



## Zambia country profile

Monitoring, reporting and verification for REDD+

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# Abbreviations

AGB	above-ground biomass
ALOS	Advanced Land Observation Satellite
BCEF	biomass conversion expansion factor
BGB	below-ground biomass
CEEZ	Centre for Energy, Environment and Engineering Zambia
CH <sub>4</sub>	methane
CIFOR	Center for International Forestry Research
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
DBH	diameter at breast height
ECZ	Environmental Council of Zambia
FAO	Food and Agriculture Organization of the United Nations
FRA	Forest Resources Assessment
FSP	Forest Support Program
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographical information systems
ILUA	Integrated Land Use Assessment
INC	Initial National Communication
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection And Ranging
LULUCF	land use, land-use change and forestry
MAI	mean annual increment
MLNREP	Ministry of Lands, Natural Resources and Environmental Protection
MODIS	moderate resolution spectroradiometer
MRV	monitoring, reporting and verification
N <sub>2</sub> O	nitrous oxide
NCCRS	National Climate Change Response Strategy
NFP	Nyimba Forest Project
NJP	National Joint Programme
NO <sub>x</sub>	nitrogen oxides
NRS	National REDD Strategy
O <sub>3</sub>	ozone

PALSAR	Phased Array type L-band Synthetic Aperture Radar
REDD	reducing emissions from deforestation and forest degradation
REDD+	reducing emissions from deforestation and forest degradation and enhancing forest carbon stocks in developing countries
SADC	Southern African Development Community
SAR	Synthetic Aperture Radar
SMA	Spectral Mixture Analysis
SNDP	Sixth National Development Plan
SPOT	Systeme Pour l'Observation de la Terre
SOC	soil organic carbon
UAV	unmanned aerial vehicles
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
UN-REDD	The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
USFS	United States Forest Service
ZARI	Zambia Agriculture Research Institute

# Executive summary

## National REDD+ strategy

Zambia is one of the nine pilot countries in the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) and is currently at the first stage of REDD+<sup>1</sup> readiness under the UN-REDD Quick Start initiative. A National REDD Strategy (NRS) is currently being developed by the National Joint Programme (NJP) to which the Center for International Forestry Research (CIFOR) is contributing technical support. A key component of the NRS is to build the capacity of relevant stakeholders, such as the Ministry of Lands, Natural Resources and Environmental Protection, to undertake forest measuring and monitoring. A specific objective of the NJP is to strengthen the monitoring, reporting and verification (MRV) capacity for REDD+ in Zambia, which is of critical importance to its effectiveness.

Zambia is currently establishing a national monitoring system for REDD+, a major component of which is the development of the Integrated Land Use Assessment (ILUA), undertaken by the Forestry Department and supported by the Food and Agriculture Organization of the United Nations. ILUA Phase I (ILUA I) has been completed and provides data toward meeting Intergovernmental Panel on Climate Change Tier 1 and Tier 2 requirements for estimates of carbon stocks. Data gathering for ILUA Phase II (ILUA II) is ongoing, including data generated from the Nyimba Forest Project (NFP), with a methodology specifically designed to enable MRV for REDD+ in Zambia. A national remote sensing analysis is also being undertaken as part of ILUA II to provide reference forest cover levels for the country.

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<sup>1</sup> Reducing emissions from deforestation and forest degradation, and enhancing forest carbon stocks in developing countries (REDD+)

## Drivers of deforestation and degradation

Land-use change and forest loss are the main contributors to Zambia's greenhouse gas emissions. Deforestation rates are significant in Zambia, with approximately 300,000 ha of forest cover lost per year. Wood extraction, agricultural expansion, infrastructure development and fires are the main drivers of deforestation and forest degradation. Charcoal production is considered one of the primary causes of forest degradation in Zambia and the main cause of carbon stock loss from forests in the country. Land clearance for agriculture is the primary cause of forest cover loss.

## Issues and challenges

A number of challenges need to be overcome to ensure an adequate MRV system for Zambia. Problems include low institutional capacity for forest monitoring, limited knowledge regarding forest resources and carbon stocks, and technical challenges such as mapping forest degradation caused by charcoal production in complex dry woodland ecosystems. ILUA II and regional projects, such as the NFP undertaken by CIFOR, have been designed to overcome these challenges.

## Major knowledge gaps

Research on woodland ecology relevant to MRV of REDD+ has focused on miombo woodland in Zambia, as the dominant and most economically important forest type. Studies have examined growth rates, standing biomass, root to shoot ratios and regeneration of miombo woodlands following extraction of wood for charcoal production. However, much of this research is not current, the majority of data is over 10 years old, and there are a number of key knowledge gaps and data deficiencies including:

- verification of above-ground biomass (AGB), below-ground biomass (BGB), soil, deadwood and litter carbon stocks within all woodland types and drivers of carbon stock change
- standing biomass and growth rates within Kalahari, mopane and munga woodlands and evergreen forests (and other forest and woodland formations), including the causes of variability in biomass levels within Zambian forest ecosystems
- the availability of regional allometric models for predicting biomass and carbon stocks specific to Zambian woodland and forest ecosystems
- verification of deforestation and forest degradation rates; in particular carbon stock losses from charcoal production and the ability to map changes associated with forest degradation using remote sensing
- the impact of fire on woodland loss and carbon stocks, including the impact of fire on soil carbon.

### Gap filling

ILUA II should fill a large number of data, methodological, capacity and eligibility gaps for MRV of REDD+ in Zambia. It should also provide data to enable IPCC Tier 3 estimates for AGB, deadwood, soil and litter carbon pools. BGB estimates may only be possible to Tier 1 or Tier 2, due to the technical challenges of measuring BGB in miombo woodlands. ILUA II will cover all the major forest types and calculate specific biomass expansion factors for Zambia.

CIFOR's NFP will complement the national level work by developing subnational scale models for MRV in Eastern Province. The

project is undertaking research in miombo, mopane and munga forest and woodland formations in Nyimba District. ILUA II and the NFP will also contribute to capacity building in the country, for example through collaboration with local partners and training of field surveyors. Additional work on MRV in Zambia is being carried out by the United States Forest Service with funding from the United States Agency for International Development, also in Eastern Province. BioCarbon Partners is also conducting work on MRV in Rufunsa District. Opportunities for collaboration between these various institutions should be explored as they share similar objectives in improving the capabilities of Zambia to develop an effective MRV system for REDD+.

As well as the major knowledge gaps and data deficiencies identified above, the capacity for MRV of REDD+ in Zambia should be improved through the following:

- The Government of Zambia should develop a coherent national strategy for REDD+, including the establishment of a specific REDD+ department or center to support and coordinate MRV activities. This may include collaboration with the inter-ministerial climate change coordination unit under the Ministry of Finance and National Planning.
- A data sharing protocol should be developed under the Forestry Department to enable the sharing of ILUA data. This should be achieved through the creation of an open access database.
- The capacity of the Forestry Department to repeat monitor ILUA field sites and use remote sensing for MRV of REDD+ should be developed.

# 1 Overview of national REDD+ strategy

## 1.1 Zambia and REDD+ readiness

Zambia is one of the nine pilot countries in the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) and is currently at the first phase of readiness for REDD+ under the UN-REDD Quick Start initiative. A National Joint Programme (NJP), facilitated by the country's Forestry Department is tasked with developing a National REDD+ Strategy (NRS). The road to the NRS includes preparing Zambian stakeholders and institutions, such as the Ministry of Lands, Natural Resources and Environment Protection (MLNREP), for coordinated implementation of REDD+. Outcome 5 of the NJP National Programme Document is to strengthen the monitoring, reporting, and verification (MRV) capacity for REDD+ in Zambia. Outcome 6, closely related to this, is to undertake an assessment of reference emission levels and forest reference level (UN-REDD 2010a). A reliable MRV system for assessing changes in carbon stock and greenhouse gas (GHG) emissions due to deforestation and forest degradation is of critical importance to the effectiveness of REDD+; MRV is therefore a key component of REDD+ readiness in participating countries.

As capacity in Zambia is limited, one of the main tasks under Phase I of UN-REDD in Zambia is to build the capacity of stakeholders to conduct REDD+ projects and MRV of carbon stocks. Improving understanding of the extent, ecology and change in Zambian forests is another key component of REDD+ readiness in the country.

## 1.2 Activities under the United Nations Framework Convention on Climate Change REDD+ program

Zambia is a non-Annex I Party to the United Nations Framework Convention on Climate Change (UNFCCC). The Initial National Communication (INC) was submitted in 2004 by the Environmental Council of Zambia (ECZ) on behalf of the then Ministry of Tourism, Environment and Natural Resources. The Second National Communication is currently being produced with the overall goals of improving national capacity in the following areas: inventory of GHG emissions, assessment of potential impacts of climate change on vulnerable sectors, and analysis of measures with the potential to reduce GHG emissions (MTNER 2007).

Under the UNFCCC REDD+ readiness process countries can implement REDD+ in three phases. Phase I includes the development of national action plans. Phase II requires capacity building and the development of a results-based national monitoring system; while Phase III requires countries to address MRV for REDD+ in line with Decision 1/CP.16 (UNFCCC 2010; Romjin et al. 2012). Having created the NJP and completed the first part of its Integrated Land Use Assessment (ILUA), Zambia is in Phase II of this process and is conducting data collection, monitoring and analysis in order to establish a national monitoring system.

## 1.3 The Nyimba Forest Project

In August 2012, the Center for International Forestry Research (CIFOR) began the Nyimba Forest Project (NFP) funded by the United States Agency for International Development (USAID). The project is currently developing models for MRV of REDD+ at the subnational

level in Zambia, using data gathered from Nyimba District, Eastern Province. CIFOR is working with district-level partners, research institutions and government departments to develop a subnational MRV prototype in Nyimba. Developing models and systems for MRV and REDD+ at the district level is of considerable importance to establishing the effectiveness of a national MRV system. District-level projects enable testing of MRV protocols and allow comparisons of national estimates of key variables such as carbon stocks and deforestation rates. The prototype MRV system developed by the NFP will be tested at district level and recommendations, based upon the outcomes of testing, will be made to the UN-REDD Coordination Unit in Lusaka.

In order to provide background information for the NFP, this paper summarizes the status of MRV and REDD+ readiness in Zambia, as well as the current state of knowledge and studies available with regards to deforestation rates, emissions from deforestation and degradation, available data sets for MRV in the country, and an assessment of key knowledge and data gaps. This paper will feed into CIFOR's ongoing MRV project in Nyimba District and complement the national REDD+ readiness activities undertaken by UN-REDD and Zambian Forestry Department.

## 1.4 Major forest types in Zambia

Zambia's vegetation is dominated by miombo, which is characterized by open woodland dominated by Caesalpinioideae tree species including *Brachystegia*, *Julbernardia* and *Isoberlinia*, often associated with a dense grass sward (Byers 2001). Caesalpinoid dry woodlands are often located on nutrient-poor soils and are generally deciduous, shedding their leaves in dry seasons of the year. Zambian woodlands have long history of human use, including extraction of wood for timber and fuel, grazing, harvesting of non-timber forest products (NTFPs) and fire. The Food and Agricultural Organization of the United Nations (FAO) classifies all Zambian forests as secondary, naturally regenerated forests with no true primary forest remaining (FAO 2010). Generally, very little undisturbed, old-growth, dry woodlands remain in southern Africa (Defrees et al. 2011).

Forest cover in Zambia comprises around 50 million hectares, or over 65% of the total

land area (Kalinda et al. 2008). Dry woodlands and forests form the majority of forest types in Zambia, which are defined as vegetation types dominated by wooded plants that cover more than 10% of the ground surface (Chidumayo and Marunda 2010). This definition encompasses a broad range of vegetation types from wooded grasslands and scrub, to closed forests. The impact of fire and long history of human use, which influences the structure and distribution of vegetation, complicates the classification of woodland vegetation into easily definable groups. In addition, many dominant tree species in Zambia are tolerant of a wide range of edaphic conditions (Chidumayo 2012a). Despite these difficulties, the main dry forests and woodlands found in Zambia can be separated into miombo, Kalahari, mopane and munga or mixed woodlands (Makumba 2003). A significant area of dry evergreen forests is also found in the country (Kindt et al. 2011). A brief summary of these main forest types is provided below.

### 1.4.1 Miombo woodland

Miombo is the most dominant woodland formation and habitat type in southern Africa (Ryan et al. 2010). Miombo woodland is also the major forest type in Zambia itself, covering approximately 45% of the total land area (Kalinda et al. 2008; Stringer et al. 2012). Miombo woodlands are of considerable economic importance in Zambia for the supply of firewood, charcoal, timber and NTFPs (Chidumayo and Kwibisa 2003).

Dominant species are represented by the genera *Brachystegia*, *Isoberlinia* and *Julbernardia*, and include key species such *Brachystegia spiciformis*, *B. boehmii*, *Julbernardia globiflora*, *J. paniulata*; and *Isoberlinia angolensis* as well as the dipterocarp, *Marquesia macroura*. Miombo woodland is generally two storied, with an open canopy, 15–21 m high. The lower story comprises species such as *Albizia antunesiana*, *Anisophyllea boehmii*, *Brachystegia stipulata* and *Dalbergia nitidula*. The open canopy results in an undergrowth of dense grass or scrub of 0.6–3.6 m high. Notable grass genera include *Andropogon*, *Brachiaria*, *Digitaria*, *Heteropogon*, *Hyparrhenia*, *Hyperthelia*, *Panicum*, *Pogonarthria*, *Tristachya* and *Urochloa* (Fanshawe 1968).

