required substantial time and research, virtually consuming most of the allocated time. At the same time, it was during the field work realised that it was impossible to access all the wanted information. Main focus in the present report has been placed on answering question 1 and 2 while questions 3 and 4 have received less attention. The latter therefore remain subjects for further investigation.

The study was carried out in close collaboration with FAO staff members in the National Forest Resources and Assessment (NFMA) programme and the Zambian Forestry Department (ZFD) under Ministry of Tourism, Environment and Natural Resources (MTENR). FAO's Division of Environment, Climate Change and Bio-energy (NRCD) provided supervision along the study course.

## 1.2. Working process

The study was undertaken during two and a half month from late February to late June 2009. The working process for the consultancy involved 4 main phases: literature review, data analysis, field work and writing/presentation of results.

To ensure that the study was carried out in concurrence with national research initiatives and other national MRV related activities it was found pertinent to establish collaboration with national stakeholders to the widest extent possible and get their input to the study. In particular the ZFD was thought to have a pivotal role as they tentatively have been assigned as the lead technical governmental entity for a future REDD programme in Zambia. For that reason, staff members of ZFD appointed as focal points for the UN-REDD programme as well as personnel responsible for the ILUA project were consulted throughout the study period. However, due to the limited experience held at ZFD in conducting studies of this nature, the main work remained in the hands of the FAO consultant.

### Literature review

In order to make certain that the report incorporated the optimal methods for estimating carbon stock based on inventory data, a review of state-of-the art studies was carried out. It was found that suitable methods for Africa are not well explored and very few empirically based studies have been made on carbon stock estimation. Likewise, a considerable amount of time was allocated to the search for ancillary data that could shed light on historical deforestation rates and drivers of carbon emission from forest conversion and degradation.

### Data analysis

The main data source for this study has been the ILUA which was carried out in Zambia during the period from 2005-2008. National wide and systematically sampled field data was analysed by applying methods identified through the literature review. Ancillary data was subsequently used for comparison and further analysis of carbon stock changes over time. An important element in the data analysis was the collaboration with the NFMA technical team which, together with the ZFD, has had the main responsibility for collecting the ILUA field data. The NFMA team has substantial experience in analysing and processing similar forest inventory data and provided technical input throughout the study. Results that came out of the ILUA project and published in the final project report (ZFD/MTENR and FAO 2008a) have been incorporated in the current study where relevant.

#### Field work

During two weeks from 3- 15 May, fieldwork was undertaken with the purpose of presenting preliminary study findings to national stakeholders, establish collaborative working arrangements and to seek input from national stakeholders for the remaining analysis and writing process. The field work also served as an opportunity for collecting ancillary data.

The mission coincided with at joint UN-REDD scoping mission with members from UNDP, UNEP and FAO. The consultant attended the week long mission which was found highly relevant in understanding the need for MRV in Zambia and how the present report could tap into already existing national MRV related activities.

Annex I presents an outline of the entire mission undertaken for this study.

#### Writing

Writing was carried out from end May to end June 2009.

## 1.3. Limitations and assumptions

A number of limitations and assumptions were required to confine the analysis and meet the expected outputs within the allocated time. Production of scientifically 'bullet proof' results require large time investment or very narrow study objectives and in depth analyses. This study seeks to explore several elements of MRV for REDD, each of which in principle individually could justify for elaborate and lengthy scientific research. Substantial scientific research in this field of work is currently being undertaken in the academia and it would be beyond the scope of this study to unveil all elements of carbon stock assessment. Consequently, this study should be perceived as but one element of the toolbox for establishing a MRV system for REDD with special focus on the South African region. The current report has striven to provide the best possible results within the allowed time frame and with the available data.

Though it is recognised that data obtained with remote sensing methods can play an important role in monitoring green house gases (GHG) emission from forest cover changes this category of data has only been applied to a minor extent in this study, namely as a source of information to estimate forest cover change. In the case of Zambia, inventory data has been considered useful as being the most comprehensive and accurate information source for carbon stock estimation.

It is assumed that the reader of the current report has a general knowledge about the relationship between land use changes and carbon emissions as well as the carbon cycle in general. The report does not go into details on these topics. The study follows the widely recognised definitions provided by FAO in the Global Forest Resources Assessment (FAO 2006) and IPCC (IPCC 2006) on land use classification, land use changes and the linkages to carbon emissions. The land use classification applied in the case of Zambia can be viewed in table 7. As for the technical definitions in estimation of carbon stocks, the IPCC 2006 guidelines for National Greenhouse Gas Inventories (in the remainder referred to as IPPC 2006 guidelines) as well as the study by S. Brown (1997) have been used as main references. The selection of methodologies for estimating carbon stock has been drawn from a number of scientific studies.

## 1.4. Information sources

This study draws on mainly three sources of information:

- Scientific literature, including the IPCC 2006 guidelines (table 1)
- National historical studies providing ancillary information of forest status
- The Integrated Land Use Assessment (ILUA) for Zambia (ZFD/MTENR and FAO 2008a).

**Table 1** List of main scientific references that were found useful in the study.

| **Generic studies on carbon estimation in tropical forests** |
|---|
| Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper no. 134 Rome. |
| Brown, S., Gillespie, A. and Lugo, A.E. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science. 35, 881–902. |
| Brown, S. and Gaston, G. 1995. Use of forest inventories and geographic information systems to estimate biomass density of tropical forests: applications to tropical Africa. Environmental Monitoring. 38, 157–68. |
| Brown, S. 2002. Measuring carbon in forests: current status and future challenges. Environmental Pollution. 116, 363–72. |
| Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers. C.Q., Eamus, D. Fölster, -h., Fromard, F., Higuchi, N., Kira, T., Lescure, J-P., Nelson, B.W., Ogawa, H., Puig, H., Riéra, B., Yamakura, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests Oecologia 145 87–9 |
| Gibbs, H.K., Brown, S., Niles, J.O. and Foley, J.A. 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environmental Research Letters (2). |
| IPCC 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Ed. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (Japan: Institute For Global Environmental Strategies). |
| **Ecosystem and region specific studies related to carbon estimation** |
| Chidumayo, E.N. 1993. Zambian charcoal production: miombo woodland recovery. Energy Policy 12, 586-597. |
| Chidumayo, E.N. 1994. Inventory of wood used in charcoal production in Zambia. A report for the Biodiversity Support Program, World Wildlife Fund, Washington DC. |
| Hofstad, O. 2005. Review of biomass and volume functions for individual trees and shrubs in Southeast Africa. Journal of Tropical Forest Science 17 (1): 151-162. |

As for national historical information, a significant number of studies have been conducted in the past, but there are few review studies that have attempted to provide a thorough overview and analysis of the forest cover trend. In addition, most of the previous surveys are undertaken independently and are not directly comparable. In this study, and as a result of this lack of overview, two references have been used as main information sources: The FRA 2005 country report for Zambia (FAO 2006b) and the 2003 Forestry Support Program Inventory (FSP 2003). While the former is making estimates of forest status trends based on a few historical data set sets, the latter provides and short review of past inventories as well as updated and independent inventory data. Table 2 originates from the FSP 2003 report and provides an overview of previous forestry inventories and assessments.

Finally, also the National Green House Gas inventory for Zambia from year 2000 (MTENR 2000) and the draft version from 2007 (ECZ 2007) have been used in this study for the purpose of comparison.

### Integrated Land Use Assessment (ILUA)

In recognition of the lack of sound and reliable national level forest resource information for Zambia, the integrated land use assessment (ILUA) was initiated in 2005. The ILUA is based on a standard national forest assessment (NFA) approach developed by FAO, which has been applied in several other countries since 2000, mainly in developing countries (e.g. Costa Rica, Guatemala, Honduras, Lebanon, Cameroon, The Philippines, Bangladesh and Nicaragua), and is ongoing in a number of other countries. The NFA design has been developed to ensure that a holistic set of data is collected to meet a number of national and international information requirements. Elaborate description of the NFA methodology is available at the webpage of FAO's programme for National Forest Monitoring and Assessment (NFMA) (www.fao.org/forestry/nfma).

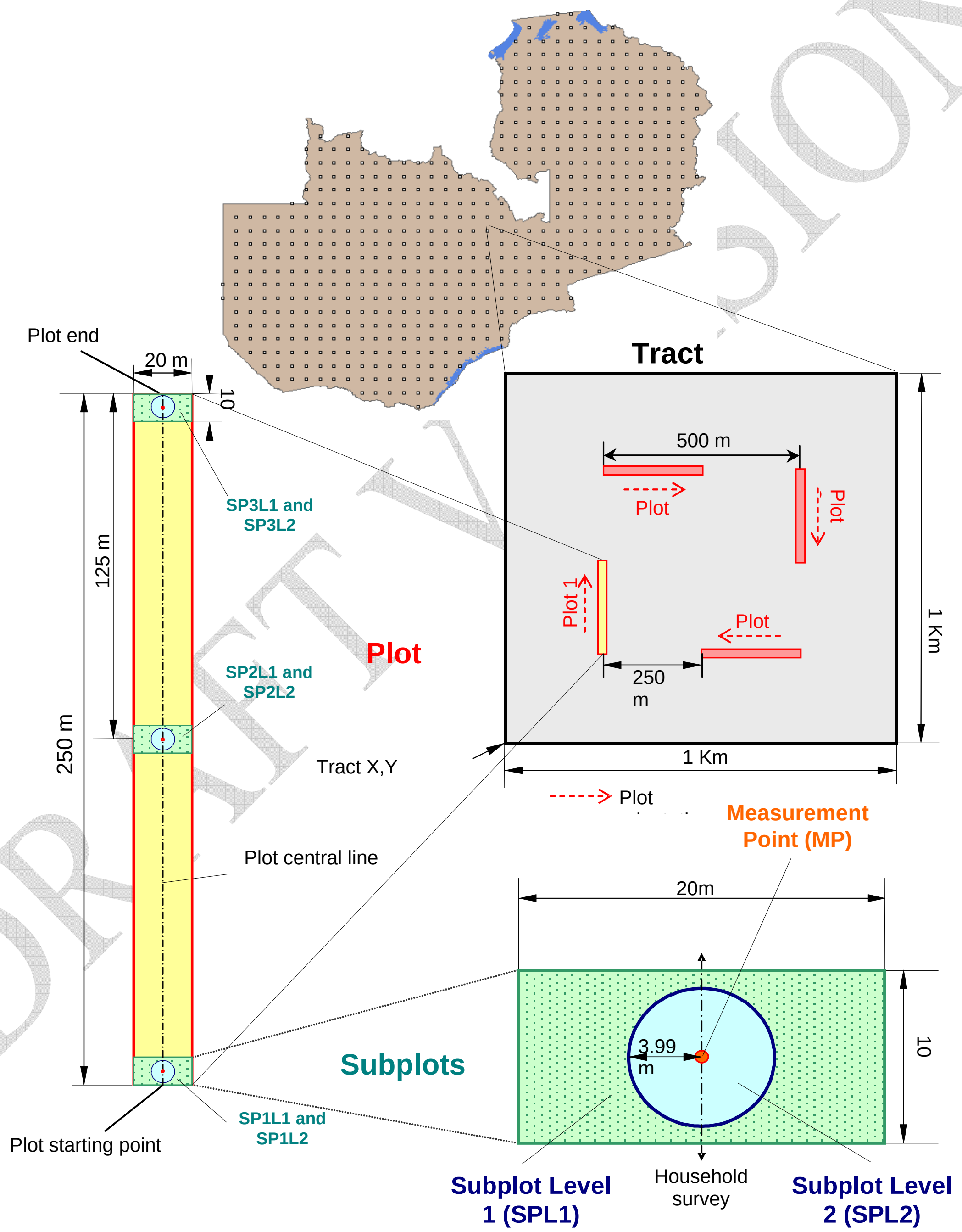




**Figure 1** Map showing the distribution of the permanent sample plots and the layout of the field plots (ZFD/MTENR and FAO 2008).

Though the core set of variables in the standard NFA approach relates to forest resources, in the case of ILUA, the assessment was extended to the sectors of agriculture and livestock. The main bulk of data collection for ILUA was conducted in 2006 (consequently, for the remainder of the report, the reference year for the ILUA data will be set to 2006) while data processing and analysis mainly was carried out in 2007.

The data was acquired through field surveys in permanent established sample plots spread across the country and consisted of field measurements, observations and local interviews which captured data related to forestry, livestock and agriculture. In additional, spatial land-cover data was generated from Land-sat Imagery from 2000 and 2005. Figure 1 depicts the layout of the sample grid and plots. The ILUA data was collected in 248 permanent sample units (often referred to as 'tracts') established systematically throughout the country at the intersections of every 30 minutes on the latitude/longitude grid. Out of the total 248 sample units, 221 of the sample units were actually inventoried (the remaining 27 sample units were left out mainly due to inaccessibility). Each sample unit (1 x 1 km) consisted of a cluster of 4 sample plots (20 m x 250 m) in which data collection was carried out. Within the sample plots, two levels of subplots were marked out in which, among other things, seedlings and smaller dimension trees were measured. Besides the bio-physical measurements in the plots, socio-economic variables were surveyed in the surrounding area following supplementary sampling procedures. In total 433.1 ha was captured in the sample, translating into a sampling intensity of approximately 0.000006%. The data set contains measurements of diameter at breast height (dbh), total height, commercial height, major branches, species, health state, etc. of 26519 trees, out of which 18420 (29%) belong to the diameter class of dbh $\geq$ 20 cm and 8099 trees (31%) to the diameter class with dbh < 20 cm.

**Table 2** Synopsis on the development of Zambian forest inventories 1932-2004 (FSP 2003).

| Period | Inventory |
|---|---|
| 1932 - 1936 | Sample plots established near Ndola to determine the productivity of Miombo woodlands. |
| 1942 - 1944 | The first extensive forest inventory identifying and estimating the timber volume availability for Copperbelt Province mines. |
| 1949 - 1951 | Small-scale forest inventory identifying and estimating the timber volume for Western Province concession harvesting. |
| 1952 - 1967 | Large-scale inventory for District Forest Management Books covering all the Districts in the country. |
| 1972 | Timber and woodland survey of East Luangwa, PFA No. 170 |
| 1984 - 1986 | First estimate of Zambia's woody biomass resource: Wood consumption and supply survey at national level. |
| 1987 | Second estimate of Zambia's woody biomass resource: SADC wood energy study based on small-scale satellite imagery. |
| 1994 - 1996 | Forest resources management study for Zambezi Teak forests in south-western Zambia in co-operartion with the Japan International Cooperation Agency (JICA). |
| 1996 | Forest inventory for Mulungushi West forest reserve, in Central Province and for Mwewa forest reserve, in Luapula Province under the Provincial Forest Action Programme (PFAP). |
| 1996 - 1998 | Forest inventories in Copperbelt, Luapula and Southern Provinces under PFAP, Phase I. |
| 1997 | SADC estimate of Zambia's forest area: 29.4 million hectares. |
| 1999 - 2001 | Forest inventories in Copperbelt, Luapula and Southern Provinces under PFAP, Phase II. |
| 2000 | FAO 2000 estimate for Zambia's forest area: 31.2 million hectares. |
| 2001 | Local forest inventories in the Central Province under the Environmental Support Programme (ESP). |
| 2002 - 2003 | Forest inventories in all nine provinces: Central, Copperbelt, Eastern, Luapula, Lusaka, Northern, North-Western, Southern and Western Provinces under the Forestry Support Programme (FSP). |
| 2004 | Fourth estimate of Zambia woody biomass resource: FSP |
| 2005 - 2008 | Integrated Land Use Assessment (ILUA) covering the whole country |

It is important to emphasis that the ILUA only provides data for one-point in time. Obtaining trend data for estimating carbon loss from land use changes is therefore not an option but would require sequential assessments or alternatively, ancillary data from past inventories. Though, historical data set are not easily available, in particular not an African country like Zambia. In the case of Zambia, only few inventories have been conducted that can be aggregated to national level and compared across time (as mentioned above and outlined in table 2). A favourable alternative is to estimate changes in forest area extent by use of remotely sensed data. However, generating reliable data using remote sensing techniques requires a high level of technical capacity, which is probably one of the reason why barely any national wide remote sensing studies, with the objective of assessing the land cover changes in Zambia, have been identified for this study. The remote sensing study, undertaken under the ILUA project, is the only available study of that nature allowing for analysis over time and approximation of forest cover changes.

# 2. Methods for calculating biomass and carbon stock

This chapter covers first part of working question 1:

***Based on forest inventory data, how can national level carbon stock in Zambia be estimated for various land use categories and carbon pools*** *and within what range are the estimates?*

## 2.1. Selection of method

Though remote sensing methods are often found advantageous in many circumstances for estimating carbon stock in forests, ground based inventories may be found more feasible in some cases, in particular in developing countries. Furthermore, carbon losses that are not caused by directly by deforestation but associated with forest degradation can be difficult to detect with optically based remote sensing methods. This as opposed to ground inventory methods, which in addition are attributed by the ability to incorporate other variables than those needed for pure carbon accounting. In the context of REDD, reducing emissions will require monitoring of e.g. the drivers of deforestation and the environmental impact of REDD related actions (UN-REDD Programme 2008). Table 3 originates from Gibbs et al. 2007 and outlines the benefits and limitations of available methods in estimating national-level forest carbon stocks. Their conclusions suggest that field inventories, as for example done in the ILUA, are simple to implement, provides estimates with low uncertainty and a good approach in countries with low capacity and labour costs. On the downside, field inventories might be expensive and slow to undertake .

Compared to ecological studies that are usually limited in geographical extent and most often not representative to a national scale, forest inventory data are preferable (Brown 1997). In that context, the ILUA approach has a number of advantages compared to a conventional forest inventory:

- ILUA contains forest data beyond the mere commercially interesting forest types, species and diameter classes;
- ILUA data has precise measurements of all trees observed in the field with dbh above or equal to 7 cm, both inside and outside forests;
- All ILUA data are georeferenced and detailed information is stored for all plots and trees;
- Permanent sample plots are established, useful for land use and carbon stock change estimates;
- The ILUA approach follows international agreed definitions and standards;
- ILUA takes a holistic approach capturing all dimensions related to forest management such as forests' environmental and socio-economic functions.