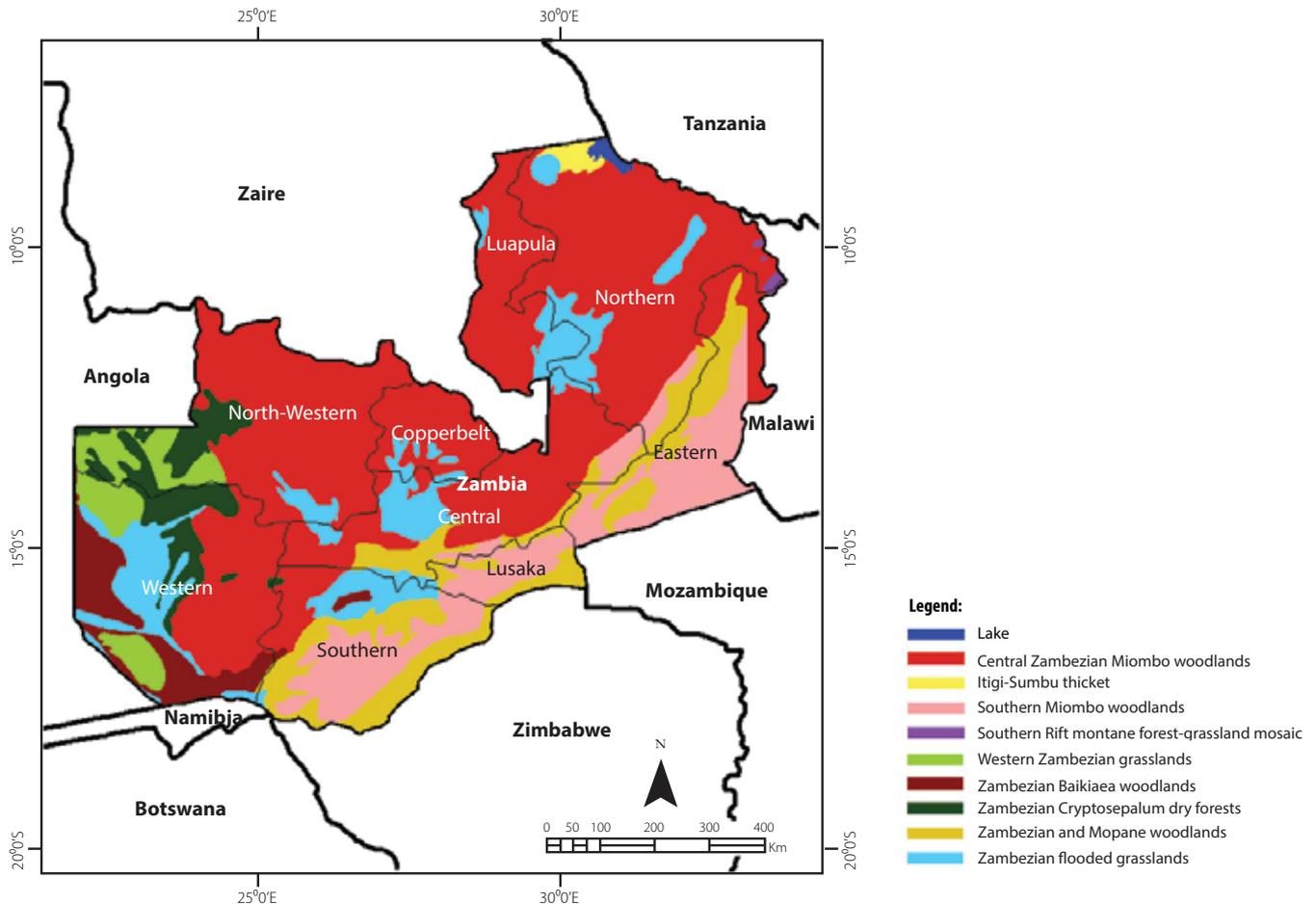


Figure 1. The ecoregions of Zambia.

Miombo woodlands are found on geologically stable rock formations and on nutrient poor soils (Bond et al. 2009). Tree cover generally exceeds 40% with rainfall normally above 600 mm per annum. If rainfall is above 1000 mm, tree cover may be greater than 60%, and canopy height can exceed 15 m; these woodlands are sometimes described as wet miombo (Timberlake et al. 2010; Kutsch et al. 2011). Wet miombo woodlands usually have a higher diversity of tree species than dry miombo, and are generally found above 1000 m on the Central African Plateau; whereas dry miombo is found at slightly lower elevations of 500–1200 m (Byers 2001). Chidumayo (1987) separated miombo woodlands in Zambia further into five subtypes based on dominant woody species and rainfall (Chidumayo 2012a).

#### 1.4.2 Kalahari woodland

Kalahari or *Baikiaea–Terminalia* woodland is found on Kalahari sands of the upper-Zambezi

basin in Zambia's Western and North-Western provinces (Mulombwa 1998; Sekeli and Phiri 2002). This woodland covers approximately 9% of the country's land area (Siampale 2008). Kalahari woodland is a secondary vegetation type formed from the disturbance of either *Baikiaea* or *Cryptosepalum* forests due to fire or agriculture (Kindt et al. 2011). Kalahari woodland is similar to miombo woodland in terms of species composition, with *Brachystegia*, *Isoberlinia* and *Julbernardia* the dominant species (Chidumayo 2012a). Other common species present include those of the genera *Guibourtia*, *Burkea*, *Diplorhynchus* and *Parinari* (Sekeli and Phiri 2002). Common grass genera and species include *Andropogon*, *Brachiaria*, *Digitaria*, *Elyonurus*, *Hyparrhenia*, *Hyperthelia dissoluta*, *Panicum maximum*, *Pogonarthria squarrosa*, *Setaria* and *Tristachya nodiglumis* (Evaristo and Kitanyi 2002). Kalahari woodland is the main source of commercial timber for Zambia.

### 1.4.3 Mopane woodland

Mopane woodlands are distributed in a band stretching from southern to eastern Zambia (Kindt et al. 2011). The woodland covers approximately 3.5% of the country's land area (Siampale 2008). Mopane woodland is important economically for timber and edible caterpillars, as well as charcoal and fuelwood.

Mopane woodland is dominated by *Colophospermum mopane*, which often grows in relatively mono-dominant stands with a limited shrub layer (Timberlake 1999). This formation is typically single storied with an open deciduous canopy approximately 6–18 m high, and has a less developed grass layer compared to miombo woodland (Makumba 2003). *C. mopane* has an extensive but relatively shallow rootstock resulting in a relatively high root biomass and readily regenerates from rootstock following disturbance (Smit and Rethman 1998). Where the mopane is mixed with other associated woodland species it may include *Adansonia digitata*, *Combretum imberbe*, *Terminalia sericea* and at times *Acacia* species. Grass species include *Chloris virgata*, *Digitaria eriantha*, *Hyparrhenia* species and *Setaria* species in wetter areas; and *Andropogon* species, *Heteropogon contortus* and *Urochloa* in drier areas (Evaristo and Kitalyi 2002).

Mopane woodland is more prevalent on heavier clay and nutrient rich, alkaline soils compared to miombo woodland (Mulombwa 1998; Timberlake et al. 2010). Rainfall in these woodlands is 400–700 mm per year (Timberlake et al. 2010) and the upper altitude limit is approximately 1400 m (Kindt et al. 2011).

### 1.4.4 Munga or undifferentiated woodlands

Munga or *Acacia–Combretum* woodland is a more open or park-like deciduous woodland. Often viewed as secondary woodland, the munga woodlands are found over a large part of central and southern Zambia, covering almost 4% of the land area (Mulombwa 1998; Siampale 2008). The woodland lacks the main species of miombo and mopane woodlands and is dominated by *Acacia*, *Combretum* and *Terminalia* species (Chidumayo 2012a). It is one to two storied with emergent

trees up to 18 m in height. The undergrowth layer is characterized by dense, tall grass; common genera include, *Brachiaria*, *Digitaria*, *Hyparrhenia* and *Setaria* (Evaristo and Kitalyi 2002). Munga woodlands are found a little beyond the drier climatic limits of miombo woodland on soils unsuitable for mopane woodland (Kindt et al. 2011).

### 1.4.5 Dry evergreen forests

Dry evergreen forests are part of the transition of forest types from Guineo-Congolian rainforest to Zambian dry woodlands. Dry evergreen forests cover less than 3–5% of the country's land area and are restricted to North-Western and Western provinces in Zambia (Siampale 2008; Chidumayo 2012a). The three subtypes are distributed on Kalahari sands (*Cryptosepalum*), lake basin (*Marquesia*) and on the plateau (*Parinari*) (Kindt et al. 2011). These forest types are three storied with a canopy up to 27 m high and a dense shrub layer of 1.5–6.0 m high. An understory of 0.3–1.3 m high is also sometimes found (Fanshawe 2010).

Dominant species (dependent on the forest type) include *Cryptosepalum exfoliatum*, *Guibourtia coleosperma*, *Marquesia acuminata*, *Marquesia macroura*, *Parinari excelsa*, *Syzygium guineense*, and *Anisophyllea pomifera* (Kindt et al. 2011). This woodland type is confined to the wetter northern parts of the region with a mean annual rainfall of 800–1400 mm. The majority of this forest type occurs at an elevation of 1000–1500 m. Disturbance of these woodland types can lead to variations of miombo woodland and Chipya forests (Kindt et al. 2011).

### 1.4.6 Other forest types

Other forest types (both evergreen and deciduous) with limited distributions across Zambia include moist evergreen forest (divided into montane, swamp and riparian types); chipya woodland (derived from dry evergreen forest); and closed deciduous forests, which are divided into *Baikiaea* and itigi types (Mukosha and Siampale 2009; Vinya et al. 2011).

### Termitaria woodland

Termitaria woodland is a bushland or scrubland vegetation type associated with termite mounds, which alter the edaphic conditions and therefore the vegetation composition. Termite mound flora in Zambia generally has a higher species richness compared to the surrounding vegetation (Kindt et al. 2011). All the main vegetation types (such as forest, woodland, thicket, scrub and grassland) can be found within termitaria woodland. These woodlands are found unevenly distributed throughout the country (except on sandy soils), including certain sandy plateau soils, montane and swamp forests, and floodplain grassland (Fanshawe 2010). Commonly occurring species include *Diospyros mespiliformis*, *Asparagus racemosus*, *Boscia angustifolia*, *Capparis tomentosa*, *Sterculia quinqueloba* and *Maerua juncea* (Sekeli and Phiri 2002).

### Plantations

Very few forest plantations occur in Zambia. Approximately 61,000 ha of tropical pine and *Eucalyptus* plantations have been established across the country with around 80% in Copperbelt Province (Mukosha and Siampale 2009). The main plantation species include *Pinus kesiya*, *Pinus oocarpa*, *Eucalyptus grandis* and *Eucalyptus cloeziana* (Sekeli and Phiri 2002).

## 1.5 Classification of Zambian woodlands

Historically various approaches have been used to classifying Zambian vegetation, including soil, stocking rates and species composition (Trapnell 1953; Lees 1962; Chidumayo 1987). The FAO classifies the woodland types found in Zambia according to global definitions. These definitions are used in the ILUA for Zambia as follows:

- Miombo woodlands are classified as semi-evergreen forests.
- *Baikiaea* and itigi forests, munga, mopane and Kalahari woodlands are classified as deciduous forests.
- Riparian, montane, swamp, *Parinari* and the lake basin chipya forests are classified as evergreen forests.
- Termitaria are classified as shrub thickets and are included as part of other wooded land.
- There are also classifications for other forested lands, which include bamboo and raffia palms.

A classification system based upon a combination of global and national requirements has been proposed for ILUA II (Chidumayo 2012a). The main difference to the ILUA I classification, as shown in Table 1, is that miombo woodland is classified as deciduous forest, rather than semi-evergreen forest, as the majority of its dominant species are deciduous. The main topographic or edaphic feature of each vegetation type is also given (Chidumayo 2012a) (Appendix 1).

## 1.6 Key drivers and processes affecting forest carbon change

### 1.6.1 Deforestation and forest degradation

Forest cover loss and forest degradation are the main processes causing forest and carbon stock change in Zambia. Deforestation rates (largely of miombo woodland) are significant in the country (Stringer et al. 2012). The most recent estimate of deforestation, provided by the ILUA, gave a range of 250,000–300,000 ha per year, or an annual decline of total forest area of 0.62% (Mukosha and Siampale 2009). A UN-REDD report based on an analysis of seven studies dating from 1969–2006, provides a deforestation estimate of 298,000 ha per year (Kamelarczyk 2009). FAO estimates have ranged from 166,000 ha to 445,000 ha of forest loss per year (FAO 2005, 2010). Chidumayo (2012b) gives an annual deforestation rate of 157,300 ha for 1965–1996 and 826,544 ha for 1996–2005. Due to the variability in these estimates, verification of current deforestation rates may be required (Kamelarczyk 2009). However, based on the most recent estimates made by UN-REDD and the ILUA, a rate of approximately 300,000 ha per annum seems a reasonable estimate.

### 1.6.2 Emissions from deforestation and forest degradation

In Zambia land-use change and forest loss is the main contributor to the country's GHG emissions. Deforestation and forest degradation in Zambia is estimated to contribute 3% to the total GHG emissions from deforestation worldwide. The UNFCCC INC estimated that carbon dioxide (CO<sub>2</sub>) emissions from forestry

**Table 1. Main forest or woodland types in Zambia.**

Vegetation type	Food and Agriculture Organization of the United Nations	Equivalent regional subtype
Closed forests	Dry evergreen forests (37,564.2 km <sup>2</sup> or almost 5% of the land area)	<i>Parinari, Marquesia, Cryptosepalum</i> , lake basin
	Dry deciduous forests (10,189.6 km <sup>2</sup> or 1.4% of the land area) (part of dry deciduous open forests)	<i>Baikiaea</i> , itigi
	Moist evergreen forests (944.22 km <sup>2</sup> or 0.12% of the land area) (part of dry evergreen forests total)	Riparian, montane, swamp
Open forests (woodlands)	Semi-evergreen forests (355,413.8 km <sup>2</sup> or 47.2% of the land area)	Miombo
	Dry deciduous forests (167,057 km <sup>2</sup> or 22.2% of the land area)	Kalahari, mopane, munga
Bushland/ scrubland	Other wooded land (14,739.9 km <sup>2</sup> or almost 2% of the land area)	Termitaria

Source: Adapted from Sekeli and Phiri 2002; MTNER 2002.

and land-use change contribute almost 70% of Zambia's total GHG emissions (MTNER 2002). At the district level forest degradation has been estimated to cause woody biomass losses of 0.3–4.0 t per hectare annually for miombo woodland in central Zambia (Chidumayo 2013).

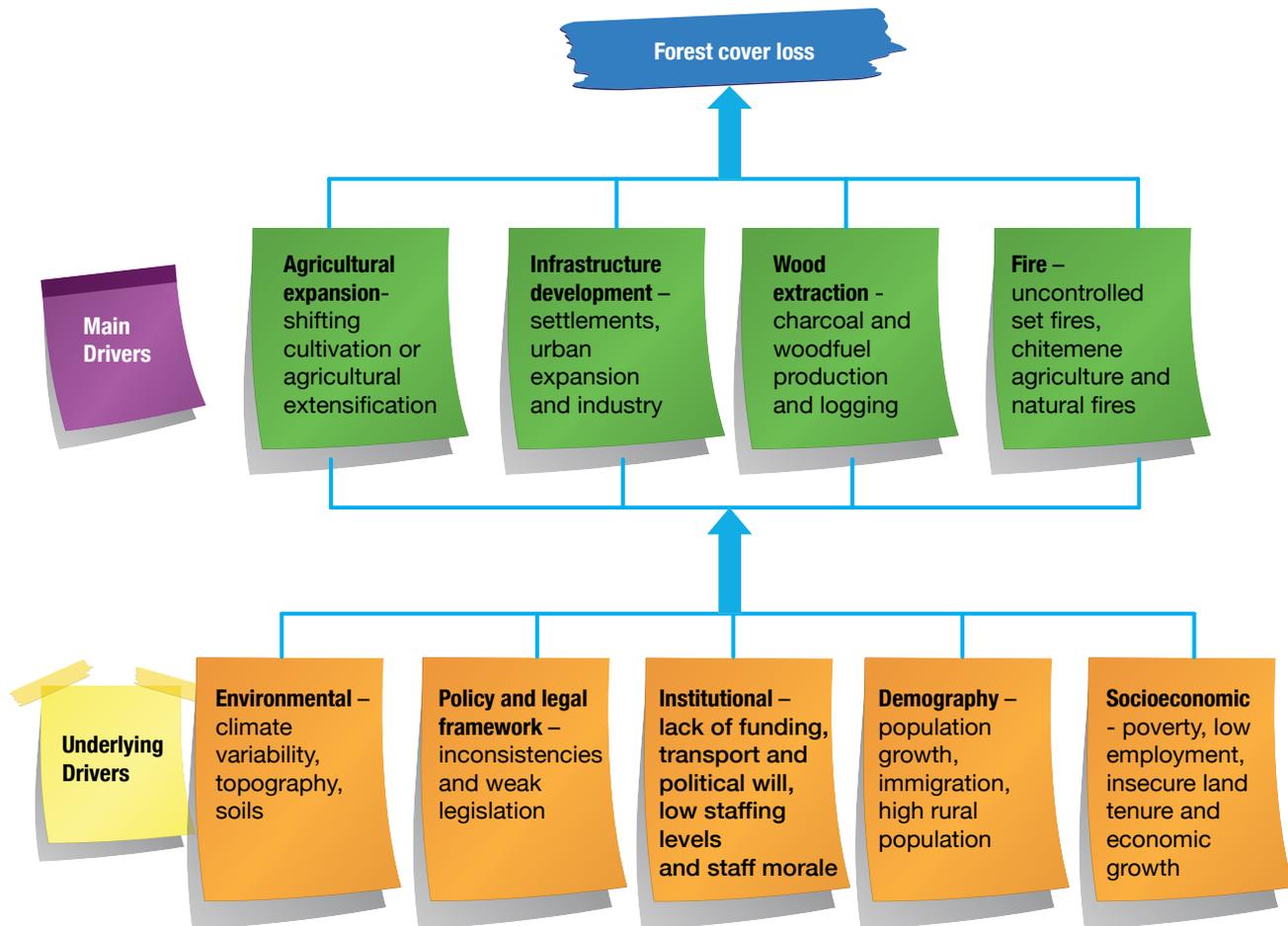
Kamelarczyk (2009) provides values for emissions from deforestation and forest degradation using biomass estimates determined by a biomass conversion and expansion factor (BCEF) and allometric equations using ILUA data. Their analysis estimated an annual decrease in carbon in above-ground biomass (AGB) from 12.8 Mt to 20.9 Mt. Estimates of the change in forest extent and biomass density indicated a decrease of 4.7–7.5 Mt of carbon. Part of the difference in these estimates could be caused by forest degradation, which may not be captured in the lower estimate. Kutsch et al. (2011) estimated total annual emissions for Zambia based on the most recent deforestation estimates from the FAO (2005, 2010) as well as Kamelarczyk (2009) combined with their own biomass estimates in miombo woodland in Zambia, giving total emissions of 13.2–102.8 Mt of carbon per year. The high level estimates in this study were due to a combination

of a high deforestation rate and biomass estimates from undisturbed woodland (Kutsch et al. 2011). Both of these studies demonstrate the current high uncertainties associated with estimating standing biomass and carbon emissions from deforestation and forest degradation in Zambia.

While the main drivers of deforestation and forest degradation in Zambia are wood extraction, agricultural expansion, infrastructure development and fires, a number of underlying causes also contribute to forest loss and degradation (Chundama 2009; Vinya et al. 2011). Vinya et al. (2011) summarize the drivers of deforestation and forest degradation in Zambia as follows (see Figure 2).

### 1.6.3 Wood extraction

Wood extraction from forests includes fuelwood removal, logging and charcoal production (Gumbo et al. 2013). Although timber is extracted from Zambian woodlands for construction and manufacture of wood products, charcoal production is the biggest single driver of wood extraction and the primary cause of forest



**Figure 2: The main and underlying drivers of deforestation in Zambia and the relationships between the two (adapted from Vinya et al. 2011).**

degradation (Clarke and Shackleton 2007; Vinya et al. 2011). The ILUA estimated that 5.8 million tonnes of wood biomass was used to produce charcoal in 2008 (Kalinda et al. 2008). Fuelwood and charcoal make up over 70% of the national energy consumption (IDLO 2011). As only 20% of the population has access to electricity, charcoal is an important source of energy for both rural and urban populations in Zambia (Foster and Dominguez 2010). It is estimated that 98% of low-income families (which make up 85% of the urban population) depend on charcoal as their main energy source (Kalinda et al. 2008). Although difficult to quantify, due to the unlicensed nature of the majority of the industry, it is estimated that charcoal production employs some 500,000 people in Zambia and contributes 2.2% of the country's gross domestic product (GDP) (Kalinda et al. 2008).

Zambeziyan dry forests contain almost 70 t per hectare of AGB suitable for fuelwood and charcoal harvesting (Malimbwi et al. 2010). The degree of forest clearing for charcoal production can vary considerably depending on the site (Malimbwi et al. 2010). If charcoal demand is low in an area, harvesting is more selective in terms of species and size classes used; whereas, in times of high demand, clear-fell harvesting of woodland is more common (Clarke and Shackleton 2007). Chidumayo has reported removal of 50–97% of the woody biomass from plots in miombo woodlands in Zambia (Chidumayo 1991, 1993). Following harvesting, tree density can recover significantly within 30 years (Chidumayo 1993); charcoal production may therefore not lead to forest clearance (just degradation). However, charcoal production does frequently lead to deforestation, as thinning for

charcoal or fuelwood facilitates subsequent clearance for agriculture (UN-REDD 2010a).

#### 1.6.4 Agricultural expansion

Agricultural expansion is the second highest driver of forest loss in Zambia (Vinya et al. 2011). A growing population has led to increased pressure for agricultural land in order to meet national and subsistence food requirements. Agricultural expansion is caused both by shifting subsistence cultivation and extensification of commercial farming. Agricultural expansion may account for up to 90% of forest cover loss, often for small-scale farming systems using shifting cultivation practices (UN-REDD 2010a; Campbell et al. 2011). Overgrazing has less impact on forest cover than arable land use, but has also been a problem in some provinces (such as Southern, Western and North-Western provinces and parts of Lusaka) and can inhibit woodland regeneration (Vinya et al. 2011).

Linked to agricultural expansion is migration, which has increased land pressure in some areas; such as the movement of commercial farmers from Zimbabwe to Zambia due to political and economic instability in Zimbabwe (UN-REDD 2010a; Vinya et al. 2011).

#### 1.6.5 Infrastructure development and industry

Although a less important driver than wood extraction and agriculture, the growing population in Zambia has resulted in the expansion of urban settlements and infrastructure at a rate of 3.2% per annum (Gumbo et al. 2013). Infrastructure development results in deforestation where development projects occur on areas of woodland and forest cover. The importance of this driver is likely to increase as Zambia needs to develop its infrastructure in a number of areas, including housing, transport (particularly rural road provision), energy, water, sanitation, irrigation and communication to enable development (Foster and Dominguez 2010).

Mining (predominantly of copper and cobalt) is a significant industrial activity in Zambia, particularly in Copperbelt and North-Western

provinces. Mining contributes over 70% of foreign exchange earnings, forming a significant part of Zambia's GDP (IDLO 2011; GRZ 2011). It is also a growing industry, with Zambia experiencing a steady increase in mining output over the last decade (GRZ 2011). Mining can cause deforestation during initial clearance, as well as the need for large quantities of wood for tunnel supports and increasing demand for charcoal to support the energy needs of miners (Chidumayo 1989; Gumbo et al. 2013). For example, at the Kalumbila mining concession the development of infrastructure is estimated to have resulted in the loss of more than 7000 ha of forest cover (Vinya et al. 2011).

#### 1.6.6 Fires

Caesalpinoid woodlands are strongly influenced by both natural and anthropogenic fires. Fires in miombo woodland and dambo grassland in southern Africa contributed 12.3% to total global emissions of CO<sub>2</sub> in 2000 (Sinha et al. 2004). Over 50% of the land area in Zambia is affected by fire, with approximately 25% of the total land cover burnt annually (Archibald et al. 2010). Fire incidences are spread throughout the country; however, high frequencies are found in the northern parts of the country and within protected forests and game management areas (Sikaundi 2012). The majority (almost 90%) of fires set in miombo woodland are anthropogenic and linked to a number of different human activities (Ribeiro et al. 2012). Fires are used to control vegetation, to enable land clearance for agriculture, to create potash for *chitemene* agriculture and to facilitate hunting (Vinya et al. 2011). Fires can also escape and spread to larger areas during charcoal production, traditional rituals, burning of sugar plantations and the creation of fire breaks around villages, particularly at the end of the dry season.

Although fire predominantly impacts grasslands, Archibald et al. (2010) estimated that 22% of uncultivated savannah woodlands (which includes all of the main dry woodland types in the country) were burnt by fires in 2001–2008. This figure rose to 33% in protected savannah woodlands (Archibald et al. 2010). A study conducted by the Zambian Environmental Management Agency in 2007–2011 using MODIS (moderate

resolution spectroradiometer) imagery indicated that deciduous woodland with sparse tree cover experiences the most severe fires each year (Sikaundi 2012). However, a large proportion of fires in Zambia are small scale leading to a mosaic of burnt area patches. High-resolution imagery may therefore be required in order to make accurate estimates of burnt areas (Sá et al. 2007).

Dry woodlands in Zambia are tolerant of fire and regenerate vegetatively from stumps and rootstocks (Chidumayo 2004). However, long-term fire regimes, including annual, and sometimes biannual burning, can result in the transition of woodland to grassland (Bond and Keeley 2005). Smaller trees, particularly those below 5 cm DBH (diameter at breast height) have high mortality (up to 12%) in intense fires in miombo woodland (Ryan and Williams 2011). Chidumayo (2013) estimated that fire caused 25–77% of total biomass loss at five permanent sample plots in miombo woodland in central Zambia. Fire can also inhibit regeneration and survival of young plants and therefore woodland recovery from clearance or degradation (Timberlake et al. 2010; Vinya et al. 2011). Less intense fire regimes may stimulate tree growth in miombo woodlands. A long-term experiment within miombo woodland in Zimbabwe showed plots burned on a 3- or 4-year cycle attained greater tree height than unburned plots (Furley et al. 2008). The timing of fires has a bearing on their impact. Fires at the start of the dry season (April–June) are less severe than later in the season, due to weather conditions and the green state of the grass sward. Burning at the end of the dry season (August–November) results in hotter fires, as grass is dry and therefore more combustible (Robertson 2005).

### 1.6.7 Underlying drivers

Linked to these main drivers of deforestation and forest degradation are the underlying high poverty levels, high population growth and large rural population of the country. Zambia is ranked 163 in world poverty by the World Bank Human Development Index (HDI) (World Bank 2012). The population growth rate for 2012 is estimated at more than 3%, giving Zambia the 11th highest population growth rate in the world (CIA 2012). It is estimated that almost 70% of the rural population depends directly on forests for energy

needs, construction, fodder, wild foods and medicines (Chundama 2009).