On the less positive side, a recent technical evaluation of the NFMA programme suggested that the inventory design, as also applied in ILUA, has the disadvantage of using a rather sparse sampling design. As a result, change estimates (e.g. in carbon stock or land use areas), which are often small, are difficult to detect or are associated with large sampling errors. However, the evaluation also concludes that the approach suits well the requirements for UNFCCC LULUCF (Land use, Land-Use Change and Forestry) reporting, both in terms of scope and precision (ZFD/MTENR and FAO 2008b).

**Table 3** Benefits and limitations of available methods to estimate national-level forest carbon stock (Gibbs et al. 2008).

| Method | Description | Benefits | Limitations | Uncertainty |
|---|---|---|---|---|
| Biome averages | Estimates of average forest carbon stocks for broad forest categories based on a variety of input data sources | • Immediately available at no cost<br>• Data refinements could increase accuracy<br>• Globally consistent | • Fairly generalized<br>• Data sources not properly sampled to describe large areas | High |
| Forest inventory | Relates ground-based measurements of tree diameters or volume to forest carbon stocks using allometric relationships | • Generic relationships readily available<br>• Low-tech method widely understood<br>• Can be relatively inexpensive as field-labor is largest cost | • Generic relationships not appropriate for all regions<br>• Can be expensive and slow<br>• Challenging to produce globally consistent results | Low |
| Optical remote sensors | • Uses visible and infrared wavelengths to measure spectral indices and correlate to ground-based forest carbon measurements<br>• Ex: Landsat, MODIS | • Satellite data routinely collected and freely available at global scale<br>• Globally consistent | • Limited ability to develop good models for tropical forests<br>• Spectral indices saturate at relatively low C stocks<br>• Can be technically demanding | High |
| Very high-res. airborne optical remote sensors | • Uses very high-resolution (~10–20 cm) images to measure tree height and crown area and allometry to estimate carbon stocks<br>• Ex: Aerial photos, 3D digital aerial imagery | • Reduces time and cost of collecting forest inventory data<br>• Reasonable accuracy<br>• Excellent ground verification for deforestation baseline | • Only covers small areas (10 000s ha)<br>• Can be expensive and technically demanding<br>• No allometric relations based on crown area are available | Low to medium |
| Radar remote sensors | • Uses microwave or radar signal to measure forest vertical structure<br>• Ex: ALOS PALSAR, ERS-1, JERS-1, Envisat) | • Satellite data are generally free<br>• New systems launched in 2005 expected to provide improved data<br>• Can be accurate for young or sparse forest | • Less accurate in complex canopies of mature forests because signal saturates<br>• Mountainous terrain also increases errors<br>• Can be expensive and technically demanding | Medium |
| Laser remote sensors | • LiDAR uses laser light to estimates forest height/vertical structure<br>• Ex: Carbon 3-D satellite system combines Vegetation canopy LiDAR (VCL) with horizontal imager | • Accurately estimates full spatial variability of forest carbon stocks<br>• Potential for satellite-based system to estimate global forest carbon stocks | • Airplane-mounted sensors only option<br>• Satellite system not yet funded<br>• Requires extensive field data for calibration<br>• Can be expensive and technically demanding | Low to medium |

Biomass is the main source for carbon stock in tropical ecosystems (Gibbs et al. 2008) and is here defined as the total amount of aboveground living organic matter in trees (including leaves, twigs, branches, main bole and bark) expressed as oven-dry tons per unit area (tree, hectare, region or country). Biomass density is referred to when expressed as mass per unit whereas total biomass for a region or country is obtained from the product of biomass density and the corresponding area

(Brown 1997). Estimation of above ground biomass, which is essentially what ILUA data are able to provide data for, will in most cases be adequate to estimate carbon stock in other pools. The carbon pools and the, for this study, associated methods for estimation of carbon contents are outlined in table 4. Biomass estimations are in this study not restricted to just forests but to all land uses where trees are observed, including closed forest, open forest, woodlands, woody savannas, woodlots, line tree planting, home gardens, living fences, solitary trees, etc.

**Table 4 Carbon pools and methods for estimation as carried out in this study.**

| **Carbon pools** | | **Method used for carbon stock estimation with ILUA data** |
|---|---|---|
| Biomass | Above ground | Applying methods as described in this section. Calculated for all land use categories. Estimates are above IPCC 2006 guidelines tier level 1 (i.e. tier level 2 or 3). Carbon fraction of biomass equal to 0.47. |
| | Below ground | Using look-up tables and correlations with above biomass as provided in the IPCC 2006 guidelines for tier level 1 estimations (below/above ground biomass fraction = 0.28 for tropical dry forest with above ground biomass > 20tonnes/ha. Calculated for all land use categories. Carbon fraction of biomass equal to 0.47. |
| Dead organic mater | Dead wood | Estimated in similar manner as for above ground biomass. Calculated for all land use categories. Carbon in stumps and in dead biomass below ground (roots of dead trees and stumps) have been excluded due to the lack of sufficient data.* Carbon fraction of biomass equal to 0.47. |
| | Litter | Using look-up tables as provided in the IPCC 2006 guidelines for tier level 1 estimates for evergreen (5.2 tonnes carbon/ha), deciduous (2.1 tonnes of carbon/ha) and other natural forest (2.1 tonnes of carbon/ha). For semi-evergreen forest (miombo), the Frost (1996) litter estimate has been applied (5.48 tonnes of biomass/ha) converted to carbon using 0.47 as carbon fraction. Only calculated for forest land use categories. |
| Soil carbon | | Using IPCC look-up tables for tier level 1 estimations. All areas are assumed to contain mineral soils (31 tonnes of carbon/ha). Soil carbon has only been calculated for the land use categories of forest and other wooded land where it is being assumed (following the tier 1 approach) that no change in soil carbon occurs with change of management. |

* The number of stumps and their associated diameter were in fact recorded in ILUA. However, the data do not indicate if a dead tree can be associated with any stump or visa versa or if the individual dead trees are still standing or lying on the forest floor. Consequently, deadwood has only been estimated 'above ground' as there is a risk of double counting if stumps and below ground were included in the calculations.

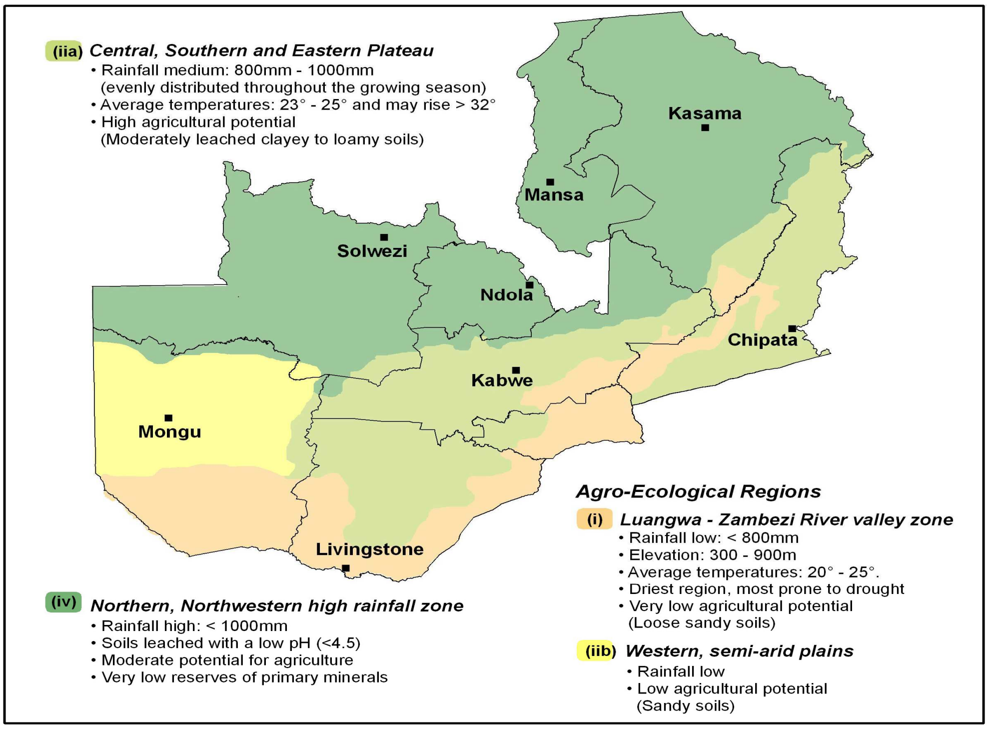


**Figure 2** Climatic zones of Zambia (ZFD/MTENR and FAO 2008a).

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**Table 5** Models applied in this study for estimation of biomass by Zambian climatic zones (see figure 2 above).

| Climatic zone | Description of zone | Models applied |
|---|---|---|
| **Luangwa Zambezi Rift Valleys** | Comprise the low rainfall (semi-arid, < 800mm), low altitude (400-900m), hot and dry areas along the Luangwa and Zambezi Rift Valleys | **i.** $Biomass = (\pi * D^2 * H * 0{,}74) / 4 * BCEF$ |
| | | **ii.** $Biomass = 10^{-0.535 + \log_{10}(pi * D^2 / 4)}$ |
| | | **iii.** $Biomass = \exp(-2.187 + 0{,}916 * \ln(\rho D^2 H))$ |
| **Central, eastern and Southern Plateau** | Consists of a sub-region of the medium rainfall (800-1000mm) plateau including main farming areas on the plateau of Central, Eastern and Southern Provinces. The altitude ranges between 900 and 1300m | **i.** $Biomass = (\pi * D^2 * H * 0{,}74) / 4 * BCEF$ |
| | | **ii.** $Biomass = \exp(-1.996 + 2.32 * \ln(D))$ |
| | | **iii.** $Biomass = \exp(-2.187 + 0{,}916 * \ln(\rho D^2 H))$ |
| **Western Plains** | Relate to a sub-region of the medium rainfall (800-1000mm) plateau comprising the Kalahari (Barotse) sand plateau and the Zambezi flood plains. The altitude ranges between 900 and 1200m | **i.** $Biomass = (\pi * D^2 * H * 0{,}74) / 4 * BCEF$ |
| | | **ii.** $Biomass = \exp(-1.996 + 2.32 * \ln(D))$ |
| | | **iii.** $Biomass = \exp(-2.187 + 0{,}916 * \ln(\rho D^2 H))$ |
| **Northern High Rainfall Plateau** | High rainfall (>1000mm) area in the north and on the plateau. The altitude ranges between 1100 and 1500m | **i.** $Biomass = (\pi * D^2 * H * 0{,}74) / 4 * BCEF$ |
| | | **ii.** $Biomass = \exp(-2.134 + 2.530 * \ln(D))$ |
| | | **iii.** $Biomass = \exp(-2.977 + \ln(\rho D^2 H))$ |

i. Volume equation used by ZFD converted to biomass by applying default BCEF (IPCC 2006)
ii. Allometric regression model by Brown (1997)
iii. Allometric regression model by Chave et al. (2005)

In general two methods exist for estimating above ground biomass using ground based forest inventory data, where this study uses both methods:

A. Use of existing volume density estimates which are then converted to biomass density and;

B. Directly estimating biomass density using biomass regression equations (allometric relationships).

### A. Volume function; BCEF

One approach to estimate biomass is through transformation of available growing stock (in volume) data from forest inventories to biomass. This is the method highlighted in the IPCC 2006 guidelines. A single discrete transformation factors is applied to merchantable volume to derive above-ground biomass. A Biomass Expansion Factor (BEF) expands the dry weight of the merchantable volume growing stock to account for non-merchantable components of the tree. Before applying such BEFs, merchantable volume ($m^3$) has to be converted into dry-weight by multiplying by the basic wood density (D) (tonnes/m3). Alternatively, Biomass Conversion and Expansion Factors (BCEF) can be used which combine the conversion and expansion. BCEF and BEF are mathematically related by: *BCEF=BCEF x D*. The IPCC 2006 guidelines provide default ranges for BEF and BCEF values as well as basic wood density values for some selected species. In this study the BCEF have been applied.

Using volume data to estimate biomass has one main advantage: in many cases the volume data already exists due to the commercial interest in recording stock of wood resources. This situation might even apply for more than one point in time. As outlined earlier in the report, Zambia has had several forest inventories in the past. Of these, the three latest (ILUA, FSP 2003, ZFAP 1996) all use the same volume function. The historical consistency in calculation method across inventories provides an excellent opportunity for comparing volume estimates and eventually biomass estimates. However, the volume function applied was developed from a sample of trees in only one region of the country and might not be representative for the entire country. The function takes into account the merchantable part of tree including branch wood. Having branches already included in the volume function suggests the use of a fairly low BEF, or in our case BCEF. In the subsequent chapters, estimates are made for the low end of the BCEF range as well as the average value (following the default values as provided for tier level 1 estimates in the IPCC 2006 guidelines) in order to illustrate the importance of selecting the right BCEF value. It is also worth to keep in mind that the volume function might be biased due to the geographically limited area for which the model was developed.

### B. Allometric regressions

As a consequence of the limitations mentioned above for using the volume function when estimating national averages of biomass, it was deemed necessary to explore alternative methods. This would allow getting comparative results and at best highlight the optimal model and associated estimate.

One approach could have been to use volume equations of more generic nature that are applicable at national level for Zambia, followed by conversion into biomass with BCEF from look-up tables. However, such volume equations were not found available and would still not eliminate the uncertainty from using default BCEF. Alternatively, a promising approach was found to be the use allometric relationships, allowing estimation of biomass directly from the unprocessed ILUA data. This approach is particularly useful in cases such as ILUA were detailed information is available capturing all species and a large proportion of the diameter classes ($\geq$ 7cm).

In general, allometric relationships can be grouped in two sub-categories:

- Generalized allometric models based on a large number of trees and locations and;

- Allometric models based on local ecological studies with a relative small number of sampled trees and/or species.

The literature review done for this study revealed the striking fact that very few studies have been conducted in Africa that provide allometric equations, and that the few available are very narrow in their geographical coverage and scope: e.g. focus has been on agroforestry systems, only few species or a small number of sampled trees included. Another problem is associated with inconsistencies in study methods and variables causing difficulties when comparing estimates (e.g diameter might be measured at breast height or at stump height and biomass might be presented as dry weight or as fresh weight). This gap in useful generalised allometric models for Africa is also noted by Gibbs et al. 2007 as well as visible in the IPCC 2006 guidelines; the guidelines suggest that in order to reach a tier 3 level of accuracy, allometric equations should be applied. However, only for Europe and The Americas specific studies are being referred to as possible sources.

Irrespectively, that the IPCC 2006 guidelines point towards the advantages of using species-specific allometric equations, contemporary research do not quite agree. Brown 1997 suggests that in cases where the models have to represent the forest biomass density for large areas (as for instance when making national level estimates in a large country like Zambia), models specifically developed for confined ecological zones are not very suitable. Even though the main bulk of Zambian woody biomass is contained in miombo woodlands, many other ecological zones prevail in Zambia. A number eco-zone specific allometric models would therefore be required to match the variability in tree biomass across all ecological zones and vegetation types. Furthermore, though a vegetation type, like for example the miombo forest, might seem as very homogeneous in terms of tree biomass the inherent variability in growing conditions will obviously affect how well an allometric model can apply to all locations within that vegetation type. For that reason, it was decided in this study to apply generalised allometric models, while recognising that these were not explicitly developed for the African ecological zones. This decision is further supported by Gibbs et al. 2007 who make the following conclusion on the use of species-specific models versus generalised models:

*"Tropical forests often contain 300 or more species, but research has shown that species-specific allometric relationships are not needed to generate reliable estimates of forest carbon stocks. Grouping all species together and using generalized allometric relationships, stratified by broad forest types or ecological zones, is highly effective for the tropics because DBH alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions (Brown 2002). Generalized allometric equations also have the major advantage of being based on larger numbers of trees that span a wider range of diameters (Brown 1997, Chave et al 2005). An extensive review of allometric equations concluded that the pan-tropic models were 'the best available' way to estimate forest biomass and recommended them over local allometric models that may be based on less than 100 destructively sampled trees (Chave et al 2004)."*

Two generalized allometric equations were selected, each displaying different levels of complexity.

*Allometric regression with one independent variable*
Some of the most straight forward allometric regression models are those presented by Brown (1997). The models have the advantage of only having one independent variable (diameter at breast height). Secondly, the BCEF default values provided by IPCC 2006 guidelines for tropical forests (and as applied in method A) are to a large extent based on allometric models presented by Brown et al. (1989), which are also the models found in Brown (1997), though here in a refined version.

Yet, the use of these simple allometric models implies a few problems. First of all, the data upon which the regression equations were developed do not represent any African locations. Secondly, due to the high variability of tree biomass with rainfall in dry areas (which apply for most parts of Zambia), this will affect the model's goodness of fit to local conditions (Brown 1997).

*Allometric regression with three independent variables*

Chave et al. (2005) present a number of allometric regressions and tested them for their ability to estimate woody biomass in tropical forests. Unfortunately, this study, apart from being one of the most comprehensive studies providing generic allometric model for tropical forest, suffers from the lack of African field sampling sites. Some bias might therefore be expected when applying the models in Zambia. However, from correspondence with the main author Jerome Chave (Chave 2009, personal comment) and other experts in this field of work, it was decided that no better alternative is available and that the bias involved by applying the models in an African context would be acceptable. Out of the set of models presented in the study, two were found applicable to the climatic zones of Zambia; those for dry tropical and moist tropical zones of Zambia (table 5 and figure 2). Both models exploit the correlation between the independent variables of tree height, dbh and basic wood density and the dependent variable of biomass. While the ILUA data set contains records of both tree height and dbh, basic wood density was not directly available. It was therefore necessary to establish a data base with basic wood densities for each of the 350 recorded species. Two main sources for wood densities were used: the online data base at World Agroforestry Centre (World Agroforestry Centre 2009) and the downloadable Global wood density database (Zanne et al. 2009). The data base established for the current study is found in Annex II. Both of the mentioned sources build on an extensive review of scientific studies. As for the Global wood density database the meta data contains information of the geographical location of the original study. This is not the case in the data base by World Agroforestry Centre. To the widest extend possible basic wood density figures have been used from African tropical or extratropical studies. However, in those cases were no data were available from African studies, wood density figures might originate from locations outside Africa. Another problem found in using global data bases was that for each species several basic wood density figures might be listed. In those instances, a range for each species' basic wood density was established. Consequently, the resulting biomass estimates will also be presented as ranges. For some species no basic wood densities were available. The decision path for assigning species with basic wood densities were as visualised in figure 3.

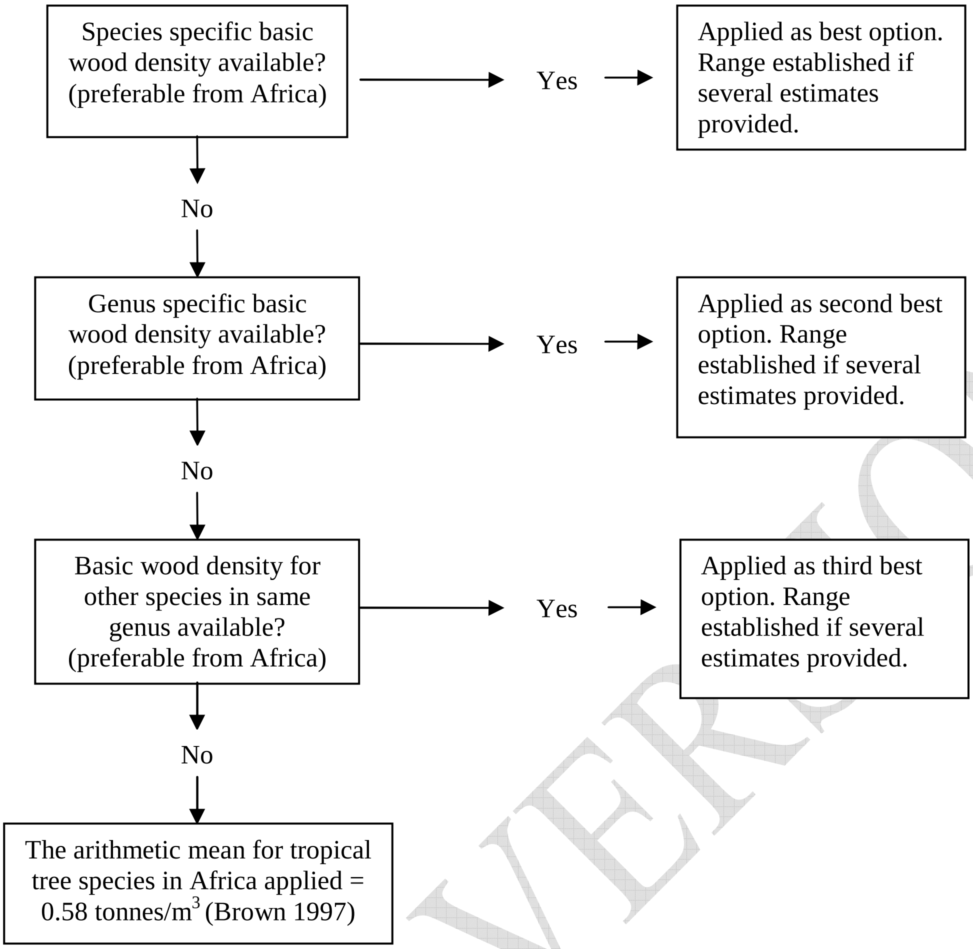


Figure 3 Decision path for assigning basic wood density values to species when calculating biomass.

The effect of using different models and parameters when estimating biomass at tree level is displayed in table 6. It can be seen that already at the lowest level of estimation (tree level), the effect is pronounced. As a means for comparison, an additional volume estimate has been included in the table. This estimate is based on a volume function developed by Malimbwi et al. (1994) (found in Hofstad 2005) for various Miombo tree species in Tanzania and the comparison with the ILUA volume estimate indicates that the latter are somewhat over estimated. This notion has not been further explored in this study.

Table 6 Example from a randomly selected cluster of trees from the ILUA data base, which compares biomass and volume estimates at tree level. The ILUA records are displayed in the first three rows (species name, dbh and height). The method denoted 'Volume; BCEF' refers to the conversion of volume estimates to biomass using BCEF. 'Allometric (*variable*)' denotes the use of allometric equations with the in bracket indicated variables. 'Wd' is short for wood density. Biomass estimates are expressed as dry weight in tonnes.

| Scientific name | Dbh | Height | Basic wood density Low | Basic wood density High | Biomass Allometric (dbh) | Biomass Allometric (dbh; height; low wd) | Biomass Allometric (dbh; height; high wd) | Volume (ILUA) | Biomass Volume; BCEF (Low) | Biomass Volume; BCEF (average) | Volume (Malimbwi et al. 1994)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Julbernadia globiflora | 42 | 17 | 0,72 | 1,08 | 1,51 | 1,10 | 1,65 | 1,74 | 1,74 | 2,61 | 1,29 |
| Combretum molle | 20 | 10 | 0,76 | 0,76 | 0,23 | 0,15 | 0,15 | 0,23 | 0,23 | 0,35 | 0,20 |
| Lannea discolor | 29 | 12 | 0,46 | 0,46 | 0,59 | 0,23 | 0,23 | 0,59 | 0,59 | 0,88 | 0,48 |
| Becium | 37 | 16 | 0,58 | 0,58 | 1,10 | 0,65 | 0,65 | 1,27 | 1,27 | 1,91 | 0,96 |
| Julbernadia globiflora | 28 | 14 | 0,72 | 1,08 | 0,54 | 0,40 | 0,60 | 0,64 | 0,64 | 0,96 | 0,50 |
| Julbernadia globiflora | 26 | 16 | 0,72 | 1,08 | 0,45 | 0,40 | 0,59 | 0,63 | 0,63 | 0,94 | 0,47 |
| Combretum molle | 30 | 16 | 0,76 | 0,76 | 0,65 | 0,56 | 0,56 | 0,84 | 0,84 | 1,25 | 0,62 |
| Erythrophleum africanum | 31 | 15 | 0,88 | 1,08 | 0,70 | 0,64 | 0,79 | 0,84 | 0,84 | 1,26 | 0,64 |
| Pericopsis angolensis | 32 | 11 | 0,72 | 0,72 | 0,76 | 0,41 | 0,41 | 0,65 | 0,65 | 0,98 | 0,56 |
| Maprounea africana | 38 | 10 | 0,47 | 0,72 | 1,18 | 0,35 | 0,53 | 0,84 | 0,84 | 1,26 | 0,74 |
| Pericopsis angolensis | 40 | 18 | 0,72 | 0,72 | 1,34 | 1,06 | 1,06 | 1,67 | 1,67 | 2,51 | 1,21 |
| Lannea discolor | 39 | 17 | 0,46 | 0,46 | 1,25 | 0,60 | 0,60 | 1,50 | 1,50 | 2,25 | 1,11 |
| Diospyros batocana | 41 | 18 | 0,64 | 1,25 | 1,42 | 0,99 | 1,93 | 1,76 | 1,76 | 2,64 | 1,27 |
| Pterocarpus angolensis | 30 | 17 | 0,52 | 0,59 | 0,65 | 0,40 | 0,46 | 0,89 | 0,89 | 1,33 | 0,65 |
| Erythrophleum africanum | 43 | 18 | 0,88 | 1,08 | 1,61 | 1,49 | 1,83 | 1,93 | 1,93 | 2,90 | 1,40 |
| Brachystegia wangermeeana | 21 | 16 | 0,60 | 0,71 | 0,26 | 0,22 | 0,26 | 0,41 | 0,41 | 0,61 | 0,30 |
| Combretum collinum | 11 | 6 | 0,65 | 0,65 | 0,05 | 0,02 | 0,02 | 0,04 | 0,04 | 0,06 | 0,04 |
| Strychnos spinosa | 13 | 5 | 0,65 | 0,65 | 0,08 | 0,03 | 0,03 | 0,05 | 0,05 | 0,07 | 0,05 |

***** The volume function was developed based on 17 trees of various Miombo tree species in Tanzania and includes stem and branches down to 1 cm diameter.

## 2.2. Accuracy and uncertainty

The total error in estimating carbon pools is made up by sampling error (the variation among sampling units), measurement error (error in measuring the parameter of interest, e.g. dbh) and regression error (in the case of this study, the error inherent in the allometric equations and in the conversion of volume to biomass using BCEF). Brown (2002) refers to work done by Phillips et al. (2000), which indicated that sampling error might amount to as much as 90-99% of the total error. It was therefore decided in this study only to consider this element of uncertainty.

The ILUA builds on a multistage sampling approach, with three stages of sampling (sampling units, plots and subplots). Each stage of sampling involves measurements of different variables and diameter classes. Hence, in order to make exact estimates of the sampling error, rather complex calculations have to be carried out – a task that would require considerable amount of time as generalised procedures are not directly available. Instead of exploring the different ways of performing the optimal statistical calculations, it was found reasonable for the purpose of this study to follow the statistical standards as applied and recommended by FAO's NFMA technical staff. Based on past experiences from other NFMA projects and the basic assumption that variation within the 1x1 km sample units is fairly small, it has been found statistically sound by the NFMA technical staff only to consider one level of sampling, namely what has previously been described as the sampling unit (in Figure 1 referred to as "Tract"). Thus, the sampling error is calculated by using the variation in biomass density estimates among the 248 sampling units in the ILUA. In the following sections, the sampling error is displayed by the confidence interval for each estimate. But as explained, the sampling errors (confidence intervals) do not account for fact that the ILUA in principle builds on a multistage sampling design. For a more thorough discussion of the NFMA sampling design, Tomppo and Anderson have made a technical review of the NFMA approach (FAO 2008).

# 3. Biomass and carbon stock estimates using ILUA data

This chapter covers second part of working question 1:

***Based on forest inventory data**, how can national level carbon stock in Zambia be estimated for various land use categories and carbon pools and **within what range are the estimates?***

The following chapter presents findings from the estimation of carbon stocks. Estimates are in the chapter only provided for the global land use categories as applied in FAO's Global Forest Resources Assessment (FRA). Charts are displayed for above ground biomass while tables present carbon stock for the relevant carbon pools. Annex III contains information for the complete set of land use categories following the classification used in ILUA (the classification scheme for Zambia is seen in table 7). Above ground biomass, below ground biomass and dead wood are estimated for all land use categories using the three different methods presented in the previous section. Because some of the methods have been applied using varying magnitude of parameters (for basic wood density and BCEF), the result is 5 different estimates for each land use category. For the land use categories of forest and other wooded land, the estimations are extended to include also the soil carbon pool. While soil carbon estimation models in general are quite complex, the IPCC 2006 guidelines on soil carbon estimation for tier level 1 suggest that soil carbon in forests can be estimated based on a simple model that assumes no effect of management. The IPCC land use categories do not specify the land use category of other wooded land and the assumption is here made that areas falling into this land use category can be treated as forest with regard to estimating soil carbon stock. The carbon stock in litter only applies to forest. Carbon contained in other vegetation than trees, e.g. grass and herbaceous vegetation found in grass land and wetlands, have not been included in this study as the ILUA do not capture these. At the end of the section, comparison is made with carbon stock estimates from other carbon stock studies. It should be noted that it is not the intention of this study to provide the "one and only" estimate, but rather to present estimates using various methods. Verification studies might be needed in the future to enable selection of the most valid method.

Table 8 presents the most fundamental result obtained from the ILUA, namely the land uses by area distribution. Following the FAO definition of forest, 66.4% of Zambia's land surface is covered by Forest. Added to this comes 8% of Other Wooded Lands, while Other Lands make up 21%. Zambia has 4.6% of its land surface covered by Inland Water.

Table 7 Distribution of land use categories as found in the ILUA (ZFD/MTENR and FAO 2008a) following the ILUA land use classification. Highlighted rows indicate main land use categories as applied in FAO's Global Forest Resources Assessment.

| **Forests (=/> 10% Canopy Cover)** | **Area ('000 ha)** | **Proportion of total land area %** |
|---|---|---|
| Evergreen Forest | 819 | 1.1% |
| Semi-evergreen Forest | 34,145 | 45.4% |
| Deciduous Forest | 14,865 | 19.8% |
| Other Natural Forests | 139 | 0.2% |
| Broadleaved forest plantations* | 0 | 0 |
| Coniferous forest plantations* | 0 | 0 |
| **Total** | **49,968** | **66.4%** |
| **Other Wooded Land (5-10% canopy cover or shrubs/bushes canopy cover >10%** | **Area ('000 ha)** | **Proportion %** |
| Wooded Grasslands | 4,897 | 6.5% |
| Shrubs/thickets | 1,158 | 1.5% |
| **Total** | **6,055** | **8.0** |
| **Other land (<5% canopy cover or shrubs/bushes canopy cover <10%)** | **Area ('000ha)** | **Proportion %** |
| Barren Land | 9 | 0% |
| Grassland | 6,085 | 8.1% |
| Marshland | 1,332 | 1.8% |
| Annual crop | 4,700 | 6.3% |
| Perennial crop | 236 | 0.3% |
| Pastures | 464 | 0.6% |
| Fallow | 2,387 | 3.2% |
| Urban | 7 | 0% |
| Rural | 551 | 0.7% |
| Extraction site/mining area | 0 | 0% |
| **Total** | **15,771** | **21.0%** |
| **Inland Water (area occupied by major rivers, lakes and reservoirs)** | **Area ('000ha)** | **Proportion %** |
| Lake | 2,693 | 3.6% |
| River | 774 | 1.0% |
| Dam | 0 | 0% |
| **Total** | **3,467** | **4.6%** |
| **Total Country Area of Zambia** | **75,261** | **100%** |

**Source:** ILUA final report (ZFD/MTENR and FAO 2008a). *None of the sample plots in ILUA felt in plantation forests. While plantations exist in Zambia, though with a relatively insignificant area representation, the ILUA data do not allow for estimation of carbon stocks in those areas.

## 3.1. Forest

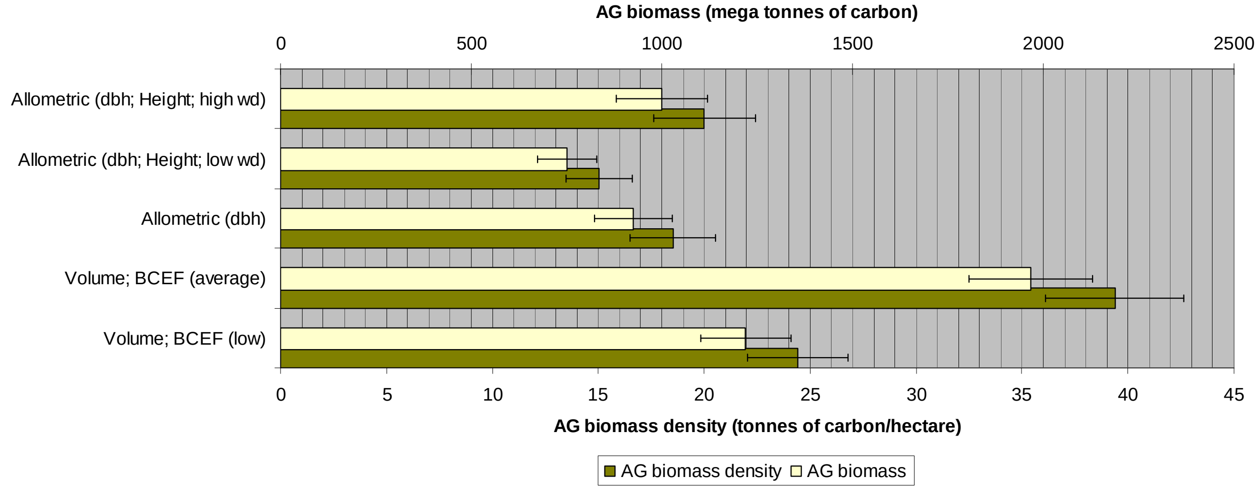


**Figure 4** Carbon stock in the above ground biomass pool for forest land across all forest types in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with the error bars.

From figure 4 and table 8 it is clear that choice of method has a large effect on the final carbon stock estimate. Depending on method, the above ground estimates span from approximately 15 tonnes of carbon/ha to 39 tonnes/ha. However, because of the estimate derived from using the average BCEF default values (using IPCC 2006 guidelines) deviate significantly from the estimates using any other method, it was as previously mentioned considered relevant to disregard this estimate as valid. After removal of this outlying estimate, the range is narrowed down to approximately 15 tonnes/ha – 24 tonnes/ha, which in total figures amounts to 750 – 1219 mega tonnes of carbon. Biomass (above and below ground) is estimate to be in the range of 960 and 1561 mega tonnes of carbon (disregarding the estimate derived from using average level of BCEFs). The total carbon stock (including biomass, dead wood, litter and soil) amounts to between 2652 mega tonnes of carbon and 3323 mega tonnes of carbon. The ratio between live biomass and dead wood biomass above ground is found to be in the range of 0.02 and 0.057.

Not surprisingly for an African country in dry tropical climatic zone, *semi-evergreen forest* (which mainly consists of miombo woodlands) makes up the main bulk of the carbon stock (figure 5). *Deciduous forest* (which includes baikiea forests, kahlari woodlands, mopane woodlands and munga woodlands) also add a significant proportion.