Additional issues include inadequate governance and inadequate funding for departments tasked with managing forestry and the environment, which has led to low staffing levels and a lack of coordination among relevant departments (IDLO 2011; Vinya et al. 2011). Government policies have also led to deforestation and degradation. Of 40 government policies relevant to REDD+ reviewed by Chundama (2009), 21 policies were found to promote forest loss by legitimizing the loss of forest resources.

An insecure land tenure system has also contributed to increased exploitation of forest resources, leading to a prevalence of shifting agriculture and a lack of sustainable management practices (Campbell et al. 2011; Vinya et al. 2011). The majority of the land in Zambia is open access, where land rights are unclear or unenforced, which can lead to unsustainable resource use for immediate gains (IDLO 2011; Vinya et al. 2011). Wood biomass levels in regrowth miombo woodland in Zambia have been shown to be lower on land subject to customary tenure than land without (Chidumayo 2002).

### 1.6.8 Carbon sequestration in Zambian forests

Forest carbon change can be positive due to sequestration in growing forests. Undisturbed woodlands in Zambia may not be carbon sinks, possibly due to the fact that growth is limited by water and nutrient availability as opposed to carbon dioxide (Kutsch et al. 2011). However, the majority of woodland in Zambia is not undisturbed. Over 65% of Zambian woodlands are secondary, with 32% of forests either moderately or heavily disturbed, and regrowth within these woodlands may lead to carbon storage (Kalinda et al. 2008; Williams et al. 2008; Kutsch et al. 2011). Woodlands in sub-Saharan Africa regenerate readily following wood harvesting and clearance for agriculture, as many common tree species re-sprout from the roots and stumps following disturbance (Luoga et al. 2004; Chidumayo 2011). The high level of disturbance and regenerating ability of miombo woodlands indicates a potential carbon

sink in regrowth woodlands in Zambia (Kalinda et al. 2008). In the majority of dry woodlands biomass accumulation with increasing age is associated with regrowth (Timberlake et al. 2010).

Fires, both natural and set for management purposes, may also influence sequestration through lowering productivity (Murwira 2009). Fire reduction may therefore increase carbon sequestration in miombo woodlands (Frost 1996; Chidumayo 2013).

### 1.7 National strategy and policy development targets for REDD+

Currently Zambia has no national action plan or national strategy for REDD+; however, REDD+ preparedness is taking place under the coordination of the Forestry Department (UN-REDD 2010a). The Government of Zambia's involvement in REDD+ is outlined in the National Climate Change Response Strategy (NCCRS) (MTNER 2010). Formed as part of the NCCRS, the Climate Change Facilitation Unit will coordinate climate change activities, formulate policies and establish an implementation framework between the MLNREP and other ministries. A draft National Forestry Policy (2010) is also aligned with REDD+ activities, for example by stating the need for forest carbon sequestration measurement standards (IDLO 2011).

### 1.8 Reference levels and monitoring, reporting and verification

In order to develop an MRV system for Zambia a National Forest Assessment and Monitoring System is currently being established. The focus is on a distributed system, in line with the government's decentralization policy, with capacity built in a number of different provinces in the country (IDLO 2011). Ten provincial forest monitoring laboratories have been established, equipped for forest monitoring and staffed with technicians from forestry, agriculture and planning sectors in order to provide decentralized monitoring expertise (Kasaro and Fox 2012).

A major component of MRV in Zambia is the development of the ILUA. This assessment is

being conducted by the Forestry Department with technical support from the FAO. Phase I of the assessment was conducted in 2005–2008. This phase involved the collection of field data from 221 sample plots across the country (covering 433.1 ha), as well as socioeconomic data from structured interviews (Kalinda et al. 2008; Mukosha and Siampale 2009). ILUA I has been criticized for its highly systematic sampling design, which does not include some woodland types with low overall national coverage, such as evergreen forests (Chidumayo 2012a).

ILUA Phase II was launched in November 2010, with fieldwork beginning in March 2013. ILUA II has been designed to collect adequate information to meet local, national, regional and international reporting requirements for MRV of REDD+. It is also intended to strengthening the capacity of the Forestry Department to be able to carry out future monitoring of forest resources (UN-REDD 2010a, 2012). The field component of ILUA II is scheduled to be completed in 2014/15. ILUA II comprises over 4000 sampling sites and will measure all major carbon pools (AGB, soil, deadwood and litter) identified by the Intergovernmental Panel on Climate Change (IPCC), apart from below-ground biomass (BGB) which is problematic to measure in Zambian woodlands (due to deep root systems), necessitating estimation using expansion factors. ILUA II has been designed to assess carbon stocks by tree species in order to provide baseline reference levels for emissions (IDLO 2011).

In addition to the ILUA field inventories, land cover change from deforestation and forest degradation has been estimated using Landsat data in order to develop a national reference emission level. The analysis has been conducted in collaboration with the Regional Centre for Mapping of Resources for Development in Nairobi. Land cover change has been estimated from land cover data from 1990, 2000 and 2010 (Kasaro and Fox 2012). Results of this national remote sensing survey are yet to be made available. The national remote sensing survey should fulfill the requirements of the IPCC guidelines to establish a historical reference scenario for forest cover changes, in order to assess forest cover change in the future.

## 1.9 Issues and challenges

A number of problems need to be overcome to ensure an adequate MRV system for REDD+ in Zambia. These problems can be broadly grouped into institutional capacity, state of knowledge and technical challenges.

### 1.9.1 Institutional capacity

Institutional and human resource capacity to monitor natural resources such as forest cover and carbon stocks is low in Zambia (Campbell et al. 2011). In common with a number of African countries, Romijn et al. (2012) assessed the capacity gap for implementing a national forest strategy in Zambia to be significant. The draft National Forestry Policy for Zambia acknowledges the decline in resources for forestry research in Zambia since the 1970s and the need to develop research expertise, facilities and an institutional framework to meet forestry research needs (MTNER 2009). The capacity to monitor and report on forest cover and emissions is currently limited to a small number of individuals in the Survey Department (MLNREP), National Remote Sensing Centre, Forestry Department, Copperbelt University and the University of Zambia. In addition, access is limited to relevant technology, such as high-resolution spatial imagery. This is particularly problematic for REDD+ as a nationwide initiative (UN-REDD 2010a). Capacity building for REDD+ is one of the key activities outlined in the NJP for Zambia (UN-REDD 2010a).

Linked to this issue is the lack of data coordination between departments and institutions that will participate in REDD+ in Zambia. No formal data storing or sharing protocol exists between these institutes, meaning data relevant to MRV is difficult to access (UN-REDD 2010a; Campbell et al. 2011). A report by UN-REDD identified the need for a specific monitoring unit for REDD+ in Zambia in order to tackle these issues (UN-REDD 2010a).

In addition, Zambia has no specific legal and policy framework for tackling climate change, aside from a climate change response strategy. A framework for institutionalizing REDD+ is needed at various levels for planning and

implementation. This is potentially a significant barrier for REDD+ readiness in Zambia (UN-REDD 2010a).

ILUA II should enable capacity building during both the fieldwork and subsequent data analysis, through collaboration with the Forestry Department. For example, extensive training has been conducted in order for field surveyors to follow the ILUA survey methodology. Training and financial support has also been provided to the Kitwe Research Centre in Copperbelt Province, to facilitate the processing and analysis of soil and litter samples and identify herbarium samples from the field teams. The ILUA should also improve data sharing and management for MRV in Zambia. Data collection and management will be achieved using Open Foris, an open source software being developed by the FAO and United States Forest Service (USFS).

### 1.9.2 State of knowledge

A major constraint to MRV in Zambia is the current state of knowledge with regards to deforestation and carbon cycling within the key woodland ecosystems of the country. It is a challenge to provide information to enable monitoring of all five REDD+ activities (deforestation, forest degradation, conservation, sustainable management of forests and enhancement of forest carbon stocks) of sufficient accuracy to meet IPCC guidelines (Romijn et al. 2012). The number of national data sets that can estimate forest cover change in Zambia is limited. Prior to ILUA I (2005–2008) the last national forest inventory was taken in 1952–1967 (Vinya et al. 2011). The impact of degradation from charcoal production (the primary cause of forest loss and degradation in Zambia) is also problematic to monitor (Kutsch et al. 2011; Gumbo et al. 2013).

In general, suitable methods for carbon stock estimation are not well developed for African countries (Kamelarczyk 2009). The carbon cycle in the miombo woodlands of Africa is also poorly understood (Williams et al. 2008; Bond et al. 2009). Information is even more scarce regarding the carbon cycle for the other major woodland types in Zambia (Kalahari, mopane and munga woodlands), which form a significant proportion

(approximately 20%) of woodland cover in the country (Grace et al. 2006; Mukosha and Siampale 2009). Understanding of the carbon cycle is particularly limited in the soil, litter and deadwood carbon pool for Zambian woodlands (Chidumayo 2011; Stringer et al. 2012). In miombo woodlands 50–80% of total system carbon is estimated to be in the top 1.5 m below ground (Walker and Desanker 2004; Ryan et al. 2010). The impact of fire is another key ecological process crucial to the understanding of carbon stocks, about which current knowledge is limited (Ryan and Williams 2011).

The ILUA I dataset is a starting point to address the inadequacies in forest inventory data for Zambia. However, ILUA I was designed for global forest inventories and is therefore not specific to forest ecosystems and structures found in Zambia (Vinya et al. 2011). Developing a comprehensive forest database is therefore a major challenge (UN-REDD 2010a; Romijn et al. 2012). The development of ILUA II will be a key step in establishing adequate MRV capacity in Zambia.

### 1.9.3 Technical challenges

Linked to both current institutional capacity and state of knowledge issues is the challenge of assessing carbon stock changes for REDD+ in Zambia. Zambia is a large country (approximately 750,000 km<sup>2</sup>) with remote and inaccessible areas. The forest cover of the country is considerable but with a highly scattered and variable distribution due to the ecology of the forests and the long history and nature of human use. Disturbance

from forest degradation (as well as fire and herbivory), coupled with the variable nature of Zambian woodlands, can result in a complex mix of different vegetation types (Ribeiro et al. 2012). Mapping degradation, particularly from charcoal production, is therefore much more complex in Zambia than in continuous tropical forest landscapes such as those found in central Africa.

Remote sensing is also challenging in Zambia due to high cloud coverage and the open canopy and seasonality of the woodlands. The open canopy and pronounced grass layer makes distinguishing woodland from other savannah types, such as wooded grassland or scrubland, difficult. This is particularly true for semi-evergreen and deciduous woodland types during the dry season when trees are not in leaf. The average annual cloud cover for the country is more than 40% with high variability; the lowest cloud cover percentages are observed in November and December (Herold 2009). However, the optimum month to capture remote sensing imagery for forest cover changes in Zambia is at the start of the dry season (May–June), when trees are still in leaf but grasslands are dying back and cloud cover is relatively low.

Despite the major institutional challenges facing MRV of REDD+ in Zambia there are considerable opportunities to develop an effective MRV system for the country. The current gaps in capacity, state of knowledge and technical challenges mean that initiatives can be specifically designed to achieve MRV objectives. For example, ILUA II has been designed with measuring and reporting for REDD+ as a key objective.

# 2 Available data and current capacities

## 2.1 National datasets available for monitoring, reporting and verification of REDD+ in Zambia

A number of datasets are available for MRV of REDD+ in Zambia, generated from field inventories as well as remote sensing and aerial photography. They include ILUA I and II, aerial photographs, the USFS MRV report and satellite imagery from Landsat, RapidEye, MODIS, WorldView 1 and 2, GeoEye and Systeme Pour l'Observation de la Terre (SPOT). The data type, dates, cost, availability, potential uses and other characteristics are presented in Table 2.

## 2.2 Data sources for the Global Forest Resources Assessment 2010 report and the Initial National Communication

### 2.2.1 Global Forest Resources Assessment 2010 report

The bulk of the Global Forest Resources Assessment (FRA) 2010 report, particularly for current trends, uses data from ILUA I. The FAO partially funded the ILUA and provided technical assistance. Specific sources for different aspects of the report that are relevant to MRV for REDD+ are provided in Table 3 (FAO 2010).

The data sources selected for the FRA 2010 report indicate the relative paucity of data relevant to monitoring and measuring forest resources in Zambia, and the importance of ILUA I as an initial assessment. The information regarding forest cover, growing stock and biomass, and therefore carbon stocks, is all based on ILUA I. No data was available for forest fires and other disturbances affecting forest health and vitality. Data was also not available regarding public expenditure on forests (FAO 2010).

### 2.2.2 United Nations Framework Convention on Climate Change National Communication

The inventories for GHG emissions given in the INC were compiled by the Centre for Energy, Environment and Engineering Zambia. Data for the inventories were derived from the following sources:

- Energy Balance for 1994
- Energy Statistics Bulletin 1974–1996
- Agriculture Statistics Bulletin 1980–1996
- Central Statistics Office
- research conducted at the University of Zambia.

The lack of reliable data on forests was identified as a weakness in the INC. The MLNREP is currently in the process of preparing its Second National Communication, which intends to address this weakness by using remote sensing.

## 2.3 Institutional framework and capacity for forest and agricultural monitoring

The MLNREP has overall responsibility for forest resources in Zambia, with monitoring of forest resources being undertaken by the Forestry Department. The Forestry Department has a presence in all nine provinces and in every district (IDLO 2011). The management of national parks in Zambia, which contain considerable forest resources, is undertaken by the Zambian Wildlife Authority. The REDD+ Coordination Unit will be based in the Forestry Department, and MRV of REDD+ will be carried out by the Forestry Department with technical assistance from the FAO (UN-REDD 2010a).

Institutional capacity for forest monitoring for REDD+ is low in Zambia. In particular the Forestry Department has suffered from a decline in funding over the last 2 decades, which has

Table 2. National datasets available for monitoring, reporting and verification of REDD+ in Zambia.