Table 8 Carbon stock in carbon pools for forest land across all forest categories in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with "+/-". The method denoted 'Volume; BCEF' refers to the conversion of volume estimates to biomass using BCEF. 'Allometric (*variable*)' denotes the use of allometric equations with the in bracket indicated variables. 'Wd' is short for wood density.

| Pool, Scale and confidence interval | Method | Volume; BCEF (low) | Volume; BCEF (average) | Allometric (dbh) | Allometric (dbh; height; low wd) | Allometric (dbh; height; high wd) |
|---|---|---|---|---|---|---|
| Biomass AG | Density (tonnes of carbon/ha) | 24,41 | 39,37 | 18,53 | 15,02 | 20,01 |
| | +/- per ha | 2,35 | 3,254815 | 2,025277 | 1,563811 | 2,3997847 |
| | Total (mega tonnes of carbon) | 1219,56 | 1967,002 | 925,8671 | 750,532 | 999,46763 |
| | +/- total | 117,5462 | 162,6134 | 101,1846 | 78,12935 | 119,89534 |
| Biomass BG | Density (tonnes of carbon/ha) | 6,834882 | 11,02384 | 5,188917 | 4,206271 | 5,6014022 |
| | +/- per ha | 0,658774 | 0,911348 | 0,567078 | 0,437867 | 0,6719397 |
| | Total (mega tonnes of carbon) | 341,4767 | 550,7605 | 259,2428 | 210,149 | 279,85094 |
| | +/- total | 32,91293 | 45,53176 | 28,3317 | 21,87622 | 33,570694 |
| Dead wood | Density (tonnes of carbon/ha) | 1,791342 | 3,857677 | 0,677367 | 0,372375 | 0,4705143 |
| | +/- per ha | 0,433884 | 0,878666 | 0,196865 | 0,090767 | 0,130117 |
| | Total (mega tonnes of carbon) | 89,49702 | 192,7329 | 33,84186 | 18,60419 | 23,507304 |
| | +/- total | 21,6772 | 43,89891 | 9,835527 | 4,534779 | 6,5007592 |
| Litter | Density (tonnes of carbon/ha) | 2,475806 | 2,475806 | 2,475806 | 2,475806 | 2,4758058 |
| | +/- per ha | na | na | na | na | na |
| | Total (mega tonnes of carbon) | 123,7111 | 123,7111 | 123,7111 | 123,7111 | 123,71106 |
| | +/- total | na | na | na | na | na |
| Soil | Density (tonnes of carbon/ha) | 31 | 31 | 31 | 31 | 31 |
| | +/- per ha | na | na | na | na | na |
| | Total (mega tonnes of carbon) | 1549,008 | 1549,008 | 1549,008 | 1549,008 | 1549,008 |
| | +/- total | na | na | na | na | na |

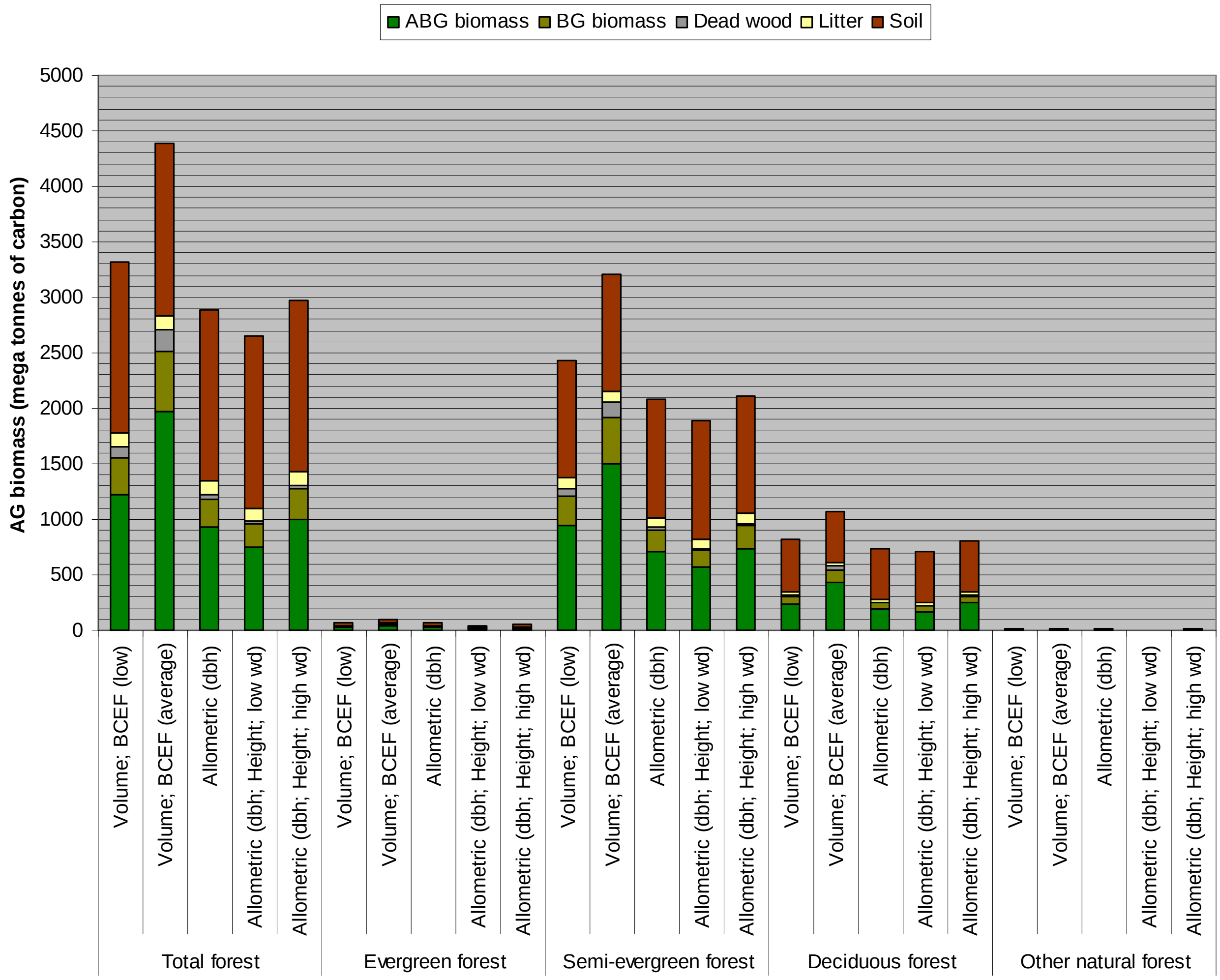


Figure 5 Distribution of carbon stock by carbon pools in the different forest categories in Zambia estimated with different methods (data displayed in table 9).



Table 9 Distribution of carbon stock by carbon pools in the different forest categories in Zambia estimated with different methods (see figure 3).

| | Metod | ABG biomass (M tonnes) | BG biomass (M tonnes) | Dead wood (M tonnes) | Litter (M tonnes) | Soil (M tonnes) | **Total** (M tonnes) |
|---|---|---|---|---|---|---|---|
| **Total forest** | Volume; BCEF (low) | 1219,56 | 341,4767 | 89,49702 | 123,7111 | 1549,008 | 3323,252 |
| | Volume; BCEF (average) | 1967,002 | 550,7605 | 192,7329 | 123,7111 | 1549,008 | 4383,214 |
| | Allometric (dbh) | 925,8671 | 259,2428 | 33,84186 | 123,7111 | 1549,008 | 2891,671 |
| | Allometric (dbh; Height; low wd) | 750,532 | 210,149 | 18,60419 | 123,7111 | 1549,008 | 2652,004 |
| | Allometric (dbh; Height; high wd) | 999,4676 | 279,8509 | 23,5073 | 123,7111 | 1549,008 | 2975,545 |
| **Evergreen** | Volume; BCEF (low) | 27,71207 | 7,759378 | 4,984604 | 4,2588 | 25,389 | 70,10385 |
| | Volume; BCEF (average) | 41,6356 | 11,65797 | 9,774859 | 4,2588 | 25,389 | 92,71622 |
| | Allometric (dbh) | 24,18561 | 6,77197 | 2,449497 | 4,2588 | 25,389 | 63,05488 |
| | Allometric (dbh; Height; low wd) | 13,04847 | 3,653571 | 0,843542 | 4,2588 | 25,389 | 47,19338 |
| | Allometric (dbh; Height; high wd) | 14,84218 | 4,15581 | 1,078783 | 4,2588 | 25,389 | 49,72457 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Semi-evergreen** | Volume; BCEF (low) | 948,6373 | 265,6184 | 70,31401 | 87,94386 | 1058,495 | 2431,009 |
| | Volume; BCEF (average) | 1493,452 | 418,1664 | 150,0022 | 87,94386 | 1058,495 | 3208,059 |
| | Allometric (dbh) | 707,7292 | 198,1642 | 24,52055 | 87,94386 | 1058,495 | 2076,853 |
| | Allometric (dbh; Height; low wd) | 564,7903 | 158,1413 | 13,59523 | 87,94386 | 1058,495 | 1882,966 |
| | Allometric (dbh; Height; high wd) | 739,2881 | 207,0007 | 17,2906 | 87,94386 | 1058,495 | 2110,018 |
| **Deciduous** | Volume; BCEF (low) | 240,2838 | 67,27947 | 13,54902 | 31,2165 | 460,815 | 813,1438 |
| | Volume; BCEF (average) | 427,5253 | 119,7071 | 31,49477 | 31,2165 | 460,815 | 1070,759 |
| | Allometric (dbh) | 190,9087 | 53,45442 | 6,654464 | 31,2165 | 460,815 | 743,049 |
| | Allometric (dbh; Height; low wd) | 171,1245 | 47,91486 | 4,076726 | 31,2165 | 460,815 | 715,1476 |
| | Allometric (dbh; Height; high wd) | 243,3827 | 68,14714 | 5,028937 | 31,2165 | 460,815 | 808,5902 |
| **Other nat. for.** | Volume; BCEF (low) | 2,92634 | 0,819375 | 0,649382 | 0,2919 | 4,309 | 8,995997 |
| | Volume; BCEF (average) | 4,38951 | 1,229063 | 1,461109 | 0,2919 | 4,309 | 11,68058 |
| | Allometric (dbh) | 3,043677 | 0,852229 | 0,217348 | 0,2919 | 4,309 | 8,714154 |
| | Allometric (dbh; Height; low wd) | 1,568792 | 0,439262 | 0,088694 | 0,2919 | 4,309 | 6,697648 |
| | Allometric (dbh; Height; high wd) | 1,954739 | 0,547327 | 0,108984 | 0,2919 | 4,309 | 7,211951 |

## 3.2. Other wooded land

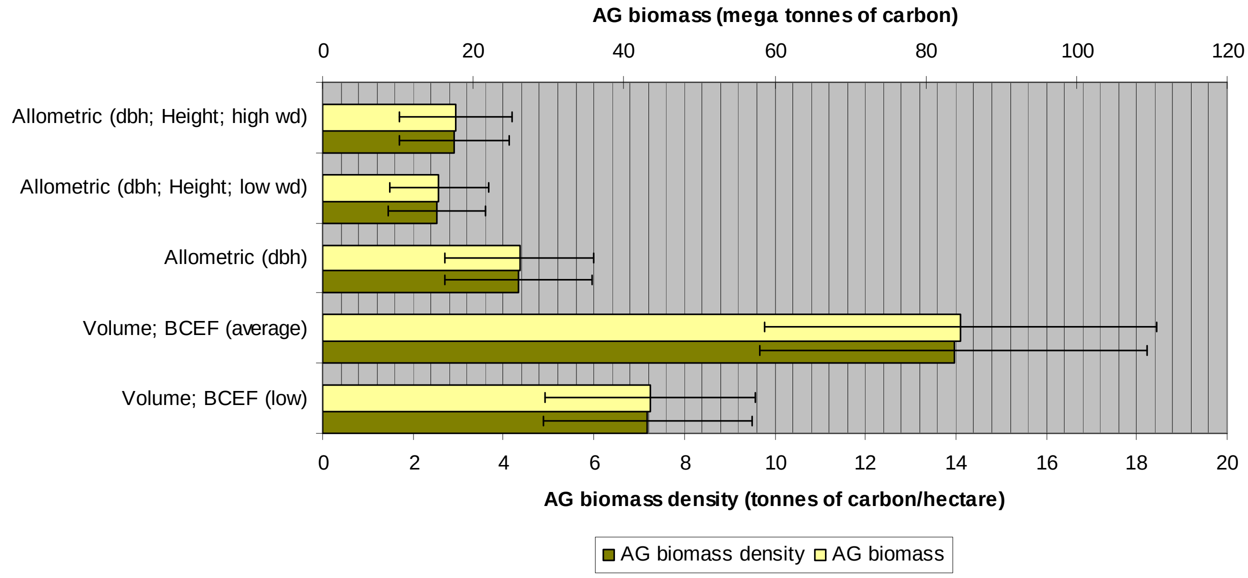


**Figure 6** Carbon stock in the above ground biomass pool for other wooded land in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with the error bars.

*Other wooded lands* contain areas of wooded grasslands with tree cover less than 10% and areas with shrubs and bushes. The biomass (above and below ground) is estimated to be in the range of 22-61 mega tonnes of carbon. The total carbon stock (biomass above and below ground, dead wood and soil) is estimated to be between 210 and 250 mega tonnes of carbon. The data are displayed in details in table 10 and show that soil carbon is making up a significant proportion of the total carbon stock (between 75% and 90%). It should be kept in mind that the biomass figures here only include woody biomass while biomass in grass and other vegetation are not accounted for. Above ground biomass in *other wooded lands* is presented in figure 6.

Table 10 Carbon stock in different carbon pools for other wooded land in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with “+/-“. The method denoted ‘Volume; BCEF’ refers to the conversion of volume estimates to biomass using BCEF. ‘Allometric (*variable*)’ denotes the use of allometric equations with the in bracket indicated variables. ‘Wd’ is short for wood density.

| Pool, Scale and confidence interval | | Volume; BCEF (low) | Volume; BCEF (average) | Allometric (dbh) | Allometric (dbh; height; low wd) | Allometric (dbh; eight; high wd) |
|---|---|---|---|---|---|---|
| Biomass AG | Density (tonnes of carbon/ha) | 7,178815492 | 13,96089521 | 4,318788292 | 2,544918813 | 2,911304522 |
| | +/- per ha | 2,303426902 | 4,281903781 | 1,630347871 | 1,077135111 | 1,22437625 |
| | Total (mega tonnes of carbon) | 43,51762482 | 84,63025696 | 26,18028124 | 15,4271721 | 17,64818417 |
| | +/- total | 13,96326008 | 25,95668916 | 9,883088241 | 6,529539824 | 7,422108334 |
| Biomass BG | Density (tonnes of carbon/ha) | 2,871526197 | 5,584358083 | 1,727515317 | 1,017967525 | 1,164521809 |
| | +/- per ha | 0,921370761 | 1,712761513 | 0,652139148 | 0,430854044 | 0,4897505 |
| | Total (mega tonnes of carbon) | 17,40704993 | 33,85210279 | 10,4721125 | 6,170868842 | 7,059273669 |
| | +/- total | 5,58530403 | 10,38267567 | 3,953235297 | 2,61181593 | 2,968843334 |
| Dead wood | Density (tonnes of carbon/ha) | 0,248116579 | 0,547947314 | 0,142324939 | 0,062539124 | 0,068502795 |
| | +/- per ha | 0,197844022 | 0,438602714 | 0,142633655 | 0,05474679 | 0,060984396 |
| | Total (mega tonnes of carbon) | 1,504070445 | 3,321629542 | 0,862766751 | 0,379109079 | 0,415260561 |
| | +/- total | 1,199320689 | 2,658787983 | 0,86463817 | 0,331872335 | 0,369684394 |
| Soil | Density (tonnes of carbon/ha) | 31 | 31 | 31 | 31 | 31 |
| | +/- per ha | na | na | na | na | na |
| | Total (mega tonnes of carbon) | 187,705 | 187,705 | 187,705 | 187,705 | 187,705 |
| | +/- total | na | na | na | na | na |

## 3.3. Other land

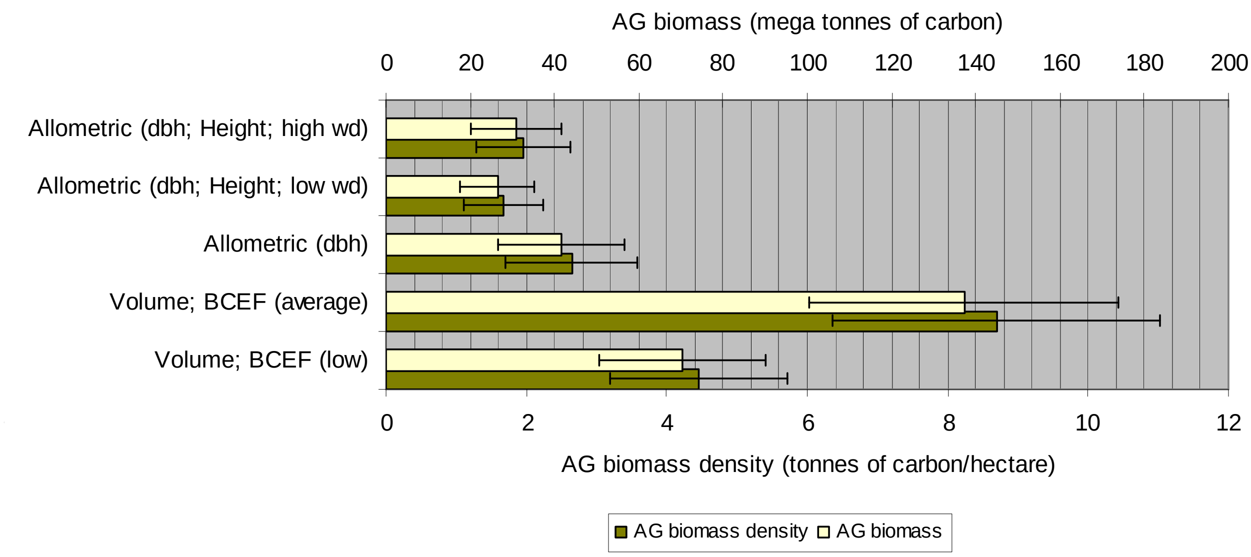


**Figure 7** Carbon stock in the above ground biomass pool for the land use category of other land in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with the error bars.

*Other lands* include all areas not covered in the already covered land use categories and that are not *inland water*. This includes: grasslands, marshlands, barren lands, annual crop, perennial crop, pastures, fallow, urban and rural areas. As for the other main land use categories, the ILUA data set only gives way for estimating carbon stock in woody live and dead biomass, whereas soil and litter has to be estimated based on IPPC default values. Neither does the ILUA record data on biomass contained in non-woody vegetation (e.g. grass and crops). The carbon stock given for the land use category of *other lands* therefore only contains what is being captured from measuring trees (live and dead) larger or equal to 7 cm in dbh. Litter is not considered as a significant carbon pool in land use areas outside forest. Due to the complexity in calculating soil carbon for areas outside forest and other wooded land (the amount of soil carbon is heavily influenced by management practices and land use type) soil carbon has not been calculated for the land use category of *other lands*.

The amount of carbon contained in biomass (above and below ground) *other lands* estimated to be in the range of 37-98 mega tonnes of carbon (table 11). Above ground biomass is presented in figure 7.

Table 11 Carbon stock in different carbon pools for the land use category of other land in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with "+/-". The method denoted 'Volume; BCEF' refers to the conversion of volume estimates to biomass using BCEF. 'Allometric (*variable*)' denotes the use of allometric equations with the in bracket indicated variables. 'Wd' is short for wood density.

| Pool, Scale and confidence interval \ Method | | Volume; BCEF (low) | Volume; BCEF (average) | Allometric (dbh) | Allometric (dbh; Height; low wd) | Allometric (dbh; Height; high wd) |
|---|---|---|---|---|---|---|
| Biomass AG | Density (tonnes of carbon/ha) | 4,45481052 | 8,695795469 | 2,642360895 | 1,678175459 | 1,95646122 |
| | +/- per ha | 1,251006264 | 2,323545775 | 0,947787855 | 0,56683949 | 0,672136495 |
| | Total (mega tonnes of carbon) | 70,25717734 | 137,1420943 | 41,67288758 | 26,46664102 | 30,85550828 |
| | +/- total | 19,72972106 | 36,64482852 | 14,94763898 | 8,939671487 | 10,60031908 |
| Biomass BG | Density (tonnes of carbon/ha) | 1,781924208 | 3,478318187 | 1,056944358 | 0,671270184 | 0,782584488 |
| | +/- per ha | 0,500402506 | 0,92941831 | 0,379115142 | 0,226735796 | 0,268854598 |
| | Total (mega tonnes of carbon) | 28,10287093 | 54,85683771 | 16,66915503 | 10,58665641 | 12,34220331 |
| | +/- total | 7,891888425 | 14,65793141 | 5,979055593 | 3,575868595 | 4,24012763 |
| Dead wood | Density (tonnes of carbon/ha) | 0,234454756 | 0,503843767 | 0,107653265 | 0,05133616 | 0,056808851 |
| | +/- per ha | 0,154248603 | 0,322693227 | 0,066998077 | 0,036366896 | 0,04016472 |
| | Total (mega tonnes of carbon) | 3,697604935 | 7,946160832 | 1,697808359 | 0,80962673 | 0,895936994 |
| | +/- total | 2,432667212 | 5,089221006 | 1,056632097 | 0,573545266 | 0,633441056 |

## 3.4. Inland water

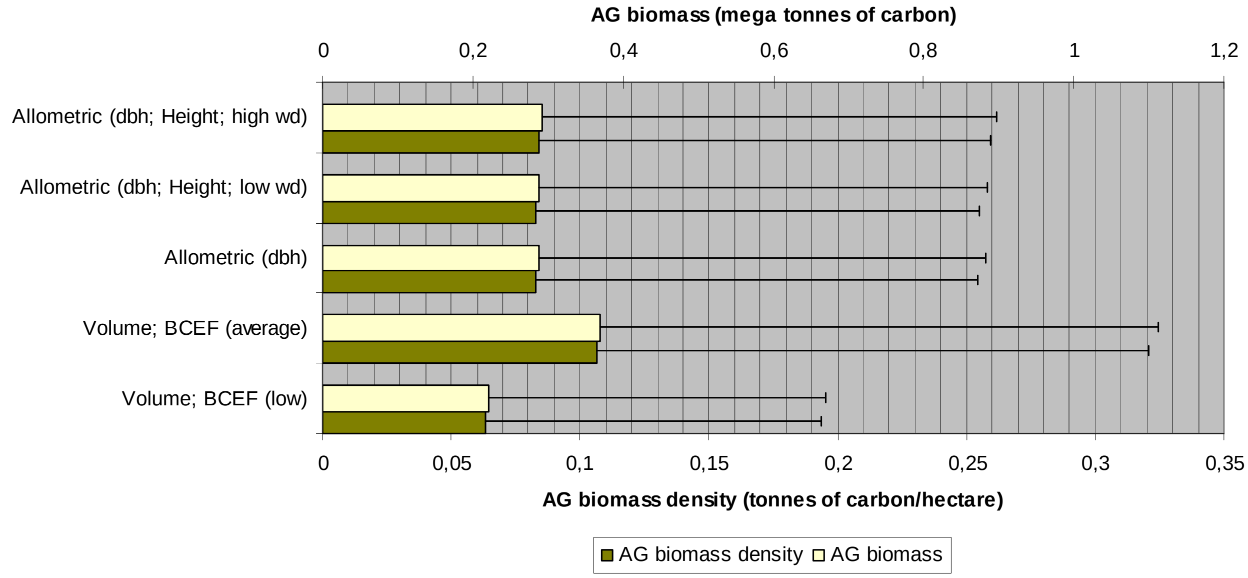


Figure 8 Carbon stock in the above ground biomass pool for the land use category of inland water in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). The confidence intervals indicated with the error bars only display the positive side to avoid negative values.

Lastly, *inland water* (lakes, rivers and dams) is estimated to contain 0.26-0.35 mega tonnes of carbon stored in woody biomass (above and below ground) (table 12). Estimates for above ground biomass alone are presented in figure 8. Like for *other land*, soil carbon and litter is excluded from the calculations.

Table 12 Carbon stock in different carbon pools for the land use category of inland water in Zambia. Estimates are displayed as total amount of carbon (in mega tonnes) and as amount of carbon per hectare (in tonnes). Confidence intervals are indicated with "+/-".The method denoted 'Volume; BCEF' refers to the conversion of volume estimates to biomass using BCEF. 'Allometric (*variable*)' denotes the use of allometric equations with the in bracket indicated variables. 'Wd' is short for wood density.

| Pool, Scale and confidence interval | Method | Volume; BCEF (low) | Volume; BCEF (average) | Allometric (dbh) | Allometric (dbh; Height; low wd) | Allometric (dbh; Height; high wd) |
|---|---|---|---|---|---|---|
| Biomass AG | Density (tonnes of carbon/ha) | 0,06351 | 0,106354923 | 0,082806254 | 0,082907889 | 0,084188768 |
| | +/- per ha | 0,12981 | 0,214544279 | 0,171529715 | 0,172435246 | 0,174867721 |
| | Total (mega tonnes of carbon) | 0,22021 | 0,368785368 | 0,28713043 | 0,287482847 | 0,291924291 |
| | +/- total | 0,45011 | 0,743931625 | 0,594778756 | 0,597918684 | 0,606353283 |
| Biomass BG | Density (tonnes of carbon/ha) | 0,0127 | 0,021270985 | 0,016561251 | 0,016581578 | 0,016837754 |
| | +/- per ha | 0,02596 | 0,042908856 | 0,034305943 | 0,034487049 | 0,034973544 |
| | Total (mega tonnes of carbon) | 0,04404 | 0,073757074 | 0,057426086 | 0,057496569 | 0,058384858 |
| | +/- total | 0,09002 | 0,148786325 | 0,118955751 | 0,119583737 | 0,121270657 |
| Dead wood | Density (tonnes of carbon/ha) | 0 | 0 | 0 | 0 | 0 |
| | +/- per ha | 0 | 0 | 0 | 0 | 0 |
| | Total (mega tonnes of carbon) | 0 | 0 | 0 | 0 | 0 |
| | +/- total | 0 | 0 | 0 | 0 | 0 |

## 3.5. Discussion of estimates

Choice of method for estimating carbon stock strongly affects the magnitude of estimate. It is therefore crucial that studies are made prior to embarking any carbon stock assessment to verify the applicability of the available methods and sub-models (e.g. by conducting destructive sampling of trees to accurately measure biomass).

In order to verify the carbon stock estimates made in this study, comparisons were made with a number of other studies. These are summarised in table 13 and show a very large range. The highest and lowest estimates differ with more than a factor of 6. Gibbs et al. 2007 use the IPCC 2006 guidelines default values to make the estimate which in the table is referenced to as IPCC 2006 and they assume the ecological zone to be tropical dry forest. For this type of forest, the IPCC 2006 guidelines suggest an average of 120 tonnes of carbon/ha which is significantly higher than found in this study (19 -31 tonnes of carbon/ha). Even if we change the assumption concerning ecological zone and let Zambia contain pure tropical scrubland (which is another vegetation type found in Zambia), the IPCC 2006 guidelines default value for this forest type is still found to be high; namely in the range of 20-200 tonnes/ha and with 70 tonnes/ha as average. Only the estimates provided by FRA 2005 and Gibbs and Brown (2007a, 2007b) are in the proximity of what is being suggested in this study. While the FRA figure is based on actual but old biomass surveys, Gibbs and Brown (2007a, 2007b) incorporate human disturbances into their estimate. All other studies assume undisturbed forests.

Table 13 Carbon stock estimates made for Zambia in various studies. All estimates are for above and below ground biomass in mega tonnes of carbon/ha.

| **Original study/data** | Olsen et al. (1983) /Gibbs (2006) | Houghton (1999)/ DeFries et al. (2002) | IPCC 2006 | Brown (1997)/ Achard et al. (2004) | Gibbs and Brown (2007a, 2007b) | FRA 2005 | This study |
|---|---|---|---|---|---|---|---|
| **Reference** | Gibbs et al. 2007 | Gibbs et al. 2007 | Gibbs et al. 2007 | Gibbs et al. 2007 | Gibbs et al. 2007 | FAO 2006 | |
| **Estimate** | 4295 | 3423 | 6378 | 3725 | 1455 | 1156 | 960-1561 |

Compared to FRA 2005 data, the ILUA shows that Zambia has more forest than assumed (42,452,000 ha versus 49,968,000 ha). In terms of carbon stock, the two set of data show estimates that are very close. While the FRA 2005 reports a total biomass carbon stock of 1156 M tonnes (corresponding to an average biomass density of approximately 27 tonnes of carbon/ha), the present study finds this figure to be in the range of 960-1561 (with biomass density ranging from 15-24 tonnes of carbon/ha) (exclusive the outlying estimate derived from using average BCEF values). As the FRA 2005 biomass figures are based on an assumption that no change in biomass density since1969 has occurred (1969 is the year from which the base line data set originates), it indicates that biomass density has decreased with between 3-12 tonnes of carbon/ha in the period from 1969 until present time.

The analysis of ILUA data suggests a dead/live ratio in forest to be in the range of 0.02 to 0.057, which is significantly lower than the ratio of 0.14 as applied in the Zambian country report for FRA 2005. This discrepancy is obviously also reflected in the dead wood carbon stock estimates. While FRA 2005 provides an estimate of 161 mega tonnes of carbon in dead wood, this study suggests a range from 18 to 89 mega tonnes. IPCC 2006 guidelines do not provide any default values on dead wood.

# 4. Estimation of deforestation rates in Zambia

> This section covers working questions 2:
>
> *What data are available for deforestation in Zambia and what is the estimated annual deforestation rate?*

Seven surveys on forest extent have been included in the analysis of deforestation rates in Zambia. The year of assessment, title and results are displayed in figure 9. The data of FRA 2005 are all based on an extrapolation of the assessments by Millington (1989) and Chakanga & Backer (1986) (FAO 2006a). The ZFAP survey from 1996 and the FSP survey from 2003 are both independent studies based on field inventories. The assessment by A. Siampale (forestry officer from ZFD) was a remote sensing study done under the ILUA project (ZFD/MTENR and FAO 2008a). A simple visual comparison of the forest area estimates in figure 9 shows a gradual decline in forest area over the years.

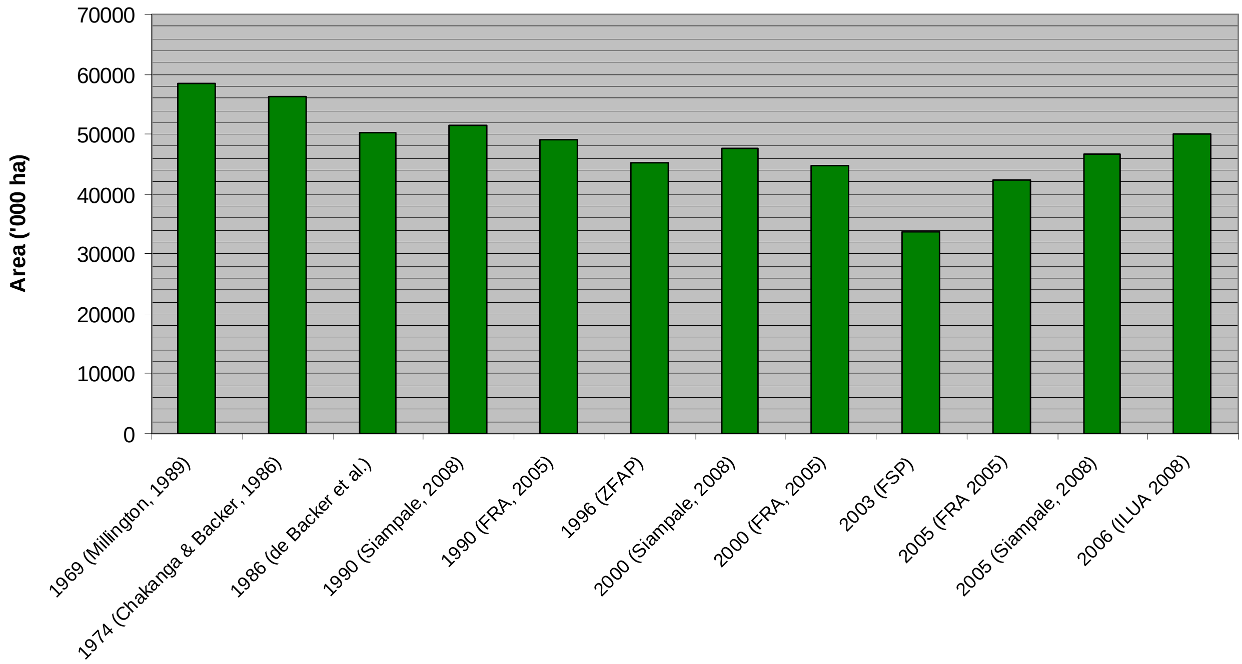


Figure 9 Historical studies quantifying forest extent in Zambia and the associated estimates**.** Reference year and name of survey is displayed for each estimate. 1969, 1974, 1990, 2000 and 2005 estimates are found in FRA 2005 (FAO 2006a). 1986, 1996 and 2003 estimates are found in FSP 2003. Estimates by Siampale for the years of 1990, 2000 and 2005 are provided by ZFD. 2006 estimate originates from the ILUA (ZFD/MTENR and FAO 2008a).

In order to make a more precise estimation of the annual deforestation rate in Zambia, the data from figure 9 was analysed across time. The data plots and associated trend lines are shown in figure 10. Because the forest area estimate from FSP inventory from 2003 is not consistent with the remaining data set it was deemed necessary to exclude this estimate from the time series. Likewise, FRA 2005 data has been excluded as these in principle are tied to the Millington and Chakanga & Backer surveys. The analysis indicates a forest area decline in the period from 1969 to 2006. The annual deforestation rate is found to be approximately 298,000 hectares (can be read from the slope parameter in the regression function). Assuming an above ground biomass density between 15 and

24 tonnes of carbon per hectare (as found in this study), the total change of carbon stock due to deforestation is estimated to be in the range of 4.4-7.2 million tonnes of carbon.

As comparison, FRA 2005 reports the annual deforestation to be in the surroundings of 444,800 ha while Siampale estimates it to be between 250,000 and 300,000 hectares.