Dataset	Data type	Dates	Cost (USD) and availability	Potential uses	Potential drawbacks	References
<b>Field inventories</b>						
Integrated Land Use Assessment Phase I (ILUA I)	ILUA I is based on the standard National Forest Assessment (NFA) approach developed by the Food and Agriculture Organization of the United Nations (FAO). Forest inventory data is collected from 221 permanent sample plots distributed systematically throughout the country. This includes DBH (diameter at breast height) measurement of all trees within plots. Socioeconomic data was also collected on agriculture and livelihoods.	2005–2008	Free ILUA data should be accessible through a database; however, this has not yet been established	Carbon stock estimation in major forest types using DBH following Intergovernmental Panel on Climate Change (IPCC) guidelines, equivalent to tiers 1 and 2	Designed for global forest inventorying and therefore not specific for ecosystems and structures found in Zambia (Vinya et al. 2011)	Kalinda et al. 2008; Mukosha and Siampale 2008
Integrated Land Use Assessment Phase II (ILUA II)	The aim of ILUA II is to provide data for carbon stock estimation to enable monitoring, reporting and verification (MRV) for REDD+ in Zambia. ILUA II features an intensification of the ILUA I survey design to cover over 4000 sampling plots across the country. ILUA II will include the development of methods to estimate carbon at the field level according to IPCC standards and the calculation of emissions factors for Zambia.	2010–ongoing (projected completion late 2014/early 2015)	Free As with ILUA I data should be accessible through Open Foris software (under development by the FAO and the United States Forest Service)	Reference level emissions for 4 carbon pools for tiers 2/3 following IPCC guidelines; below-ground biomass (BGB) equivalent to Tier 1	Accessibility: capacity for data sharing is currently low between government departments in Zambia	MTNER 2010a
<b>Remote sensing and aerial photography</b>						
Aerial photographs	An extensive archive of aerial photographs is held at the Survey Department within the Ministry of Lands, Natural Resources and Environmental Protection (MLNREP). For example for 1967k, 1:30,000-scale photographs are available for all of Eastern Province. The last nationwide capture of aerial photography was conducted in 1983.	1956–1996 (the last aerial photography campaign across all parts of the country)	High cost and based on approval from the Survey Department	Historical records of forest cover and forest cover change	High time-cost to print, scan, geo-reference and mosaic images in order to determine forest cover	USFS 2012
Landsat	Landsat offers medium-resolution satellite imagery. It provides the longest running imagery, with the most recent satellite (Landsat 7) launched in 1999. Resolution is 15–60 m, with temporal resolution of 16 days. Landsat 8 is scheduled to be launched in February 2013.	Data available for land-use maps from 1990, 1995, 2000, 2005 and 2010	Free (US Geological Survey Global Visualization Viewer - (GloVis))	Reference levels, for land-use change. Availability means it is particularly useful on a national scale. National Remote Sensing Survey is currently using Landsat imagery to develop reference level for forest cover	Lower resolution imagery compared to Rapid Eye, WorldView and GeoEye. May make estimates of carbon losses from forest degradation or deforestation of open woodlands problematic	Kalinda et al. 2008; Mukosha and Siampale 2008 Landsat: www.landsat.org GloVis: http://glovis.usgs.gov/

Dataset	Data type	Dates	Cost (USD) and availability	Potential uses	Potential drawbacks	References
Moderate resolution spectroradiometer (MODIS)	MODIS offers low-resolution imagery (250–1000 m) captured in 36 spectral bands. It was launched in 1999 and images the earth every 1–2 days. It is suitable for providing measurements for large-scale rapid changes.	From 1999	Free. Good coverage for Zambia	Used by Zambian Environmental Management Agency to measure fire incidences across the country. Can be used combined with National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data to estimate net primary productivity as an indicator of carbon sequestration potential	Low resolution, not suitable to assess forest cover change on a national scale due to degradation and deforestation	Sikaundi 2012; Murwira 2009; Rahman et al. 2004; <a href="http://modis.gsfc.nasa.gov/related/">http://modis.gsfc.nasa.gov/related/</a>
RapidEye	RapidEye offers high-resolution satellite imagery (5 m) with a large archive and capacity to acquire data for large areas (4 million km <sup>2</sup> per day).	From 2010	Geo Data Design Ltd. Good coverage for Zambia Archive and tasking = USD 1.28 per km <sup>2</sup>	Assessing forest cover changes due to deforestation. Tasking available for regional/project level studies. May be useful for validation of results from studies using Landsat	5 m resolution may not be sufficient to determine all forms of forest degradation accurately	<a href="http://www.rapideye.com">www.rapideye.com</a> <a href="http://www.datadesign.co.za">http://www.datadesign.co.za</a>
WorldView 1 and 2	WorldView offers high-resolution satellite imagery (1 m). WorldView 1 was launched in 2007 and WorldView 2 in 2009. It is able to collect images for more than 1 million km <sup>2</sup> per day.	WorldView 2 from 2010	Geo Data Design Ltd. Archive and tasking = USD 25–35 per km <sup>2</sup>	Assessing forest cover changes due to deforestation. Tasking available for regional/project level studies. May be useful for validation of results from studies using Landsat	Limited coverage for Zambia prior to 2010	<a href="http://www.digitallobe.com">www.digitallobe.com</a> <a href="http://www.datadesign.co.za">http://www.datadesign.co.za</a>
GeoEye 1	GeoEye 1 is currently the most advanced commercial satellite imagery at 0.5 m resolution, with positional accuracy CE90 and RMSE. It was launched in 2008.	From 2010	Geo Data Design Ltd. Limited availability for Zambia Archive = USD 17.50 per km <sup>2</sup> ; tasking = USD 30 per km <sup>2</sup>	Assessing forest cover changes due to deforestation. Tasking available for regional/project level studies. May be useful for validation of results from studies using Landsat	Limited coverage for Zambia prior to 2010	<a href="http://www.geoeeye.com">www.geoeeye.com</a> <a href="http://www.datadesign.co.za">http://www.datadesign.co.za</a>
Système Pour l'Observation de la Terre (SPOT)	SPOT offers high-resolution satellite imagery (1.5–20 m). SPOT 1 launched in 1986. SPOT 6 and SPOT 7 should continue to produce imagery until 2024.	6 years of cloud-free SPOT imagery covering >80% of the country is available for 1990–2005	Astrium-geo.com From around USD 1500 per scene (60 x 60 km). Price varies considerably depending on satellite and image years	Assessing forest cover changes due to deforestation	Potentially expensive, and cloud-free coverage is not always available (approximately 70% mean annual cloud-free coverage for Zambia from 2006–2008)	Herold 2009 <a href="http://smsc.cnes.fr/SPOT/">http://smsc.cnes.fr/SPOT/</a>

**Table 3. Data sources for the Global Forest Resources Assessment 2010 report.**

Variable	Data source	Notes
Classification of land cover types	Chakanga and de Backer 1986	These forest types were merged into standard forest type definitions of the Food and Agriculture Organization of the United Nations (FAO)
Land cover	Integrated Land Use Assessment (ILUA) 2005–2008 Kalinda et al. 2008; Mukosha and Siampale 2009	Uses standard FAO forest type definitions for Zambian woodlands. Reference year is 2007
Plantation forests cover and expansion	Ministry of Tourism, Natural Resources and Environment (MTNER) – Zambian Forestry Action Plan (1998) and the Plantation Expansion Programme (2000)	ILUA I field assessment did not cover any of the relatively small number of plantation forests in the country
Growing stock	ILUA 2005–2008 Kalinda et al. 2008; Mukoshi and Siampale 2009	Gives estimates for both commercial and overall growing stock, including all species
Biomass – above-ground biomass (AGB) and below-ground biomass (BGB)	ILUA 2005–2008 Kalinda et al. 2008; Mukosha and Siampale 2009	Calculated using Intergovernmental Panel on Climate Change (IPCC) default biomass conversion and expansion factors. Root to shoot ratio of 0.24 for calculating BGB from AGB

particularly impacted regional (provincial and district) capacity and the ability of the Forestry Department to carry out functions such as forest patrols and forest monitoring at a district level (IDLO 2011). Capacity is also low, in terms of technical expertise, for the use of remote sensing for forest monitoring. There is also lack of technical equipment, such as computer software and survey vehicles, as well as problems with low bandwidth and therefore Internet speeds in Zambia (Herold 2009). REDD+ readiness activities as outlined in the NJP have a strong focus on capacity building for forest monitoring, particularly with regard to developing the capabilities for completing ILUA I and II.

The Ministry of Agriculture and Livestock is responsible for governance of agriculture in Zambia. The Zambia Agriculture Research Institute (ZARI) is the largest agriculture research group in the country, with 10 research stations throughout the country. ZARI conducts research and provides technical advice related to agriculture in Zambia, particularly with regards to improving productivity, such as through increased yields.

## 2.4 Available data and approaches to support spatial planning and land-use management

ILUA I and II will contribute data to support spatial planning and land-use management in Zambia. For example ILUA I provides socioeconomic data primarily from structured interviews. This information can be used to design policies for sustainable management of natural resources (Mukosha and Siampale 2009). Data collected from sample households includes:

- income from and employment in forestry and agriculture
- population levels and degree of encroachment into forests by communities living around forest areas
- the types of forest products and resources used by communities; including timber species and level of harvesting of important timber species
- the main agriculture crops and livestock production activities
- land ownership and access to land.

ILUA I had a low intensity of sampling points, limiting its use for district-level land-use planning; however, ILUA II will provide more district- and provincial-level data (MTNER 2010a).

## 2.5 Evolving technologies

The use of remote sensing is an effective way of estimating base-level forest cover and deforestation rates on a national or regional scale for REDD+ (Mitchard et al. 2009). The ILUA used Landsat imagery to assess land cover change, and a national reference level for forest cover is currently being completed for Zambia using Landsat data (Mukosha and Siampale 2009). However, there are a number of technical limitations regarding the use of remote sensing for estimating biomass, including the degree to which remote sensing technologies can determine carbon stocks and carbon stock changes at a sufficient resolution for the needs of REDD+ (Le Toan et al. 2011). The open structure of the major woodland types and the scattered nature of forest loss due to degradation and deforestation means higher resolution imagery may be required for accurate estimates of forest cover change in Zambia (Romijn et al. 2012). However, many high-resolution imagery datasets have limited coverage within the miombo ecoregion (see Table 2) (Ribeiro et al. 2012). Spectral Mixture Analysis (SMA) is a technique that has the potential to overcome the spatial and temporal heterogeneity of miombo woodland types in order to map vegetation cover. Although current SMA techniques have not been applied to miombo, it has been used in ecosystems with structural similarities to miombo woodland (Ribeiro et al. 2012).

Additional technologies with potential applications for MRV in relation to REDD+ include radar, Synthetic Aperture Radar (SAR), and LiDAR (light detection and ranging) sensors (GOF/ GOLD 2010). LiDAR and radar remote sensing can measure stand structural variables (such as height, volume and basal area) as well as biomass and changes in these variables due to disturbance (Schugart et al. 2010). Radar is less sensitive to weather conditions compared to optical sensors, making wet season measurements within Zambian woodlands possible (Ribeiro et al. 2012). Mitchard et al. (2009) used L-band radar backscatter (derived

from ALOS PALSAR)<sup>1</sup> to predict AGB in four African landscapes, including woodland ecosystems in Mozambique. However, they suggest field plots remain essential for validation and for estimating a correction factor for AGB in grasses and stems with a DBH below 10 cm (Mitchard et al. 2009). Ryan et al. (2011) used radar imagery (25 m resolution L-band radar imagery) in central Mozambique to produce maps capable of detecting changes in carbon stocks of as little as 12 mg of carbon per hectare. Loss of carbon from degradation had a greater level of uncertainty, which is significant in a Zambian context due to the high level of degradation from charcoal production. However, the advantages of this method are that cloud and atmospheric effects are largely irrelevant and backscatter (or L-band normalized radar cross-section) has been shown to have a reasonably direct relationship to woody biomass (Ryan et al. 2011).

Radar and LiDAR can also be used in conjunction to provide complementary information regarding forest structure (Schugart et al. 2010). A combination of radar and LiDAR was used by Mitchard et al. (2012) to map tropical forest biomass in Lopé National Park, Gabon. However, cost and availability of LiDAR data may be prohibitive for MRV of REDD+ in Zambia. Acquisition of LiDAR via aircraft is currently expensive and satellite LiDAR data is not available until ICESat 2 is launched in 2015 (Mitchard et al. 2012). The ILUA intends to gather LiDAR data through tasking of flights in selected test areas, in order to assess biomass and carbon for different forest types (MTNER 2010a).

Another recent technology, which has potential applications for MRV in Zambia, is the use of unmanned aerial vehicles (UAVs) or drones. Small, unmanned aircraft are now available at relatively cost-effective prices and are capable of covering large areas of forests in a single flight. Applications include monitoring of forest cover changes using aerial photography, particularly at project-level scales. UAVs have several advantages, such as the ability to survey on demand, ease of repeatable monitoring and the ability to generate high-resolution imagery. There is also potential for UAVs to be used in conjunction with LiDAR devices (Wallace et al. 2012).

<sup>1</sup> Advanced Land Observation Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR)

# 3 State of knowledge

## 3.1 Growth rates and standing biomass

### 3.1.1 Growth rates

Growth rates both in mature and regrowth miombo woodlands are relatively low. Net primary production in miombo woodlands is 900–1600 gm<sup>-2</sup> per year and the annual increment of woody biomass is approximately 3–4% in mature stands (Frost 1996). Vinya et al. (2011) cites annual growth rates in ring width of 4.4–5.6 mm for regrowth and 2.3–4.8 mm for mature woodland in southern Africa. The average wood annual increment for all Zambian forests is 1.3–2.7 t per hectare per year (Siampale 2008). Table 4 provides a range of growth rate estimates, from 0.7 t to 1.4 t of carbon per hectare annually, for miombo woodlands in Zambia and neighboring countries. Growth rates for a number of common species found in Zambian woodlands are given in Appendix 1. Growth rates can vary depending on the age since regrowth in disturbed plots, as well as ecological conditions such as fire and rainfall. Rainfall is particularly important for productivity in miombo woodlands (Ribeiro et al. 2012).