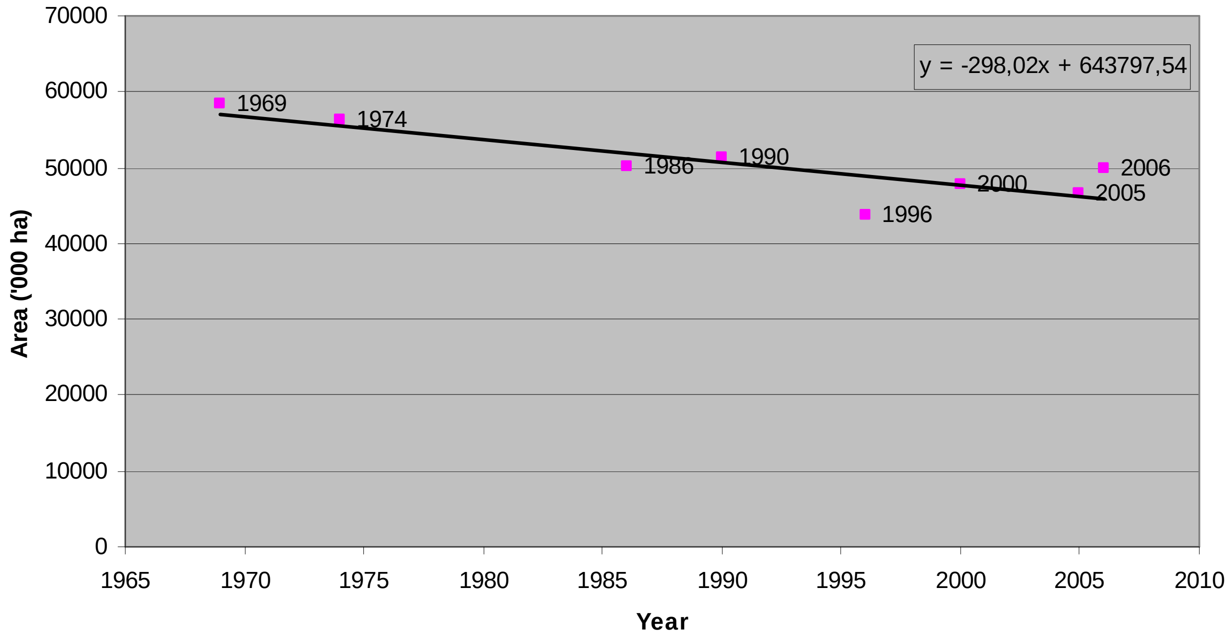


Figure 10 Regression function indicating the annual change in forest extent in Zambia in the period from 1969 to 2006 (ILUA).

# 5. Emissions from deforestation and forest degradation

> This chapter covers working question 3:
>
> *Based on historical data and carbon stock estimate derived from ILUA data, what has been the annual decrease in forest carbon stock from deforestation and degradation in Zambia?*

The loss of carbon in Zambia cannot solely be ascribed to deforestation, e.g. due to removal of forest areas for agricultural expansion and human settlements. Forest degradation plays a significant role in carbon stock reduction in Zambia, with demand for wood energy as main cause. The degree of which forest degradation occurs on the ground is extremely difficult to quantify over large areas by using. However, one approach is to estimate the change of total carbon stock over time. By comparing the five different estimates for above ground biomass as determined in this study with historical data, an approximated loss of carbon stock is estimated (figure 11). Four historical surveys are included in the regression analysis: de Backer et al. (1986), the ETC study (1986), ZFAP inventory (1996) and FSP inventory (2003) (all estimates found in FSP 2003). Though the data sets are not perfectly comparable, they provide the best available information on biomass over time. Only for ILUA, data were available that allowed computing biomass estimates, while information from the remaining surveys were restricted to growing stock estimates (in volume). As a result, to allow comparable estimates, historical growing stock figures had to be converted to biomass. This was done by applying an average BCEF determined from the ILUA data (not to be confused with the average BCEF as provided in IPCC 2006 guidelines) and subsequently converting it into carbon (carbon fraction equal to 0.47). The average BCEF values applied in the conversion of the historical volume data were calculated by relating the above ground biomass carbon stock estimates in forest (as derived from applying each of the five methods) with the ILUA volume estimate. Performing a conversion of volume into biomass back in time requires the assumption that the average relationship between growing stock and biomass at national level did not changed during the course of time. Such an assumption might not hold as a decrease in growing stock level (m3/ha) (which we assume is what has occurred) most probably will affect the BCEF value; the density and BCEF are usually negatively correlated, i.e. the BCEF value decreases with increasing growing stock level. In turn, the older the data set, the less power should the BCEF have. However, this discrepancy is most probably negligible compared to the general level of uncertainty in the comparison of historical data sets.

The regression analysis shows a negative relationship between time and above ground biomass and the annual decrease is found to be in the range of 12.8 – 29.9 mega tonnes of carbon (again the method using the average BCEF level is disregarded, though it interesting to observe for the purpose of comparison). The estimated annual carbon loss can be read in the slope parameter in the regression functions in figure 11. Though the R-squared value is low, this it is not an indication for above ground biomass in forest not being correlated with time, but rather it indicates that time alone cannot explain the variation in the sample of biomass estimates.

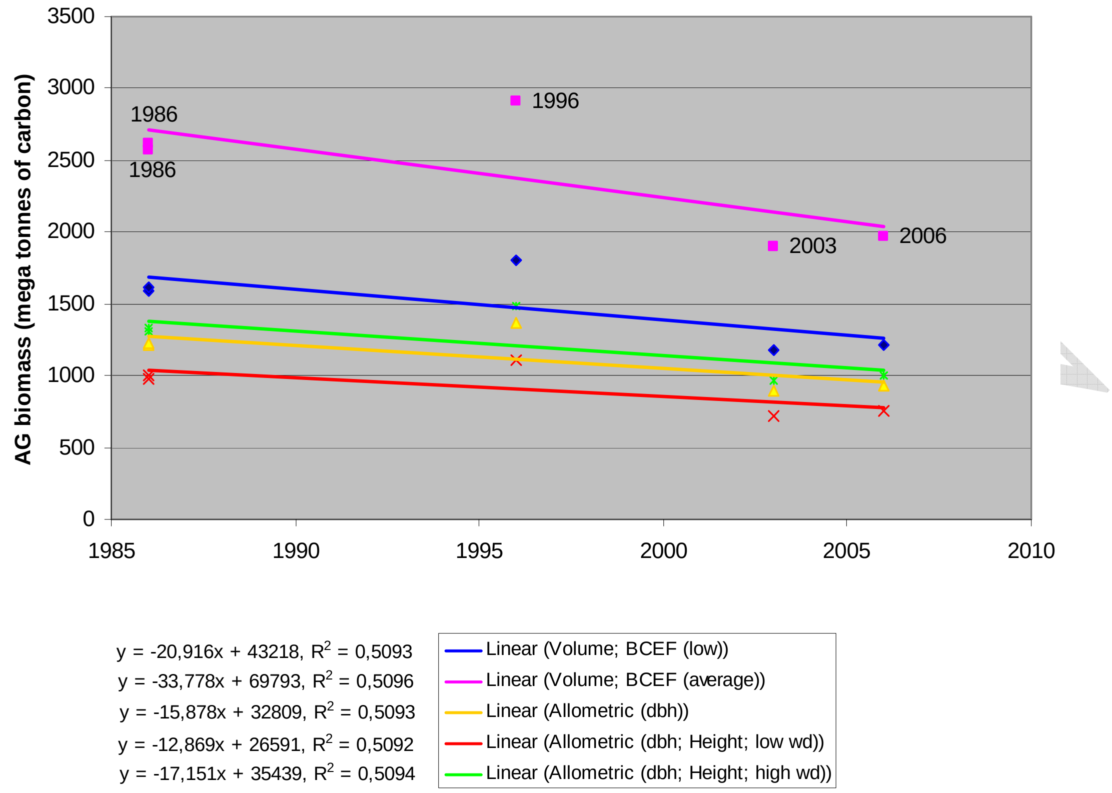


**Figure 11** Regression functions to estimate the annual carbon loss from deforestation and forest degradation in the period from 1986 to 2006 (ILUA) with past inventories as data.

Conclusively, based on analysis of historical data sets, two estimates of annual carbon stock decline are obtained. Firstly, using the change in forest extent and biomass density as variables in determining carbon stock change gives us an annual decrease in above carbon stock in the range of 4.7 – 7.5 mega tonnes of carbon. Using growing stock and biomass estimates as variables yield a loss in carbon stock between 12.8- 29.9 mega tonnes of carbon. The difference between these two estimates could be speculated to stem from forest degradation which is not captured in the change of forest extent. However, uncertainty associated with the measurements without doubt explains much of the discrepancy between the estimates.

The draft national communication for 2005 to be submitted to UNFCCC estimates the annual CO2 emission from forestry and land use change to be 41007 Gg, which correspond to 11 million tonnes of carbon. Out of this, roughly half is assessed stemming from charcoal and wood energy production (ECZ 2007).

The occurring forest degradation is also indicated in a decline in growing stock level over time. Comparison of past inventories reveals an altered standing volume per hectare (table 14). The best comparable inventories are the ZFAP (1996), the FSP (2003) and ILUA (2006), as they are applying similar volume equation as well as involved actual field sampling across the entire country. Though part of the difference between estimates may stem from varying focus of the inventories, it could also reflect the ongoing forest degradation.

**Table 14** Changes in growing stock levels over time by comparing different forest inventories.

| **Inventory** | ZFAP (1996) | FSP (2003) | ILUA (2006) |
|---|---|---|---|
| **Growing stock level (m3/ha)** | 94 | 83 | 55 |

# 6. REDD potentials under different land use development scenarios

This chapter covers working question 4:

*What are the potential scenarios for REDD in terms of land-use development in Zambia?*

Though this part of the study is the least explored, the assessment of carbon stock trends in Zambia indicates a clear decline in woody biomass. This stems mainly from two well known sources: deforestation caused by expansion of agricultural areas and human settlements and forest degradation due to the extensive extraction of wood to meet energy demands (firewood and charcoal). For charcoal alone, a study done under the ILUA programme (ZFD/MTENR and FAO 2008b) estimated that in 2008 the extraction of wood would reach 5.8 million tonnes of biomass, equal to approximately 2.7 million tonnes of carbon (table 15). Potentials therefore exist to mitigate the loss of carbon from both deforestation and forest degradation.

**Table 15** Estimated charcoal production and associated wood consumption. Adapted from ZFD/MTENR and FAO 2008b.

| Year | Charcoal production (million tonnes) | Wood biomass used (million tonnes) |
|---|---|---|
| 1969 | 0.33 | 1.375 |
| 1980 | 0.49 | 2.042 |
| 1990 | 0.685 | 2.854 |
| 2000 | 0.905 | 3.771 |
| **2008*** | **1.392** | **5.800** |

Data sources: Chidumayo (1994); FNDP (2006) and; ILUA data (2008). Note: * = indicates estimated charcoal consumption for 2008 based on population data and average charcoal consumption per capita. Includes both urban and rural charcoal consumption (while the other estimates reflect consumption by urban households only). Urban and rural charcoal consumption is 95% and 5% respectively.



By relating rate of deforestation and rate of biomass loss, the analyses elaborated in the previous sections also indicate a general decrease in biomass density, i.e. forests seem to have lower amount of woody biomass per hectare now than compared to previous periods. This has obvious implications for REDD potentials in Zambia. First of all, the potentials to reduce carbon stock losses are smaller than presumed by other sources (e.g. the IPCC 2006 guidelines, see table 7) as a large proportion of the carbon stock has already been degraded. This historical (and probably also present) pressure on the forest resource should of course influence the establishment of a business as usual baseline for REDD payments. This simply because the historical rate of carbon emission will most probably not continue along the same line but rather slow down together with decreasing biomass density. Furthermore, if deforestation will be used as variable in forecasting emission levels, default biomass density values (as fore example suggested by IPCC 2006 guidelines) should be revised and down graded. On the other hand, and maybe relevant for REDD payments, the gap between the current and historical carbon stock levels leaves much room for sequestration of carbon from the atmosphere, both through reforestation and afforestation.

In order to explore the potential for carbon sequestration in forest, an analysis was made on how the carbon stock depends on the level of disturbance. The ILUA data set contains information about the level of disturbance detected in each sampled land use section. The difference in carbon stock by carbon pool is presented in figure 12. It is important to note that this analysis was only done by using one biomass estimate (i.e. on methodology), namely the one derived from conversion of volume to biomass using low IPCC default values. Because the estimates, as has been seen in chapter 3, so heavily depend on choice of method, the correlation analysis of the carbon stock and disturbance level, therefore should mainly be viewed as an example of the data potential of ILUA. Never the less, the estimates provide an indication of the relative difference between carbon stocks in forest subject to different disturbance levels. Not surprisingly, heavily disturbed forests have a lower biomass density than undisturbed forest (though no statistically significant difference can be proven). Surprisingly though, slightly and moderately disturbed forests have a larger biomass density, which is explained by an increased regrowth subsequent to tree clearing. Chidumayo (1993) finds that plant density in first and second regrowth miombo forest after clearing was 3.6 and 5.7 times respectively than in old growth. It is therefore not possible firmly to conclude that extraction of wood has a negative impact of the remaining biomass. Whether there is a net loss or gain of carbon over time from the extraction of wood will depend on the level of extraction and the annual sequestration from tree increment. Though important for analysing the carbon sequestration potentials in Zambia, these issues are not further explored in this study.

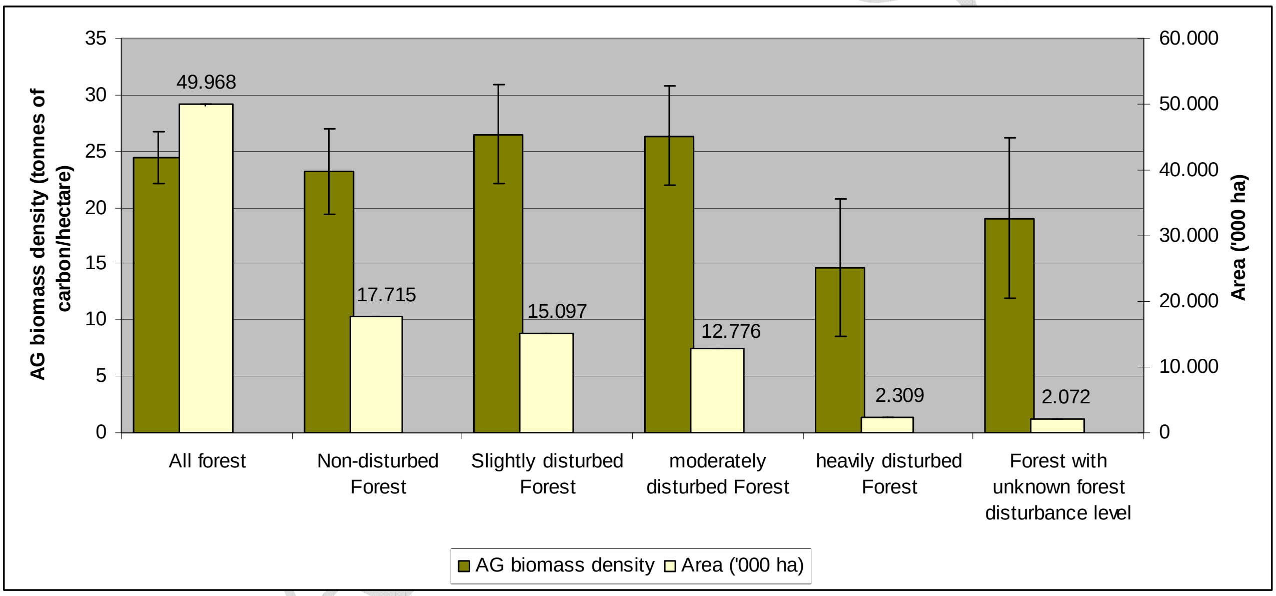


**Figure 12** Distribution of forest areas and above ground biomass density subject to different levels of disturbance. Please note that above ground biomass was estimated based on the conversion of growing stock by applying low range BCEF values.

Apart from the issues already pointed at with potential implication for Zambia's involvement in a REDD agreement, the ecological effects of climate change is a matter to consider. The Zambian National Adaptation Programme of Action (NAPA) from 2007 found that climate changes seem to jeopardize regeneration of miombo forest (MTENR 2007). The Initial National Communication under UNFCCC from 2000 (MTENR 2000) concludes from its analysis that:

*"Projections of future vegetation distribution patterns indicated that under projected climatic variables-1, miombo woodland cover would suffer a 50 percent reduction across the country whereas mopane and munga would predominate. The kalahari and dry evergreen forest (e.g . Cryptosepalum, Parinari and Marquesia) would disappear. For another set of projected climatic variables-2 the country would be predominantly covered by miombo, chipya, kalahari and Cryptosepalum while mopane, munga and Baikiaea species would disappear."*

Again, future ecological changes caused by climate changes will potentially have implications for the outcome of a REDD agreement in Zambia and should be considered in the design phase of such a scheme.

# 7. Conclusion and recommendations

Following the four working questions, the following conclusions can be made:

1. Choice of method for estimating carbon stock strongly affects the magnitude of the estimate and it is therefore crucial that studies are made prior to embarking any carbon stock assessment to verify the applicability of the available methods and sub-models (e.g. by conducting destructive sampling of trees to accurately measure biomass). Applying different estimation methods on field inventory data, it was found that the total carbon stock in Zambian forest amounts to between 2652 and 3323 mega tonnes. Above ground biomass in forest is estimated to be in the range of 960 and 1561 mega tonnes of carbon, which translates into between 15 and 24 tonnes of carbon per hectare. Semi-evergreen forest (miombo) makes up the main bulk of woody biomass in Zambia. The carbon pool in soil is also suggested to contribute considerable to the total carbon stock in forest with an estimated quantity of 1549 mega tonnes. Other land use categories outside forests have not surprisingly insignificant importance compared to forest in terms of carbon storage in woody biomass. The study provides forest carbon stock estimates that are distinguishable different from previous estimates in the literature, which is argued to be caused by overestimation in other studies.
2. Very few forest cover data are available for Zambia that are consistent and comparable over time. Trend estimations are consequently constrained and lack accuracy. For the purpose of estimating annual deforestation in Zambia, the most reliable historical data set was collected and a regression was made with time as the independent variable and forest extent as dependent variable. The analysis suggests an annual deforestation of approximately 298,000 hectares.
3. Another regression was made with the biomass estimates derived from the current study and past forest inventory data on growing stock. The growing stock estimates had to be converted to biomass. The output of the regression suggests that the annual loss in biomass carbon is between 12.8 and 29.9 mega tonnes of carbon. The results indicate that loss in carbon can not only be ascribed to deforestation but that a considerable amount stems from degradation of the remaining forest areas.
4. The potentials to reduce carbon stock losses are smaller than previously suggested in the literature as a large proportion of the carbon stock seems already to have been degraded. This historical (and probably also present) pressure on the forest resource should of course influence the establishment of a business as usual baseline for REDD payments. This simply because the historical rate of carbon emission most probably will not continue along the same line but rather slow down together with decreasing biomass density. Furthermore, if deforestation will be used as variable in forecasting emission levels, default biomass density values (as fore example suggested by IPCC 2006 guidelines) should be revised and down graded. On the other hand, and maybe relevant for REDD payments, the gap between the current and historical carbon stock levels leaves room for carbon sequestration, both through reforestation and afforestation.