The average growing stock for Zambia is estimated at 39.1 m<sup>3</sup> per hectare over all land-use classes and forest types (UN-REDD 2010a). The national growing stock for Zambia (based on gross volume of all living trees with a DBH greater than 7 cm), is estimated at 2.8 billion cubic meters, of which 2.1 billion cubic meters is from semi-evergreen miombo dominated woodlands (Kalinda et al. 2008).

Carbon accumulation in Zambian miombo woodlands is greatest in the first 50 or 60 years after regrowth, with a limited increase in carbon stocks after that (Chidumayo 2011). The most significant biomass recovery occurs within 30 years, with woody biomass production peaking within 18–20 years in regrowth woodlands (Chidumayo

1993; Frost 1996). Williams et al. (2008) found that wood carbon stocks could recover within 20–30 years on abandoned farmland in Mozambique. The Forestry Department of Zambia (as well as those in Botswana and Zimbabwe) use a commercial cutting cycle of around 40 years (Sitoe et al. 2010). For charcoal production in miombo woodland in Tanzania, Malimbwi et al. (2005) estimated that miombo forests could be harvested every 8 years and maintain approximately 70% of the standing biomass at this rate.

### 3.1.2 Standing biomass

A high degree of uncertainty is associated with biomass (and therefore carbon stocks) in savannah landscapes (Grace et al. 2006). Standing biomass in Zambia is highly variable and dependent on a number of factors including stand age, soil type, rainfall, herbivory and fire (Frost 1996; Kutsch et al. 2011). Rainfall has a strong influence on biomass in miombo woodlands; for old-growth or lightly used miombo woodland approximately 55 t of dry biomass per hectare is found in dry miombo compared to around 90 t per hectare in wet miombo (Frost 1996; Clarke and Shackleton 2007). Table 5 provides a range of biomass estimates, mainly for miombo woodland types in Zambia and neighboring countries. Biomass estimates for evergreen forests and the deciduous woodlands are limited. The ILUA and the Zambia Country Study carried out by the Centre for Energy, Environment and Engineering Zambia (CEEZ) for the INC, provide some estimates for evergreen forests and deciduous woodland types. Evergreen woodland has a higher biomass level than miombo, whereas open deciduous woodlands have a slightly lower level (CEEZ 1999; Mukosha and Siampale 2009).

Kamelarczyk (2009) produced AGB estimates across all forest types in Zambia using ILUA data equivalent to tiers 2 or 3 of the IPCC guidelines.

Table 4. Growth rates for woodlands in the miombo ecoregion.

Conditions and factors of growth rate estimate	Growth rates (t C/ha/pa, or m <sup>3</sup> /ha/pa)* or annual ring growth in mm, or basal area increment in m <sup>2</sup>	Reference
<b>Biomass</b>		
Biomass regrowth of young miombo woodland cleared 16 years previously	0.98 t/ha/pa (2.47 fresh weight) and annual basal area increment of 0.5 m <sup>2</sup> /ha/pa	Stromgaard 1985
Growth rate from yields for coppiced plots aged 6–29 years from Kabwe Rural, Lusaka Rural and Mumbwa districts in Zambia	2.49 t/ha (biomass)	Chidumayo 1991
Above-ground biomass and below-ground biomass at eight old-growth miombo woodland sites in central Zambia and woody biomass regrowth at miombo woodland sites harvested for charcoal production	2–3 t/ha (biomass)	Chidumayo 1993
Two sites in miombo woodlands of the Southern Highlands of Tanzania: Longisonte forest reserve in Vwawa Division and Zelezeta Village forest reserve in Igamba division of Mbozi District	Mean above-ground carbon density of the miombo ecosystem was 19.2 t/ha-1	Munishi et al. 2010
Assessment of the impacts of elevation, tree species and management on carbon stock on the slopes of Rungwe Mountain in Tanzania. Twenty 15 m-radius plots with trees of DBH >10 cm were used to collect tree measurements as well as soil samples at depths of 10, 20 and 30 cm	Above-ground carbon content increased with altitude, ranging from 9.2 t/ha at 2031 m to 561.7 t/ha at 2312 m  Soil carbon content tended to increase down the slope, ranging from 3.8 t/ha at 2312 m to 4.7 t/ha at 2031 m	Mwakisunga and Majule 2012
<b>Growth rates</b>		
Wood biomass growth rate as mean annual increment of wood biomass in experimental coppiced woodland aged 3–29 years and plots aged 48–49 years in the Copperbelt region of Zambia	1.97 t/ha/pa (SD = 1.68). Ranged from 0.41 t/ha for plots aged 3–6 years to 2.91 t/ha for plots aged 7–29 years. 1.68 t/ha (SD = 0.39) for 48–49 year plots. Early burnt plots had a mean annual increment (MAI) of 0.60 t/ha compared to 0.22 t/ha for late burnt plots	Chidumayo 1990
Growth rate in dry miombo woodland in Zambia over 35 years	0.9 t C/ha/pa	Chidumayo 1997
Average for dry miombo in Zambia and Zimbabwe	0.75 t C/ha/pa	Frost 1996
Stand growth rate for miombo woodland at Kitulangalo near Morogoro, Tanzania	2.3 m <sup>3</sup> /ha/pa	Malimbwi et al. 2005
Regrowth for 14 plots in miombo woodland in the buffer zone of Gorongosa National Park, Central Nhambita, Mozambique	0.7 (SD = 0.19) t C/ha/pa Regrowth rates ranged from 0.43 t C/ha/pa to 0.87 t C/ha/pa	Williams et al. 2008

\* 1 m<sup>3</sup> = 0.35 t

**Table 5. Biomass and carbon estimates in miombo woodlands in Zambia and neighboring countries.**

Biomass/carbon estimate type	Biomass (t/ha)	Carbon equivalent (t/ha)	Reference
<b>Estimates for Zambian woodland from recent studies</b>			
Four different above-ground biomass (AGB) estimates using Integrated Land Use Assessment (ILUA) data; two biomass conversion and expansion factors (BCEFs) and two allometric equations	32–52	15–24	Kamelarczyk 2009
Estimates using the Intergovernmental Panel on Climate Change (IPCC) methodological framework (2006) using BCEFs with growing-stock levels to calculate AGB, below-ground biomass (BGB) and deadwood (AGB estimates given)	All forests: 83.8 (SE = 8.2) Evergreen: 108.2 Semi-evergreen: 93.1 Deciduous: 61.2 Other natural forests: 67.2	39.39 50.85 43.76 28.76 31.59	Mukosha and Siampale 2009
AGB for disturbed and undisturbed forests using the IPCC methodological framework (2006) using BCEFs with growing-stock levels to calculate AGB, BGB and deadwood (AGB estimates given)	Undisturbed: 79.37 Disturbed: 37.06	37.30 17.42	Kalinda et al. 2008
Median AGB for 3 plots in miombo woodland in the Kataba Forest Reserve and one plot in disturbed forest (following logging for charcoal production) in Western Province, Zambia	Forest reserve: 150.56 Disturbed forest: 24	70.76 11.28	Kutsch et al. 2011
<b>Recent estimates for miombo woodland in countries adjacent to Zambia</b>			
Woody tree and soil carbon estimates for miombo woodland in the Nhambita area, Gorongosa District, Mozambique	Woody biomass: stems 45.12; roots 18.09 Soil carbon: not applicable	21.2 (SD = 1.4) 8.5 (SD = 0.5) 76.2 (SD = 9.9)	Ryan et al. 2010
AGB in miombo woodland in the Eastern Arc Mountains of Tanzania	Carbon: 13–30 (mean 23.4)	6.11–14.1 (mean 10.1)	Shirima et al. 2011
Mean stem and median soil carbon and wood regrowth for 14 plots in miombo woodland in the buffer zone of Gorongosa National Park, Central Nhambita, Mozambique	Stem carbon: 40.43 Soil carbon: not applicable	19.0 (SD = 8.0) 57.9	Williams et al. 2008
<b>Miombo ecoregion/African dry woodland estimates</b>			
Carbon stock in tonnes per hectare for Zambezan phytoregion from a number of published sources	88–97	41.36–45.59	Timberlake et al. 2010
Estimate for Zambezan warm dry woodlands. Based on unpublished allometric equation using basal area and utilizing tree and stand measurements from a number of published studies	93 (SD = 4)	43.71	Chidumayo 2011

Table 5. Continued

<b>Older studies</b>			
Estimates given for different woodlands in the Zambian country study used for greenhouse gas inventories for Zambia's Initial National Communication (INC). (Kalahari miombo equates to Kalahari woodland)	Closed evergreen forests: 158	74.26	CEEZ 1999 (used to calculate greenhouse gas emissions from land use, land-use change and forestry for Zambia's INC)
	Closed deciduous forests: 58	27.26	
	Wet miombo: 76	35.72	
	Kalahari miombo: 43	20.21	
	Mopane: 46	21.62	
Average AGB for old-growth, mixed-age stands in dry miombo woodland in Zambia and Zimbabwe, and approximate value for wet miombo old-growth stands	Munga: 46	21.62	Frost 1996
	Termitaria: 25	11.75	
AGB and BGB at eight old-growth miombo woodland sites in central Zambia and woody biomass regrowth in miombo woodland sites harvested for charcoal production	Dry miombo: 55	25.85	Chidumayo 1993
	Wet miombo: 90	42.3	
BGB in old-growth dry miombo woodland in central Zambia	AGB: 69.9 (SD = 20.8)	32.85	Chidumayo 1993
	BGB: 38.9 (SD = 9.9)	18.29	
Mean dry biomass for miombo woodland in 17 plots, including small (<0.1 ha) and large plots (>0.1 ha) from Kabwe Rural, Lusak Rural and Mumbwa districts in Zambia.	32.7	15.37	Chidumayo 1991
	Mean: 81.0 (SD = 7.3)	38.07	
	Small plots: 141.8	66.65	
Mean AGB for miombo woodlands in nine old-growth plots in the Copperbelt region of Zambia	Large plots: 78.4	36.85	Chidumayo 1990
	92.5 (SD = 14.1)	43.48	
Study in four plots in miombo woodland, with different levels of disturbance (ranging from complete clearance 16 years previously to harvesting 6 years previously) in Kasama, Northern Province, Zambia	AGB of 16-year undisturbed stand: 48.28 t/ha	22.70	Stromgaard 1985

Note: IPCC guidelines give the conversion rate of carbon as 0.47 t of carbon per tonne of dry biomass (Eggleston et al. 2006).

Four different methods were used to estimate biomass, including the IPCC BCEFs (average and low values) and allometric equations from studies by Brown (1997) and Chave et al. (2005). These methods produced carbon estimates within AGB ranging from 15 t per hectare to 24 t per hectare (using the IPCC conversion rate of 0.47 for biomass to carbon). BGB estimates were made equivalent to Tier 1, using a below- to above-ground biomass fraction of 0.28. Total above- and below-ground biomass was estimated to be in the range of 960–1561 Mt of carbon. With total carbon stock (including biomass, deadwood, litter

and soil) estimated at 2652–3323 Mt of carbon. Due to its greater prevalence, the majority of biomass was calculated to be in semi-evergreen forests (mainly comprising miombo woodlands) with a significant proportion of biomass found in deciduous woodlands (Kamelarczyk 2009). Kamelarczyk (2009) produced lower biomass estimates than some previous studies (including ILUA I) and concluded that verification studies are needed, involving destructive sampling of trees in order to clarify biomass estimates. Chidumayo (2012b) also produced lower estimates using ILUA I data with carbon in above-ground woody

biomass, estimated to be approximately 14 t per hectare across all woodland types in Zambia.

The ILUA also produced its own estimates for AGB and BGB solely using the methodology provided by the IPCC best practice guidelines (Eggleston et al. 2006). Total national biomass (above and below ground) was estimated to be 5.6 billion tonnes. This equates to approximately 2.8 billion tonnes of carbon (Mukosha and Siampale 2009). The ILUA reports provide estimates for the different forest types found in Zambia and for disturbed and undisturbed forests (Kalinda et al. 2008; Mukosha and Siampale 2009) (Table 5). However, these estimates using IPCC BCEFs are subject to a high degree of uncertainty and lead to overestimates of biomass levels in ILUA I (Kamelarczyk 2009; Chidumayo 2012c).

### 3.2 Allometric equations

The use of allometric equations is the preferred method of estimating biomass where forest inventory data exists, since it reduces uncertainty in estimates. Allometric equations are also necessary in order to achieve Tier 2 and Tier 3 level estimates under IPCC best practice guidelines. A number of allometric equations are now available to estimate AGB from forest data. However, there are a limited number available from Africa and within dry forest regions, including the open woodlands found in Zambia (Kamelarczyk 2009). The most recent equation developed for miombo woodland is based on the destructive sampling of 119 trees, comprising 19 species, and is suitable for estimation of biomass within miombo woodlands in Zambia (Chidumayo 2013). Ryan et al. (2010) developed a site-specific allometric equation for both AGB and BGB in miombo woodland in the Nhambita area of Mozambique, based on the destructive harvest of 29 trees, 23 of which were excavated for root biomass calculation. Site-specific equations have also been developed by Chidumayo (1990) from destructively harvested trees in miombo woodland in Zambia, and Abbot et al. (1997) for miombo woodlands in Malawi. However, verification of these models is required to determine their applicability outside the sample sites. A number of equations have also been calculated for *C. mopane*; however, these studies are all more than 15 years old and their current applicability may need verifying (e.g. Guy 1981;

Scholes 1990; Tietema 1993). No specific models have been developed for the evergreen forests found in Zambia. A common equation for African dry forests has also been produced by Chidumayo (2011) in order to estimate wood biomass from basal area.

Due to the limitations of the above equations, the most suitable equation for national-level inventories may be the one developed by Chave et al. (2005). The equation uses the largest available dataset of 2410 trees harvested in 27 sites across the tropics. Generalized allometric equations are often better for national-scale assessments as many smaller studies are site specific having used a small number of species and samples in order to derive equations (Gibbs et al. 2007; Henry et al. 2010). Despite the fact that it is limited by a lack of African study sites, the Chave et al. (2005) equation has also been found to be accurate by several site-specific studies within Africa, which have recommended its use for regional-scale studies (Djomo et al. 2010; Henry et al. 2010; Vieilledent et al. 2011). Two dry forest equations from Chave (2005) were utilized in the UN-REDD study Carbon Stock Assessment and Modelling in Zambia, which was determined to be the most useful for AGB estimates in Zambian climatic zones (Kamelarczyk 2009).

At a subnational level general models for each main forest type are preferable. As part of ILUA II, Chidumayo (2012c) has compiled an assessment for existing models used in sub-Saharan African dry forests. Data from destructively sampled trees were collated for Zambia, Tanzania and Botswana (including 82 species from miombo, mopane and munga woodlands) to develop new allometric equations. This study provides models for miombo, munga and mopane woodland types, as well as for all forest types and several key species and species groups in Zambian woodlands (Chidumayo 2012c).

### 3.3 Root biomass and root to shoot ratios

A significant proportion of biomass is found below ground in African dry woodlands (Chidumayo 2011). Chidumayo (1993) estimated BGB as 36% of total biomass (below and above ground). Many species common to miombo woodlands

have extensive root systems with tap roots that can extend more than 5 m, which makes studies of root biomass difficult (Frost 1996). Chidumayo (1993) reported root biomass in soil layers as follows: 76% in 0–50 cm, 21% in 50–100 cm and 3% below 101–150 cm. For a study area in Mozambique, Ryan and Williams (2010) estimated a ratio of root to stem biomass of 0.27–0.58 with a mean of 0.42. Frost (1996) calculated ratios of 0.53 and 0.47. These ratios are higher than the AGB/BGB biomass fraction of 0.28 for tropical dry forests from the IPCC default tables (higher range) used by Kamelarczyk (2009). Further estimates of BGB are included in Table 5.

### 3.4 Deadwood and litter pools

Limited information is available regarding deadwood and litter carbon pools in the different forest types in Zambia. Frost (1996) gives a range of standing litter within miombo woodlands of 3.27–12.00 t of biomass per hectare. Only one of the studies cited was based within miombo woodland in Zambia, which had an annual average of total litter of 5.48 t of biomass per hectare (Frost 1996).

The ILUA estimated deadwood biomass using an IPCC BCEF in relation to the growing stock estimate. This gave a total deadwood estimate of over 400 million tonnes within forests in Zambia (Mukosha and Siampale 2009). Kamelarczyk (2009) also uses a BCEF to make estimates of deadwood biomass using ILUA data. However, below-ground deadwood biomass and stump deadwood biomass were excluded due to insufficient data. Estimates of carbon stock with deadwood were 0.37–1.79 t per hectare. All carbon within deadwood was assumed to have the same ratio to living biomass of 0.47, which may need to be adjusted to a lower fraction. The ratio between deadwood biomass and live biomass ranged between 0.020 and 0.057 (Kamelarczyk 2009).

Both Kamelarczyk (2009) and the ILUA estimated litter using IPCC look-up tables (equivalent to Tier 1 estimates), although Kamelarczyk (2009) used the Frost (1996) litter estimate (5.48), rather than the IPCC default value for semi-evergreen forest. Litter was estimated to account for 2.48 t of carbon per hectare across all forest types (Kamelarczyk 2009).

### 3.5 Intergovernmental Panel on Climate Change expansion factors

There are very few country-specific BCEFs for Zambia, as a result the ILUA used default IPCC BCEFs in order to estimate AGB, BGB, deadwood and litter biomass (Kalinda et al. 2008). However, as the carbon stock estimates derived using BCEF default values (using IPCC guidelines) were significantly different from estimates using other methods, Kamelarczyk (2009) considered these estimates invalid. When using a low BCEF value the estimates were more comparable with the estimates given by allometric equations (Kamelarczyk 2009). The two latest forest inventories, the ILUA and the Forest Support Program (FSP) inventory, utilized a volume function developed by the Zambian Forestry Department based on trees sampled from only one region of the country, as such it may not be representative of the whole country (Kamelarczyk 2009).

### 3.6 Soil organic matter loss following deforestation

Soil carbon stock information for Zambian forests is limited. Miombo soils have low concentrations of organic matter with an average of 1%–2% in the topsoil (Chidumayo 1997). Ryan et al. (2010) found the soil carbon pool in miombo woodland to be highly variable, which was correlated with soil texture. As with the litter carbon pool both the ILUA and Kamelarczyk (2009) made Tier 1 level estimates for soil carbon, which are subject to a great deal of uncertainty. Kamelarczyk (2009) used the value for mineral soils of 31 t per hectare (IPCC 2003).

In savannah ecosystems, soil carbon stocks often exceed woody carbon stocks. As much as 50–80% of total system carbon is estimated to be in the top 1.5 m below ground (Walker and Desanker 2004). Disturbance of soils due to agriculture alters nutrient cycling (such as through increased microbial respiration) and can cause a loss of soil carbon (Walker and Desanker 2004; Williams et al. 2008). Soil carbon can therefore be a significant emitter of CO<sub>2</sub> when woodland is cleared. For sites in Zimbabwe, King and Campbell (1994) calculated a carbon

loss of approximately 10% (in the top 0.5 m of soil), when miombo woodland was converted to arable land or pine plantations. Williams et al. (2008) found soil carbon stocks in abandoned farmland had a maximum of 74 t of carbon per hectare compared to a maximum of 140 t of carbon per hectare in miombo woodland soils in Mozambique. No significant increase in soil carbon stocks was found over the period of regrowth, suggesting a slow accumulation of carbon in these soils. Wood carbon stocks on abandoned land were capable of recovery in 2–3 decades but soil stocks did not change during this time period. Walker and Desanker (2004) found an average of 40% less soil carbon in agricultural soils compared to miombo woodland soils in Malawi and also reported slow recovery rates of soil carbon in abandoned farmland. The significant loss of carbon recorded in these studies may only apply to woodland converted to agriculture. Kutsch et al. (2011) found no significant difference in soil carbon content between plots within highly disturbed (for charcoal production) and undisturbed miombo woodland in Western Province, Zambia.

Fire is another key factor influencing carbon emissions from soil in Zambia. Bird et al. (2000), in a study in a savannah ecosystem in Zimbabwe, reported that lower fire frequencies resulted in an approximately 10% increase in soil carbon stocks, whereas higher fire frequencies caused an approximate 10% decrease. Plots where fire was excluded had a 40–50% increase in carbon stocks in the first 5 cm of soil depth. Chiduymayo and Kwibisa (2003) also found fire reduced soil organic matter in Zambia.

### 3.7 Wood density of tree species

The Global Wood Density Database (Chave et al. 2009; Zanne et al. 2009) has specific wood densities for a large number of African species including from within Zambia. This database has been used to derive wood densities for AGB estimates in a number of studies (Kamelarczyk 2009; Lewis et al. 2009; Djuikouo et al. 2010). The World Agroforestry Database is another source of species-specific wood densities (ICRAF 2009). Kamelarczyk (2009) used these databases

to produce a new database of wood densities for the 350 species recorded in the ILUA I data. Chidumayo (2012b) also calculated specific wood density for 31 tree species found in miombo woodland in Zambia.

Mean wood densities for African tree species as a whole have also been calculated by Brown (1997) 0.58 g cm<sup>-3</sup>, Henry et al. (2010) 0.59 g cm<sup>-3</sup> and Duikouo et al. (2010) 0.60 g cm<sup>-3</sup>. These estimates are similar to the average wood density of 0.62 g cm<sup>-3</sup> given by the IPCC (2003). For miombo woodlands in Mozambique, Williams et al. (2008) calculated a mean wood density of 0.56 g cm<sup>-3</sup> (ranging from 0.40 g cm<sup>-3</sup> to 0.71 g cm<sup>-3</sup>). A lower density was reported by Shirima et al. (2011) of 0.39 g cm<sup>-3</sup> (ranging from 0.22 g cm<sup>-3</sup> to 0.56 g cm<sup>-3</sup>) for miombo woodland in Tanzania.

### 3.8 Non-carbon dioxide emissions associated with land-use change

Major GHGs other than CO<sub>2</sub> include methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), ozone (O<sub>3</sub>) and the halocarbons. In addition to CO<sub>2</sub>, deforestation and forest degradation and subsequent land-use change cause the release of CH<sub>4</sub> and N<sub>2</sub>O as well as carbon monoxide (CO), which influences concentrations of CH<sub>4</sub>. Halocarbons are emitted as a result of activities such as industry, and deforestation is not a contributor to emissions of these gases. Ozone is produced as a result of emissions from CH<sub>4</sub>, CO and nitrogen oxides (NO<sub>x</sub>) (Houghton 2005).

In Zambia, burning of fuelwood and charcoal, and burning associated with agriculture and natural fires are likely to be main causes of non-CO<sub>2</sub> emissions. The INC estimated on-site burning to contribute 226.23 Gg of CH<sub>4</sub>, 0.311 Gg of N<sub>2</sub>O and 11.24 Gg of NO<sub>x</sub>; figures were not produced for off-site burning. Fires in miombo woodland and dambo grassland in southern Africa were estimated to contribute to global annual emissions from savannah fires worldwide of the following GHGs: CO (12.6%) and NO<sub>x</sub> (10.3%). In Zambia, total emissions of CH<sub>4</sub> from the use of biofuels (charcoal and fuelwood) were similar or greater than dry season emissions from woodland and grassland fires (Sinha et al. 2004).

# 4 Future developments in forests and agriculture

## 4.1 Future trends in drivers of forest carbon change

The deforestation rate in Zambia is likely to increase over the coming decade due to the growing population and a resultant increased demand for natural resources. A trend analysis by Vinya et al. (2011) indicated that forest cover loss would increase until 2020 and then decrease during 2020–2030; however, the baseline estimate and subsequent increase in deforestation rate for this analysis is very high (890,400 ha in 2000–2010, rising to 1,358,200 ha in 2020) considering the most recent estimates of the deforestation rate.

It was not possible to gather specific information regarding future activities that may cause forest carbon change. For example, forest allocation maps or mining concession areas were not readily available. The lack of capacity for sharing this kind of information is one of the challenges for MRV of REDD+ in Zambia. Compounding this difficulty is the fact that a large proportion of the forest carbon change activities in Zambia, such as charcoal production or expansion of subsistence agriculture, are illegal or unregulated and are therefore not officially recorded.

## 4.2 Plans to expand agriculture and other land uses

With a growing population and high levels of poverty the Zambian government is duty bound to explore opportunities to expand agriculture and

infrastructure. The government's aim is to become a middle-income country by 2030 (GRZ 2006). In order for this to be achieved Zambia will have to utilize its natural resources including forest areas (GRZ 2011).

The Sixth National Development Plan (SNDP) identifies the expansion of agriculture as key for economic growth, due to the size of Zambia's natural resources (GRZ 2011). The National Agricultural Policy (2004–2015) encourages the expansion of areas under cultivation (including large-scale commercial farming), in order to achieve food security (IDLO 2011). The policy indicates the potential for agricultural expansion, stating that of the 58% of the total land area having medium to high suitability for agricultural production only 14% is currently used for farming (MAC 2004).

The Zambian government also intends to encourage the development of the mining industry, a significant contributor to the country's GDP and economic growth, by facilitating the opening of new mines, promoting small-scale mining and diversifying the industry. The goal is to increase the contribution of mining to at least 20% of GDP (from an average of 9.1% in 2006–2009) by 2015 (GRZ 2011). The government also emphasizes the need for construction of infrastructure, such as roads, in order to enable economic growth in Zambia. The SNDP and the Zambian Vision document also recognize the need for construction of new housing to meet a national housing deficit (GRZ 2006, 2011).

# 5 Gap assessments

## 5.1 Background

As has been outlined earlier in this report, Zambia and the miombo ecoregion in general have a number of knowledge gaps in terms of scientific research relevant to MRV of REDD+. Bond et al. (2009) regard the limited data on deforestation, the high variability of miombo woodland vegetation and a poor understanding of the carbon cycle as key issues for estimating carbon supply in miombo region countries for REDD+. Stringer et al. (2012) list the following as knowledge gaps regarding carbon storage and sequestration in drylands in sub-Saharan Africa:

- AGB: lack of observational data regarding present day AGB storage and lack of quantitative assessment of human and ecological drivers of AGB, including fire
- soil organic carbon (SOC): insufficient information on the amount, distribution and form of SOC; lack of empirical data to test soil respiration models and unique factors effecting SOC in drylands
- lack of understanding regarding carbon stocks, ecosystem services provision and the future drivers of change.

The Global Observation for Forest Cover and Land Dynamics (GOFC/GOLD) Sourcebook (2011) recommends incorporating the data of past scientific studies into estimation of carbon stocks if the data is less than 10 years old. A large proportion of the previous studies in miombo woodland in Zambia are from the late 1980s and early 1990s. As such much of this research may not be suitable for calculation of current carbon stocks for the purposes of REDD+.