A second phase of the ILUA project is currently in the pipeline and should adapt to MRV requirements for REDD. The analysis provided in the present study has the potential to serve as input to the design of next ILUA phase in relation to carbon assessment and the development of

Zambia's REDD readiness position in general. Likewise, already ongoing research projects in Zambia with REDD relevance have to be recognised and included in developing a MRV system. The study revealed that several research initiatives are ongoing in the country and that some capacities are available nationally. It is therefore key to insure close collaboration across governmental and non-governmental stakeholders who are in a position to provide national specific input to the REDD readiness process.

# References


Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer FAO Forestry Paper no. 134 Rome.

Brown, S., Gillespie, A. and Lugo, A.E. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science 35: 881–902.

Brown S and Gaston G 1995 Use of forest inventories and geographic information systems to estimate biomass density of tropical forests: applications to tropical Africa Environ. Monit. Assess. 38 157–68.

Brown S 2002 Measuring carbon in forests: current status and future challenges Environ. Pollut. 116 363–72

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers. C.Q., Eamus, D. Fölster, -h., Fromard, F., Higuchi, N., Kira, T., Lescure, J-P., Nelson, B.W., Ogawa, H., Puig, H., Riéra, B., Yamakura, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests Oecologia 145 87–9

Chave 2009. Email correspondence. May 2009.

Chidumayo, E.N. 1993. Zambian charcoal production: miombo woodland recovery. Energy Policy 12, 586-597.

Chidumayo, E.N. 1994. Inventory of wood used in charcoal production in Zambia. A report for the Biodiversity Support Program, World Wildlife Fund, Washington DC.

FAO 2006a. Global Forest Resources Assessment 2005. Progress towards sustainable forest management. FAO Forestry Paper 147. FAO Rome.

FAO 2006b. FRA 2005 country report. Zambia. No. 062. FAO Rome.

FAO 2008. Technical review of FAO's Approach and Methods for National Forest Monitoring and Assessment (NFMA). NFMA working paper no. 38. FAO Rome.

ECZ 2007. Consulting services for the development of inventory of green house gases fro the environmental council of Zambia. Draft version. Copperbelt environmental project. Environmental Council of Zambia.

FSP 2003. Zambia Forest Resource Assessment 2003. EU – Forestry Support Programme in Zambia – 8 ACP/ 051.

Gibbs, H.K., Brown, S., Niles, J.O. and Foley, J.A. 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environmental Research Letters (2)

Hofstad, O. 2005. Review of biomass and volume functions for individual trees and shrubs in Southeast Africa. Journal of Tropical Forest Science 17 (1): 151-162.

IPCC 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Ed. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (Japan: Institute For Global Environmental Strategies)

MTENR 2000. Initial national communication under United Nations Framework Convention on Climate Change. Ministry of Tourism, Environment and Natural Resources.

MTENR 2007. Formulation of the national adaptation programme of action on climate change. Ministry of Tourism, Environment and Natural Resources.

OECD and IEA 2009. GHG mitigation actions: MRV issues and options. Jane Ellis and Sary Moarif. Downloaded at: http://www.oecd.org/dataoecd/26/44/42474623.pdf (June 2009).

UN-REDD Programme 2008. Role of satellite remote sensing in REDD. UN-REDD working paper no. 1. Downloaded at: http://www.un-redd.org/LinkClick.aspx?fileticket=p7Ss-fE7AR0%3D&tabid=587&language=en-US (May 2009).

ZFD/MTENR and FAO 2008a. Integrated land use assessment (ILUA). Zambia 2005-2008. Zambia Forestry Department/Ministry of Tourism, Environment and Natural Resources and FAO.

ZFD/MTENR and FAO 2008b. Use of integrated land use assessment (ILUA ) data for forestry and agricultural policy review and analysis in Zambia. Zambia Forestry Department/Ministry of Tourism, Environment and Natural Resources and FAO.

World Agroforestry Centre 2009. Http://www.worldagroforestry.org/Sea/Products/AFDbases/wd/. Accessed April 2009.

Zanne, A.E., Lopez-Gonzalez, G.*, Coomes, D.A., Ilic, J., Jansen, S., Lewis, S.L., Miller, R.B., Swenson, N.G., Wiemann, M.C., and Chave, J. 2009. Global wood density database. Dryad. Identifier: http://hdl.handle.net/10255/dryad.235. Accessed May 2009.

## Annex I Field work schedule

| Date | Activity |
|---|---|
| 29 April 2009 | Travel from Copenhagen to Rome. Briefing at FAO HQ with Peter Holmgren (NRCD) and the NFMA team (FOMR). |
| 30 April 2009 | Meetings with various resource persons at FAO HQ |
| 1 May 2009 | Work |
| 2 May 2009 | Work |
| 3 May 2009 | Travel from Rome to Lusaka |
| 3-8 May 2009 | Joint UN-REDD scoping mission |
| 3 May 2009 | Meeting in Lusaka with UN-REDD scoping team:<br>FAO: Jesper Tranberg, Rebecca Tavani, Edward Kilawe and Kewin Kamelarczyk<br>UNEP: Richard Kaguamba<br>UNDP:Tim Clairs, Elspeth Halverson and Carina Kjelstad |
| 4 May 2009 | - Briefing at UN-house Lusaka. Attendances apart from the UN-REDD team: Mrs. Elsie Atafuah (Global Mechnism of the UNFCCD), Dr. Noureddin (FAOR-Zambia), Mr. Kokwe (FAOR-Zambia), UN country representative.<br>- Meeting at with acting Primary Secretary at Ministry of Tourism, Environment and Natural Resources (MTENR).<br>- Meeting with the Zambian Climate Change Facility Unit headed by Prof. Prem Jain.<br>- Meeting with acting director of the Forestry Department |
| 5 May 2009 | - Meeting at Ministry of Water and Energy Meeting at Ministry of Lands with Primary secretary<br>- Meeting at Environmental Council of Zambia<br>- Meeting at Ministry of Lands Meeting at Ministry of Lands with Primary secretary |
| 6 May 2009 | - Meeting with Professor Emanual Chidumayo and staff from forestry department<br>- CP meeting at UN-house |
| 7 May 2009 | Stakeholder meeting |
| 8 May 2009 | - Meeting at Ministry of Lands with Primary secretary<br>- Debriefing at MTENR<br>- Debriefing at FAOR |
| 9-10 May 2009 | Working at hotel. |
| 11 May 2009 | Working at FAO. Meetings with staff from the Forestry Department. Data collection |
| 12 May 2009 | Meeting with consultants at Centre for Energy, Environment and Engineering Zambia. |
| 13May 2009 | Working at FAO. Data collection. |
| 14 May 2009 | Presentation of preliminary study findings at the Forestry Department. |
| 15 May 2009 | Travel from Lusaka to Copenhagen. |

# Annex II Basic wood densities for tree species identified in ILUA

| Scientific species name | Wood density in tonnes per cubic metre | | | Substituting species or genus used where species specific data were not available | Reference |
|---|---|---|---|---|---|
| | Low | Medium | High | | |
| Acacia albida | 0,49 | 0,56 | 1,00 | Acacia sp. | www.worldagroforestry.org |
| Acacia erioloba | | 1,06 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Acacia gerrardi | | 0,77 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Acacia nigrescens | 0,49 | 0,56 | 1,00 | Acacia sp. | www.worldagroforestry.org |
| Acacia nilotica | 0,65 | | 0,83 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Acacia polyacantha | 0,72 | | 0,84 | | www.worldagroforestry.org |
| Acacia sieberana | 0,49 | 0,56 | 1,00 | Acacia sp. | www.worldagroforestry.org |
| Acacia tortilis | 0,49 | 0,56 | 1,00 | Acacia sp. | www.worldagroforestry.org |
| Acacia erubescens | 0,49 | 0,56 | 1,00 | Acacia sp. | www.worldagroforestry.org |
| Adansonia digitata | | 0,28 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Adina microcephala | 0,72 | | 1,08 | | www.worldagroforestry.org |
| Afzelia bipindensis | | 0,82 | | | www.worldagroforestry.org |
| Afzelia quanzensis | 0,67 | | 0,76 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Agauria salicifolia | no data | no data | no data | | |
| Albizia adianthifolia | 0,48 | | 0,72 | | www.worldagroforestry.org |
| Albizia amara | | 0,76 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Albizia antunesiana | 0,48 | 0,72 | 0,84 | | www.worldagroforestry.org |
| Albizia gummifera | 0,36 | | 0,84 | | www.worldagroforestry.org |
| Albizia harveyi | 0,32 | | 0,95 | Albizia sp. | www.worldagroforestry.org |
| Albizia versicolor | 0,48 | | 0,84 | | www.worldagroforestry.org |
| Allophylus africanus | | 0,45 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Amblygonocarpus andongensis | 0,84 | | 1,08 | | www.worldagroforestry.org |
| Anisophyllea boehmii | 0,75 | | 0,77 | Anisophyllea laurina | http://datadryad.org/repo/handle/10255/dryad.235 |
| Anisophyllea pomifera | 0,75 | | 0,77 | Anisophyllea laurina | http://datadryad.org/repo/handle/10255/dryad.235 |
| Annona senegalensis | | 0,40 | | Annona muricata | www.worldagroforestry.org |
| Azanza garckeana | no data | no data | no data | | |
| Baikiaea plurijuga | 0,82 | | 0,96 | | www.worldagroforestry.org |
| Balanites aegyptiaca | 0,72 | | 0,84 | | www.worldagroforestry.org |
| Balanites maugahamii | 0,72 | | 0,84 | Balanites aegyptiaca | www.worldagroforestry.org |
| Baphia bequaertii | 0,60 | | 0,72 | Baphia nitida | www.worldagroforestry.org |
| Baphia massaiensis | 0,60 | | 0,72 | Baphia nitida | www.worldagroforestry.org |
| Baphia obovata | 0,60 | | 0,72 | Baphia nitida | www.worldagroforestry.org |
| Bauhinia galpinii | | 0,69 | | Bauhinia petersiana | http://datadryad.org/repo/handle/10255/dryad.235 |
| Bauhinia petersiana | | 0,69 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Bauhinia tomentosa | | 0,69 | | Bauhinia petersiana | http://datadryad.org/repo/handle/10255/dryad.235 |
| Becium obovatum | no data | no data | no data | | |
| Berchemia discolor | | 0,92 | | | www.worldagroforestry.org |
| Berlinia giorgi | 0,60 | | 0,64 | Berlinia bracteosa | http://datadryad.org/repo/handle/10255/dryad.235 |
| Bersama abyssinica | 0,72 | | 0,84 | | www.worldagroforestry.org |
| Borassus aethiopium | 1,02 | | 1,14 | Borassus flabellifer | www.worldagroforestry.org |
| Boscia albitrunca | no data | no data | no data | | |
| Boscia angustifolia | no data | no data | no data | | |
| Boscia cauliflora | no data | no data | no data | | |
| Boscia salacifolia | no data | no data | no data | | |
| Brachystegia allenii | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia boehmii | no data | 0,65 | no data | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia bussei | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia floribunda | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia longifolia | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia manga | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia microphylla | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia spiciformis | 0,60 | 0,70 | 0,71 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia stipulata | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia taxifolia | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia utilis | | 0,83 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Brachystegia | 0,60 | 0,70 | 0,71 | Brachystegia speciformis | http://datadryad.org/repo/handle/10255/dryad.235 |

| | | | | | |
|---|---|---|---|---|---|
| wangermeeana | | | | | |
| Bridelia cathartica | 0,45 | | 0,88 | Bridelia sp. | www.worldagroforestry.org |
| Bridelia duvigneaudi | 0,45 | | 0,88 | Bridelia sp. | www.worldagroforestry.org |
| Bridelia micrantha | | 0,67 | | | www.worldagroforestry.org |
| Burkea africana | 0,55 | 0,69 | 0,70 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Burttia prunoides | no data | no data | no data | | |
| Bysorcarpus orientalis | no data | no data | no data | | |
| Canarium schweinfurthi | 0,31 | | 0,45 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Canathium vulgare | 0,56 | | 1,06 | Canthium sp. | www.worldagroforestry.org |
| Canathium zanzibaricum | 0,56 | | 1,06 | Canthium sp. | www.worldagroforestry.org |
| Canthium lactescens | | 0,72 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassia abbreviata | | 0,88 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassia angolensis | | 0,88 | | Cassia abbreviata | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassia petersiana | | 0,88 | | Cassia abbreviata | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassia siamea | | 0,88 | | Cassia abbreviata | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassia singueana | | 0,88 | | Cassia abbreviata | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassia spectabilis | | 0,88 | | Cassia abbreviata | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassine aethiopica | | 0,83 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cassipourea congensis | | 0,66 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cathormion altissimum | 0,72 | 0,78 | 0,84 | Cathormion umbellatum | www.worldagroforestry.org |
| Chrysophyllum bangweolense | | 0,50 | | Chrysophyllum sp. | www.worldagroforestry.org |
| Chrysophyllum gorungosanum | | 0,54 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Chrysophyllum magalismontanum | | 0,50 | | Chrysophyllum sp. | www.worldagroforestry.org |
| Cleistanthus milleri | 0,55 | | 0,82 | Cleistanthus sp. | www.worldagroforestry.org |
| Colophospermum mopane | 0,90 | | 1,20 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum celastroides | | 0,65 | | Combretum fragrans | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum collinum | | 0,65 | | Combretum fragrans | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum fragrans | | 0,65 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum imberbe | | 1,06 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum molle | | 0,76 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum mossambicense | | 0,65 | | Combretum fragrans | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum psidioides | | 0,65 | | Combretum fragrans | http://datadryad.org/repo/handle/10255/dryad.235 |
| Combretum zeyheri | | 0,65 | | Combretum fragrans | http://datadryad.org/repo/handle/10255/dryad.235 |
| Commiphora mollis | | 0,37 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cordia africana | 0,36 | | 0,72 | | www.worldagroforestry.org |
| Craibia affinis | no data | no data | no data | | |
| Craterosiphon quarrei | no data | no data | no data | | |
| Croton megalobotrys | | 0,55 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cryptosepalum exfoliatum | 0,69 | | 0,80 | Cryptosepalum staudtii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cryptosepalum maraviense | 0,69 | | 0,80 | Cryptosepalum staudtii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cryptosepalum pseudotaxus | 0,69 | | 0,80 | Cryptosepalum staudtii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Cussonia arborea | 0,36 | | 0,48 | | wold agroforestry |
| Cussonia spicata | 0,36 | | 0,48 | Cussonia arborea | wold agroforestry |
| Cyathea dregei | no data | no data | no data | | |
| Dalbergia melanoxylon | | 1,25 | | | wold agroforestry |
| Dalbergia nitidula | 0,90 | | 1,20 | Dalbergia melanoxylon | http://datadryad.org/repo/handle/10255/dryad.235 |
| Dalbergiella nyasae | no data | no data | no data | | wold agroforestry |
| Danniella aslteeniana | 0,48 | | 0,60 | Daniellia klainei | wold agroforestry |
| Delonix regia | 0,44 | | 0,80 | | wold agroforestry |
| Dialiopsis africana | no data | no data | no data | | |
| Dialium angolense | 0,75 | 1,10 | 1,25 | Dialium sp. | wold agroforestry |
| Dialium engleranum | | 0,80 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Dichrostachys cinerea | 0,60 | | 1,19 | | wold agroforestry |
| Diospyros batocana | 0,64 | 1,03 | 1,25 | Diospyros sp. | wold agroforestry |
| Diospyros chamaethamnus | 0,64 | 1,03 | 1,25 | Diospyros sp. | wold agroforestry |
| Diospyros kirkii | | 0,63 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Diospyros mespiliformis | 0,77 | | 0,85 | | wold agroforestry |

| | | | | | |
|---|---|---|---|---|---|
| Diospyros mweroensis | 0,64 | 1,03 | 1,25 | Diospyros sp. | wold agroforestry |
| Diplorhynchus condylocarpon | 0,67 | 0,72 | 0,84 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Dombeya erythroleuca | | 0,48 | | Dombeya burgessiae | http://datadryad.org/repo/handle/10255/dryad.235 |
| Dombeya rotundifolia | | 0,48 | | Dombeya burgessiae | http://datadryad.org/repo/handle/10255/dryad.235 |
| Dracaena reflexa | no data | no data | no data | | |
| Ekebergia banguelensis | | 0,51 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ekebergia capensis | | 0,51 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Entada abyssinica | no data | no data | no data | | |
| Entandrophragma caudatum | | 0,49 | | Entandrophragma excelsum | http://datadryad.org/repo/handle/10255/dryad.235 |
| Entandrophragma delevoyi | | 0,49 | | Entandrophragma excelsum | http://datadryad.org/repo/handle/10255/dryad.235 |
| Entandrophragma excelsum | | 0,49 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Eriocoelum lawtoni | no data | no data | no data | | |
| Erythrina abyssinica | | 0,43 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Erythrina excelsa | 0,24 | | 0,38 | Erythrina sp. | www.worldagroforestry.org |
| Erythrophleum africanum | 0,88 | | 1,08 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Erythrophleum suaveolens | 0,89 | 0,72 | 0,97 | | www.worldagroforestry.org |
| Eucalyptus camaldulensis | 0,70 | | 0,98 | | www.worldagroforestry.org |
| Eucalyptus citriodora | | 0,80 | | | www.worldagroforestry.org |
| Eucalyptus cloeziana | no data | no data | no data | | |
| Eucalyptus grandis | 0,60 | | 0,75 | | www.worldagroforestry.org |
| Eucalyptus paniculata | 0,84 | | 1,20 | | www.worldagroforestry.org |
| Eucalyptus pilularis | 0,72 | | 1,08 | | www.worldagroforestry.org |
| Eucalyptus resinifera | 0,60 | | 1,08 | | www.worldagroforestry.org |
| Eucalyptus robusta | | 0,77 | | | www.worldagroforestry.org |
| Eucalyptus tereticonis | 0,60 | | 0,80 | | www.worldagroforestry.org |
| Eugenia bukobensis | 0,45 | | 1,10 | | www.worldagroforestry.org |
| Euphorbia candelabrum | | 0,20 | | No data available. Value approximated to insure that the mean value of 0.58 is not applied (because of the species' nature of being a succulent with a very low dry weight) | |
| Euphorbia cooperi | | 0,20 | | No data available. Value approximated to insure that the mean value of 0.58 is not applied (because of the species' nature of being a succulent with a very low dry weight) | |
| Euphorbia ingens | | 0,20 | | No data available. Value approximated to insure that the mean value of 0.58 is not applied (because of the species' nature of being a succulent with a very low dry weight) | |
| Euphorbia obovalifolia | | 0,20 | | No data available. Value approximated to insure that the mean value of 0.58 is not applied (because of the species' nature of being a succulent with a very low dry weight) | |
| Fagara chalybea | 0,60 | | 0,84 | Fagara leprieurii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Fagara macrophylla | 0,60 | | 0,84 | Fagara leprieurii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Faurea intermedia | | 0,65 | | Faurea saligna | http://datadryad.org/repo/handle/10255/dryad.235 |
| Faurea saligna | | 0,65 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Faurea speciosa | | 0,72 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ficalhoa laurifolia | no data | no data | no data | | |
| Ficus brachylepsis | 0,19 | | 0,74 | Ficus sp. | www.worldagroforestry.org |
| Ficus brachypoda | 0,19 | | 0,74 | Ficus sp. | www.worldagroforestry.org |
| Ficus capensis | | 0,29 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ficus carica | 0,19 | | 0,74 | Ficus sp. | www.worldagroforestry.org |
| Ficus ingenis | | 0,51 | | | http://datadryad.org/repo/handle/10255/dryad.235 |

| | | | | | |
|---|---|---|---|---|---|
| Ficus stulhlmanni | 0,19 | | 0,74 | Ficus sp. | www.worldagroforestry.org |
| Ficus sycomorus | 0,41 | | 0,44 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ficus verruculosa | 0,19 | | 0,74 | Ficus sp. | www.worldagroforestry.org |
| Ficus wakefieldii | 0,19 | | 0,74 | Ficus sp. | www.worldagroforestry.org |
| Flacourtia indica | 0,85 | 0,86 | 0,88 | | www.worldagroforestry.org |
| Garcinia huillensis | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Garcinia jovis-tonantis | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Garcinia kingaensis | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Garcinia livingstonei | | 0,73 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Garcinia pachyclada | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Garcinia punctata | | 0,82 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Garcinia robsonoaa | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Garcinia smeathmannii | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Garcinia volkensii | 0,69 | | 1,12 | Garcinia sp. | www.worldagroforestry.org |
| Gardenia imperialis | 0,63 | | 0,83 | Gardenia sp. | www.worldagroforestry.org |
| Gardenia jovi-tonantis | | 0,73 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Gmelina arborea | 0,40 | 0,48 | 0,56 | | www.worldagroforestry.org |
| Grewia bicolor | 0,73 | | 0,90 | Grewia sp. | www.worldagroforestry.org |
| Grewia spp | 0,73 | | 0,90 | Grewia sp. | www.worldagroforestry.org |
| Grumilea buchanani | no data | no data | no data | | |
| Gulbourtia coleosperma | | 0,66 | | | www.worldagroforestry.org |
| Haplocoelum foliolosum | no data | no data | no data | | |
| Harungana madagascariensis | | 0,47 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Harungana massaeinsis | | 0,47 | | Harungana madagascariensis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Heeria reticulata | no data | no data | no data | | |
| Hexalobus monopetalus | | 0,66 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Homalium abdessammadi | no data | no data | no data | | |
| Hoshindia opposita | no data | no data | no data | | |
| Hymenocardia acida | no data | no data | no data | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Hymenodictyon floribundum | no data | no data | no data | | |
| Hyphaene ventricosa | no data | no data | no data | | |
| Indigofera rhynchocarpa | no data | no data | no data | | |
| Isoberlinia angolensis | 0,72 | | 0,96 | Isoberlinia tomentosa | www.worldagroforestry.org |
| Isoberlinia tomentosa | 0,72 | | 0,96 | | www.worldagroforestry.org |
| Ixora rhodesiaca | 0,94 | | 1,01 | Ixora sp. | www.worldagroforestry.org |
| Jacaranda mimosifolia | no data | no data | no data | | |
| Julbernadia globiflora | 0,72 | 0,78 | 1,08 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Julbernadia paniculata | 0,72 | 0,78 | 1,08 | Julbernadia globiflora | |
| Khaya nyasica | | 0,52 | | | www.worldagroforestry.org |
| Kigelia africana | | 0,56 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Kirkia acuminata | | 0,51 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Landolphia kirki | no data | no data | no data | | |
| Lannea discolor | | 0,46 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Lannea edulis | | 0,46 | | Lannea discolor | http://datadryad.org/repo/handle/10255/dryad.235 |
| Lannea gossweileri | | 0,46 | | Lannea discolor | http://datadryad.org/repo/handle/10255/dryad.235 |
| Lannea humilis | | 0,46 | | Lannea discolor | http://datadryad.org/repo/handle/10255/dryad.235 |
| Lannea schimeri | | 0,46 | | Lannea discolor | http://datadryad.org/repo/handle/10255/dryad.235 |
| Lannea stuhlmannii | | 0,46 | | Lannea discolor | http://datadryad.org/repo/handle/10255/dryad.235 |
| Lonchocarpus capassa | | 0,69 | | Lonchocarpus sp. | www.worldagroforestry.org |
| Lonchocarpus eriocalyx | | 0,69 | | Lonchocarpus sp. | www.worldagroforestry.org |
| Lonchocarpus nelsii | | 0,77 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Maesa lanceolata | no data | no data | no data | | |
| Maesopsis eminii | 0,38 | | 0,48 | | www.worldagroforestry.org |
| Magnistipula bangweolensis | no data | no data | no data | | |
| Magnistipula butayei | no data | no data | no data | | |
| Magnistipula sapinii | no data | no data | no data | | |
| Magnistipula thonninge | no data | no data | no data | | |
| Maprounea africana | 0,47 | | 0,72 | Maprounea guianensis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Markhamia acuminata | | 0,78 | | | http://datadryad.org/repo/handle/10255/dryad.235 |

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|---|---|---|---|---|---|
| Markhamia obtusifolia | | 0,78 | | Markhamia acuminata | http://datadryad.org/repo/handle/10255/dryad.235 |
| Marquesia acuminata | | 0,76 | | Marquesia macroura | http://datadryad.org/repo/handle/10255/dryad.235 |
| Marquesia macroura | | 0,76 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Maytenus cymosus | | 0,50 | | Maytenus heterophylla | http://datadryad.org/repo/handle/10255/dryad.235 |
| Maytenus ovatus | | 0,50 | | Maytenus heterophylla | http://datadryad.org/repo/handle/10255/dryad.235 |
| Memecylon flavovirens | 0,77 | | 1,15 | Memecylon sp. | www.worldagroforestry.org |
| Milletia bequarti | no data | no data | no data | | |
| Mimusops zeyheri | | 0,81 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Mitragyna stipulosa | | 0,46 | | Mitragyna indet | http://datadryad.org/repo/handle/10255/dryad.235 |
| Monopetalanthus richardsiae | 0,46 | | 0,53 | Monopetalanthus pellegrini | http://datadryad.org/repo/handle/10255/dryad.235 |
| Monotes africanus | | 0,75 | | Monotes glaber | http://datadryad.org/repo/handle/10255/dryad.235 |
| Monotes elegans | | 0,75 | | Monotes glaber | http://datadryad.org/repo/handle/10255/dryad.235 |
| Monotes glaber | | 0,75 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Monotes katangensis | | 0,75 | | Monotes glaber | http://datadryad.org/repo/handle/10255/dryad.235 |
| Newtonia buchanani | 0,45 | | 0,59 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ochna pulchra | | 0,63 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ochna schweinfurthiana | | 0,62 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ochthocosmus lemaireanus | | 0,73 | | Ochthocosmus barrae | http://datadryad.org/repo/handle/10255/dryad.235 |
| Olax obtusifolia | | 0,77 | | Olax dissitiflora | http://datadryad.org/repo/handle/10255/dryad.235 |
| Oldfieldia dactylophylla | 0,82 | | 0,85 | Oldfieldia africana | http://datadryad.org/repo/handle/10255/dryad.235 |
| Oncoba spinosa | | 0,58 | | Oncoba welwitschii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ozoroa reticulata | no data | no data | no data | | |
| Pachystela brevipes | no data | no data | no data | | |
| Pandanus livingstoneanus | no data | no data | no data | | |
| Parinari capensis | | 0,68 | | Parinari sp. | |
| Parinari curatellifolia | 0,62 | | 0,72 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Parinari excelsa | | 0,68 | | | www.worldagroforestry.org |
| Parinari polyandra | | 0,68 | | Parinari sp. | www.worldagroforestry.org |
| Parkia filicoidea | | 0,68 | | Parinari sp. | www.worldagroforestry.org |
| Peltophorum africanum | | 0,59 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Peltophorum pterocarpum | 0,51 | 0,66 | 0,78 | | www.worldagroforestry.org |
| Pericopsis angolensis | | 0,72 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Phoenix dactylifera | no data | no data | no data | | |
| Phoenix reclinata | no data | no data | no data | | |
| Phyllanthus mulleranus | no data | no data | no data | | |
| Phyllocomus lemaireanus | no data | no data | no data | | |
| Piliostigima thonningii | no data | no data | no data | | |
| Pinus caribaea | 0,41 | | 0,51 | | www.worldagroforestry.org |
| Pinus kesiya | 0,53 | | 0,56 | | www.worldagroforestry.org |
| Pinus lelophylla | no data | no data | no data | | |
| Pinus merkusii | | 0,52 | | | www.worldagroforestry.org |
| Pinus michoacana | no data | no data | no data | | |
| Pinus oorcapa | 0,60 | | 0,72 | | www.worldagroforestry.org |
| Pinus patula | 0,36 | | 0,60 | | www.worldagroforestry.org |
| Podocarpus milanjianus | 0,36 | | 0,84 | | www.worldagroforestry.org |
| Protea angolensis | no data | no data | no data | | |
| Protea gaguedi | no data | no data | no data | | |
| Protea welwitschii | no data | no data | no data | | |
| Pseudolachnostylis maprouneifolia | | 0,62 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Psorospermum spp | no data | no data | no data | | |
| Pteleopsis anisoptera | 0,64 | | 0,72 | Pteleopsis hylodendron | http://datadryad.org/repo/handle/10255/dryad.235 |
| Pteleopsis myritifolia | 0,64 | | 0,72 | Pteleopsis hylodendron | http://datadryad.org/repo/handle/10255/dryad.235 |
| Pterocapus antunesii | | 0,70 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Pterocarpus angolensis | 0,52 | | 0,59 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Pterocarpus brenanii | | 0,80 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Pterocarpus chrysothrix | 0,52 | | 0,59 | Pterocarpus angolensis | http://datadryad.org/repo/handle/10255/dryad.235 |

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|---|---|---|---|---|---|
| Pterocarpus rotundifolius | 0,52 | | 0,59 | Pterocarpus angolensis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Raphia farinifera | no data | no data | no data | | |
| Rauvolfia caffra | 0,44 | | 0,49 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Rhus longipes | | 0,83 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Rhus quantiniana | | 0,83 | | Rhus longipes | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ricinodendron rautanenil | 0,19 | | 0,23 | Ricinodendron heudelotii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Rothmania fischeri | no data | no data | no data | | |
| Rothmannia englerana | no data | no data | no data | | |
| Rothmannia whitefieldii | no data | no data | no data | | |
| Salix babylonica | | 0,44 | | Salix sp. | www.worldagroforestry.org |
| Salix subserrata | | 0,44 | | Salix sp. | www.worldagroforestry.org |
| Sapium ellipticum | 0,48 | | 0,72 | | www.worldagroforestry.org |
| Schrebera alata | | 0,61 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Schrebera trichoclada | | 0,80 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Sclerocarya caffra | 0,47 | | 0,56 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Securidaca longepedunculata | no data | no data | no data | | |
| Securidaca welwitschii | no data | no data | no data | | |
| Securinega virosa | no data | no data | no data | | |
| Spathodea campanulata | | 0,27 | | | www.worldagroforestry.org |
| Steganotaenia aralicaea | no data | no data | no data | | |
| Sterculia africana | | 0,28 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Sterculia quinqueloba | 0,60 | | 0,96 | | www.worldagroforestry.org |
| Sterculis tragacantha | no data | no data | no data | | |
| Stereospermum kunthianum | | 0,60 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Strychnos cocculoides | | 0,65 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Strychnos innocua | | 0,87 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Strychnos madagascariensis | no data | no data | no data | | |
| Strychnos potatorum | | 0,73 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Strychnos pungens | | 0,70 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Strychnos spinosa | | 0,65 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Strychnos stuhlmanni | | 0,65 | | Strychnos spinosa | http://datadryad.org/repo/handle/10255/dryad.235 |
| Swartzia madagascaiensis | 0,96 | | 1,20 | | www.worldagroforestry.org |
| Syzigium cordatum | | 0,75 | | | www.worldagroforestry.org |
| Syzigium guineense | 0,60 | | 0,84 | | www.worldagroforestry.org |
| Syzigium owariense | 0,45 | | 1,10 | Syzigium sp. | www.worldagroforestry.org |
| Tabernaemontana angolensis | | 0,55 | | Tabernaemontana crassa | http://datadryad.org/repo/handle/10255/dryad.235 |
| Tamarindus indica | 0,80 | | 0,90 | | www.worldagroforestry.org |
| Tarinna neurophylla | | 0,84 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Terminalia brachystemma | | 0,88 | | Terminalia mollis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Terminalia mollis | | 0,88 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Terminalia sericea | | 0,72 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Terminalia stenostachya | | 0,88 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Terminalia stuhlmannii | | 0,88 | | Terminalia mollis | http://datadryad.org/repo/handle/10255/dryad.235 |
| Toona ciliata | 0,33 | | 0,60 | | www.worldagroforestry.org |
| Trema Orientalis | 0,42 | | 0,47 | | www.worldagroforestry.org |
| Trichilia emetica | 0,56 | | 0,60 | | www.worldagroforestry.org |
| Uapaca benguelensis | | 0,74 | | Uapaca sp. (air dry) | www.worldagroforestry.org |
| Uapaca guineensis | 0,48 | | 0,84 | | www.worldagroforestry.org |
| Uapaca kirkiana | 0,58 | | 0,72 | | www.worldagroforestry.org and http://datadryad.org/repo/handle/10255/dryad.235 |
| Uapaca nitida | | 0,65 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Uapaca pilosa | | 0,74 | | Uapaca sp. (air dry) | |
| Uapaca robynsii | | 0,74 | | Uapaca sp. (air dry) | |
| Uapaca sansibarica | | 0,53 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Uvaria angolensis | no data | no data | no data | | |
| Uvariustrum hexaloboides | no data | no data | no data | | |

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|---|---|---|---|---|---|
| Vangueriopsis lancifiora | no data | no data | no data | | |
| Vincentella passargei | no data | no data | no data | | |
| Viridivia suberosa | no data | no data | no data | | |
| Vitex amboinensis | 0,34 | | 1.01 | Vitex sp. | www.worldagroforestry.org |
| Vitex doniana | | 0,40 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Vitex madiensis | 0,34 | | 1.01 | | www.worldagroforestry.org |
| Vitex mombasae | 0,34 | | 1.01 | | www.worldagroforestry.org |
| Vitex payos | 0,34 | | 1.01 | | www.worldagroforestry.org |
| Vitex potersiana | 0,34 | | 1.01 | | www.worldagroforestry.org |
| Voacanga schweinfurthi | no data | no data | no data | | |
| Voacanga thouari | no data | no data | no data | | |
| Xeroderris stuhlmannii | | 0,63 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ximenia americana | | 0,95 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Ximenia caffra | | 0,95 | | Ximenia americana | http://datadryad.org/repo/handle/10255/dryad.235 |
| Xylopia aethlopica | 0,40 | | 0,98 | Xylopia sp. | www.worldagroforestry.org |
| Xylopia katangensis | 0,40 | | 0,98 | Xylopia sp. | www.worldagroforestry.org |
| Xylopia odoratissima | 0,40 | | 0,98 | Xylopia sp. | www.worldagroforestry.org |
| Xylopia rubescene | 0,40 | | 0,98 | Xylopia sp. | www.worldagroforestry.org |
| Xylopia scutiflora | 0,40 | | 0,98 | Xylopia sp. | www.worldagroforestry.org |
| Xylopia tomentosa | 0,40 | | 0,98 | Xylopia sp. | www.worldagroforestry.org |
| Zanha africana | | 0,86 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Zanthoxylum chalybeum | 0,43 | | 0,61 | Zanthoxylum leprieurii | http://datadryad.org/repo/handle/10255/dryad.235 |
| Zyziphus abyssinica | | 0,81 | | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Zyziphus mauritiana | 0,58 | | 0,70 | | http://datadryad.org/repo/handle/10255/dryad.235 |
| Zyziphus pubescens | 0,54 | | 1,08 | Zyziphus sp. | www.worldagroforestry.org |

# Annex III Carbon stock estimates for all land use categories