In summary, the main knowledge gaps relevant to MRV for REDD+ are: accurate forest cover trend data and verification of deforestation rates; the development of specific allometric models for estimation of biomass in different forest types; estimates of emissions from forest degradation

due to charcoal production and woodland fires; and litter and deadwood carbon stocks. Soil carbon is another carbon pool subject to a great deal of variation and with limited understanding regarding the causes of the variation (Williams et al. 2008).

Capacity is also low in Zambia for MRV, and strengthening of various institutional procedures needs to occur in order for repeat monitoring of REDD+ to be achievable. ILUA II and other regional-level projects should go some way to filling many of these knowledge and capacity gaps, as outlined below.

### 5.1.1 Studies within open deciduous woodland and evergreen forest

The specific vegetation cover in Zambia is determined by factors such as rainfall, soil type and altitude as well as historical human use and management. As carbon stocks vary significantly due to these factors further research to differentiate between standing biomass levels in different woodland types is necessary (GOFC/GOLD 2011). A major knowledge gap exists in that studies that do address standing biomass growth rates and emissions from carbon stock losses are focused on miombo woodland, as this is the dominant and most economically important woodland type in Zambia. However, the country has significant coverage of mopane, Kalahari and munga woodlands and evergreen forest, which are also subject to deforestation and degradation. It is therefore not known how loss of biomass from these vegetation types will affect carbon emissions. ILUA I did include some sampled tracts within Kalahari (20) and mopane (12) woodland; however, tracts within munga woodland (2) and within closed forest, including evergreen forest (1), were limited (Chidumayo 2012a). ILUA II has been designed to encompass all forest types, which may allow more accurate estimates of biomass within Kalahari, mopane and munga woodland types.

## 5.2 Gap assessment for international requirements

### 5.2.1 Available data meeting the reporting requirements of the Intergovernmental Panel on Climate Change

The most recent IPCC guidelines require estimation of carbon stock changes for five carbon pools in forests: AGB, BGB, deadwood, litter and soil organic matter (Eggleston et al. 2006). The IPCC gives three tiers for reporting carbon stocks depending on the level of accuracy. Tier 1 comprises emissions factors using default global values. Tier 2 is based on country-specific activity data and static forest biomass information. Tier 3 requires more detailed methods such as country-specific allometric models. Tier 3 also requires country-specific forest inventories and repeated measures in order to assess forest carbon change (IPCC 2003; Eggleston et al. 2006). The data generated from ILUA I is suitable for meeting Tier 2 specifications of the IPCC good practice guidelines with regards to AGB and deadwood (UN-REDD 2010b). ILUA I data only enables estimation of carbon stocks in BGB, litter and soil pools equivalent to Tier 1 (Kamelarczyk 2009). ILUA II is intended to enable Zambia to move from Tier 2 to Tier 3 levels for reporting carbon stocks. However, soil sampling to determine carbon content from organic matter is costly, which may limit the amount of soil sampling that can be undertaken for ILUA II (Chidumayo 2012a). The hard mineral soils and deep tap roots of dry woodlands in Zambia also make sampling to determine BGB problematic.

Using the IPCC look-up tables to provide default estimates per hectare for BGB (ratio to AGB), soil and litter is subject to a high degree of uncertainty. Chidumayo (2012b) suggests that the IPCC BCEFs are not suitable for REDD+ reporting in Zambia as they resulted in significant overestimation of biomass levels in ILUA I. Kamelarczyk (2009) found that applying the average BCEF values following IPCC guidelines resulted in a much higher estimate compared to other methods; as such, this method was considered invalid. The low BCEF values resulted in estimates more similar to those using allometric equations. The calculation of accurate country-specific BCEFs is therefore important for REDD+ monitoring and reporting in Zambia.

### 5.2.2 Data to support an assessment of land use, land-use change and forestry

Emissions from land use, land-use change and forestry (LULUCF) in Zambia come predominantly from biomass burning on site (fires), from biomass decay and from offsite biomass burning, mainly through charcoal. In order to compile the GHG inventory for the INC, the emission factors and related activity data were sourced locally (MTNER 2002). Zambia-specific information used for the GHG inventory included estimates for standing biomass within the different woodland and forest types (see CEEZ estimates in Table 5).

ILUA I provides some information regarding the degree of biomass burnt from charcoal and fuelwood in Zambia, including energy use in relation to forest distribution. The main gap for GHG inventory from LULUCF is a lack of country-specific expansion factors for Zambia, including for the different woodland types. ILUA II will calculate specific expansion factors for the woodlands in Zambia. The relative degree and contribution to land-cover change from fire, charcoal production and shifting agriculture, particularly for different parts of the country, are also important areas for further research. In addition, the variability of recent estimates of the deforestation rate for Zambia suggests that verification using remote sensing is required (Kamelarczyk 2009). The national remote sensing survey (currently ongoing) should provide a more accurate estimate of reference level deforestation rates.

## 5.3 Gap assessment for national requirements

### 5.3.1 Data meeting national policy requirements and principles

Zambia currently has no national strategy with regards to REDD+. National policy requirements are therefore aligned with the international reporting requirements of the IPCC. The main policy requirements related to MRV are derived from Outcome 5 and Outcome 6 of the NJP document for Zambia as outlined below (UN-REDD 2010a):

Outcome 5: Monitoring, reporting and verification capacity to implement REDD+ strengthened

- Output 5.1: REDD+ integrated with forestry inventory system (ILUA)
- Output 5.2: Operational forest monitoring system established and institutionalized
- Output 5.3: GHG emissions and removals from forest lands estimated and reported

In terms of Outcome 5 and its outputs, ILUA II has been designed to provide specific data for assessment of carbon stocks in all of the main woodland types in Zambia. As such, it should enable assessment of GHG emissions from forested land. Until ILUA II is completed and the results published, an assessment of this outcome cannot be completed. One concern is that the data for ILUA I have not been readily available. The data sharing capacities for ILUA II need to be strengthened in order for all of the above outputs to be realized. The results of ILUA II should be made available through an open access database (Open Foris) currently being developed (MTNER 2010a). Steps have already been taken to establish an operational forest monitoring system for Zambia (Output 5.2), including the development of regional monitoring centers.

An additional concern for ILUA II has been raised regarding the sampling design. The current sampling design is an intensification of the systematic design used in ILUA I. Chidumayo (2012a) suggests that ILUA II should include stratified sampling to ensure coverage of all major land types, including the unevenly distributed closed forests types such as evergreen forest.

Outcome 6: Assessment of reference emission level and reference level undertaken

- Output 6.1: Historical rates of forest area and carbon stock changes reviewed
- Output 6.2: National circumstances assessed

Output 6 will also be addressed primarily by ILUA II. The national remote sensing survey should provide accurate reference-level deforestation rates and therefore emissions when combined with inventory data (Output 6.1). As with the field component of ILUA II, until this survey is completed an assessment of this outcome cannot be carried out. The ILUA has

provided socioeconomic data that will contribute to Output 6.2, as will the recent protected area gap analysis produced for the country (MTNER 2012). Data needs relevant to national priorities are provided below.

#### 5.4 Gap assessment for subnational requirements

The number of regional MRV projects in Zambia is limited. As such CIFOR's NFP will be an important component of REDD+ readiness for Zambia by developing a pilot MRV system. The project will contribute to capacity building for MRV of REDD+ through collaboration with local partners including the Forest Department at district level; the Zambian Wildlife Authority, through the Directorate of Game Management Areas; and the associated Community Resources Boards, etc. The NFP will also complement national work being undertaken for MRV of REDD+; for example, field components of the project will follow the protocol for the ILUA as far as possible.

The USFS is providing technical assistance for remote sensing in Zambia's Eastern Province. This provides an opportunity for building capacity in remote sensing and geographical information systems (GIS) of Forestry Department staff and other stakeholders. Another important REDD+ and MRV stakeholder operating in Zambia is the Southern African Development Community (SADC), which is interested in the development of integrated MRV systems for REDD+ in the SADC region. As such they are also conducting an MRV project similar to the NFP in the northern part of Eastern Province. The focus of the project will be on improving forest inventory data and land-use data to improve forest management at a district level. As these regional programs and the national program (ILUA) have similar objectives and aims for forest measurement and monitoring in Zambia, there are significant opportunities for collaboration. For example, the SADC will provide funds for intensification of ILUA field plots within their study area.

## 5.5 Recommendations for gap filling

### 5.5.1 Data and methodological gap filling

Research in the following areas would be beneficial in filling data and methodological gaps (as outline above, ILUA II and the NFP should fill many of these data gaps):

- Development of specific allometric equations for biomass estimation in Zambia; currently the best available regional equations are not developed in Africa. This should include destructive sampling to verify standing biomass within different forest types (Kamelarczyk 2009).
- BGB, deadwood, litter and soil only have generic estimates using IPCC default values. Further research for miombo woodlands and deciduous woodlands in Zambia is needed.
- Identification of high carbon soils and what causes variation in soil carbon in Zambian woodlands (Williams et al 2008).
- The impact of fire on woodland loss and carbon stocks; including whether fire control in recovering woodland can stimulate accumulation of soil carbon and greater tree biomass (Williams et al. 2008).
- Deadwood estimation within all forest types.
- Methods developed to assess forest degradation and biomass estimates in Zambia using remote sensing, i.e. use of different resolution datasets to determine the most cost-effective and accurate methods. Studies should also couple remote sensing with field studies for verification of measurements (Ribeiro et al. 2012).

### 5.5.2 Eligibility and capacity gap filling

The establishment of a centralized REDD+ center or department is an important step in ensuring the success of REDD+ in Zambia. Linked to this is the need for a national REDD+ policy from the government to ensure that a legal framework for REDD+ schemes is in place. The national REDD+ center should have overall responsibility for MRV of REDD+ in Zambia and should improve monitoring and reporting of forest cover changes in Zambia. For example, the coordination center could be responsible for reporting how future plans for land-use change, such as mining concessions, will affect forest cover.

ILUA II and work by UN-REDD, as well as regional projects by CIFOR, USAID, USFS and SADC will contribute to building capacity for MRV of REDD+ in Zambia. Of particular importance are the following areas:

- increasing the use of remote sensing and GIS by Forestry Department staff for repeat monitoring of land cover and forest cover changes
- development of a national forest monitoring system that complies with international standards
- development of (establishing and maintaining) local level monitoring systems that effectively and efficiently feed the national forest monitoring system
- improving the ability to estimate future carbon emissions projections combining remote sensing and GIS, and in situ data
- enhancing the ability of the Forestry Department and other stakeholders to resurvey ILUA sites.

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# Appendix: Growth rates for selected tree species in miombo woodland in Zambia and neighboring countries

Species and location	Growth rate	Reference
<i>Baikiaea plurijuga</i> (Zambian teak)	MAI 0.13–0.20 cm	Crockford (unpublished) in Siteo et al. 2010
<i>Brachystegia floribunda</i> – regrowth miombo woodland in Zambia	4.4 mm mean annual ring width growth	Syampungani et al. 2010
<i>Brachystegia spiciformis</i> , Western Province, Zambia	2.4–3.3 mm diameter per annum	Grundy 2006
<i>Brachystegia spiciformis</i> , central Zimbabwe	0.3–2.7 mm diameter per annum	Trouet et al. 2006
<i>Brachystegia spiciformis</i> , western Zimbabwe	3.1 mm diameter per annum	Holdo 2006
<i>Burkea africana</i> , western Zimbabwe	1.7 mm diameter per annum	Holdo 2006
<i>Erythrophleum africanum</i> , western Zimbabwe	1.6 mm diameter per annum	Holdo 2006
<i>Isoberlinia angolensis</i> – regrowth miombo woodland in Zambia	5.6 mm mean annual ring width growth	Syampungani et al. 2010
<i>Julbernardia paniculata</i> – regrowth miombo woodland in Zambia	4.4 mm mean annual ring width growth	Syampungani et al. 2010
<i>Pterocarpus angolensis</i> , South Africa	MAI 4.5 mm per annum BAI 6.4%	Shackleton 2002
<i>Pterocarpus angolensis</i> , western Zimbabwe	0.3 mm diameter per annum	Holdo 2006
<i>Pterocarpus angolensis</i> , Tanzania	0.8–4.8 mm diameter per annum	Boaler 1966; in Siteo et al. 2010
<i>Pterocarpus angolensis</i> , western Zimbabwe	3.0–4.1 mm diameter per annum	Stahle et al. 1999
<i>Terminalia sericea</i> , western Zimbabwe	2.2 mm diameter per annum	Holdo 2006

BAI = basal area increase; MAI = mean annual increment.

Note: Annual diameter increase = approximately mean annual ring width x 2

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Zambia is one of the nine pilot countries for the UN-REDD programme and is currently at the first phase of readiness for REDD+ under the UN-REDD quick start initiative. A National Joint Programme (NJP) is tasked with developing a national REDD+ strategy. Outcome 5 of the NJP Programme Document is to strengthen the Monitoring Reporting and Verification (MRV) capacity for REDD+ in Zambia. A reliable system of Monitoring Reporting and Verification (MRV) is of critical importance to the effectiveness of REDD+.

This report provides a comprehensive overview of the national REDD+ strategy and institutional capacity for MRV of REDD+ as well as the current state of knowledge of various elements critical to MRV of REDD+ in Zambia including: Current drivers and rates of deforestation and forest degradation; a review of standing biomass, forest growth rates and carbon stock estimates; and data sets available for MRV in Zambia.

The report also identifies knowledge and data gaps that need to be filled in order to develop an effective MRV system for REDD+ in the country. Key knowledge gaps, such as carbon stocks and growth rates within different forest types, are outlined as well as recommendations as to how knowledge gaps and capacity to implement MRV of REDD+ can be addressed. The report also details how CIFOR's research in Zambia, particularly the Nyimba forest project in the Eastern Province, will contribute to MRV of REDD+ for Zambia.



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