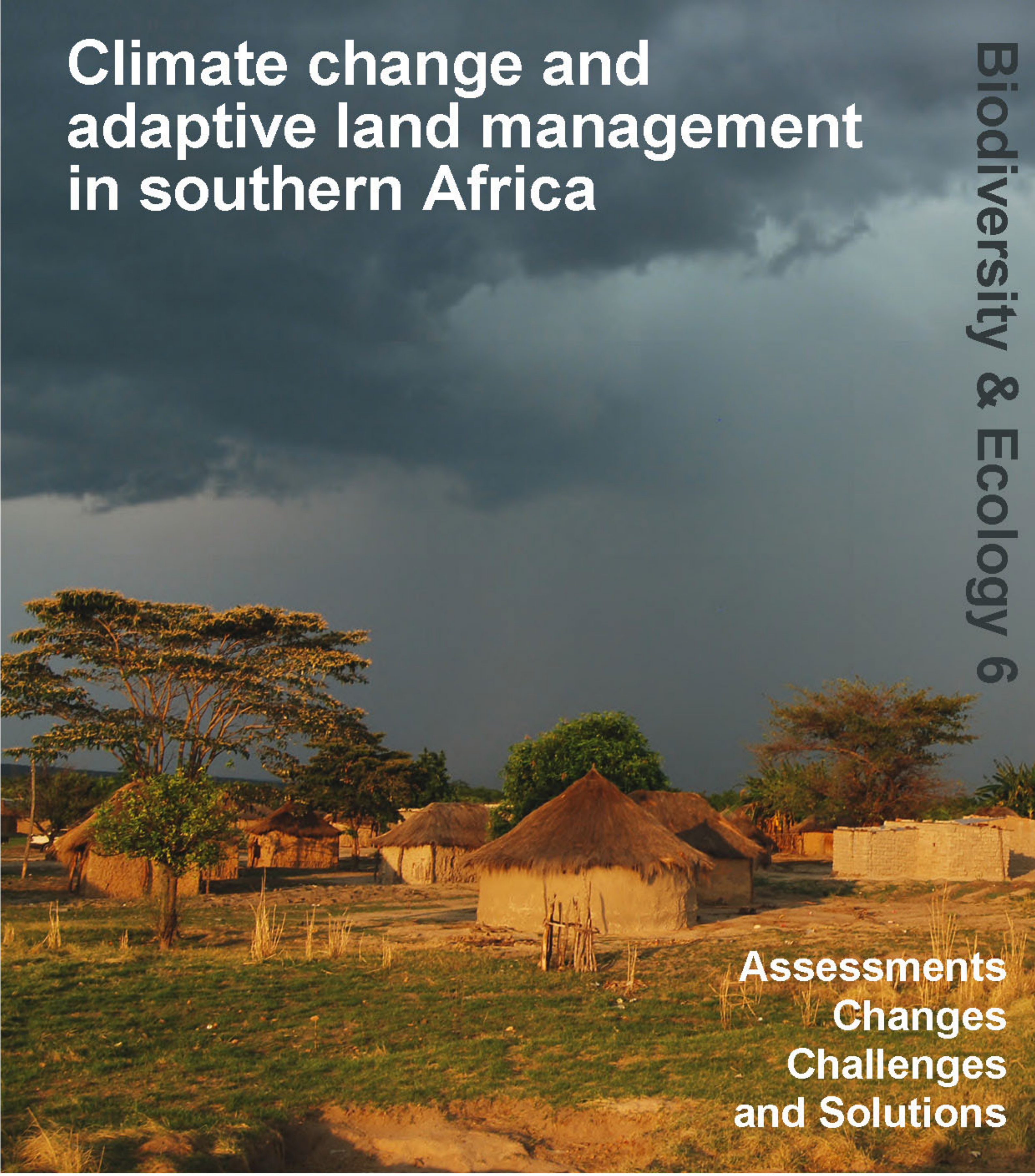
Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



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Changes
Challenges
and Solutions

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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Forest resources

Woodland resources and management in southern Africa

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Abstract: The countries of southern Africa have an average forest cover of 32% with most forest situated in the tropics. These dry to moist forests are deciduous with a few evergreen species. The open canopy allows enough light to reach the ground to allow the development of a rich grass layer. Generally, these forests are referred to as woodlands. The article gives an overview of the Miombo, *Baikiaea* and Mopane woodlands of Angola, Zambia, Namibia, and Botswana and focuses on their composition, wood and non-wood resources. Plantation forestry is briefly discussed with most information from South Africa, which has the largest commercial forestry sector in the region. Threats to the southern African woodlands are highlighted, and the current status of woodland monitoring and management is summarised.

Resumo: Os países da África Austral têm uma cobertura florestal média de 32%, com a maioria das florestas situadas nos trópicos. Estas florestas secas ou húmidas são decíduas, com algumas espécies de folha perene. A copa aberta permite que luz suficiente chegue ao solo para permitir o desenvolvimento de uma camada rica de herbáceas. No geral, estas florestas são referidas como matas. O artigo apresenta uma visão geral das matas de Miombo, *Baikiaea* e Mopane de Angola, Zâmbia, Namíbia e Botswana, concentrando-se na sua composição e recursos lenhosos e não-lenhosos. A plantação florestal é brevemente discutida, com a maior parte da informação proveniente da África do Sul, a qual tem a maior indústria comercial de exploração florestal na região. São destacadas as ameaças às matas da África Austral e é resumido o estado actual de monitorização e gestão das matas.

Introduction

Southern Africa has about 190 million ha of forests with an average of 32% forest cover. Forest types range from tropical moist and rainforest in the north to subtropical dry and humid forest, as well as mountain forest, in the south (Fig. 1). Most vegetation classified by FAO as tropical forest is commonly named "woodland" in the region, for example Miombo or Mopane woodland (Timberlake & Chidumayo, 2011; Chirwa et al., 2014). Woodlands differ from forests because of their more open canopy cover and the characteristic presence of grasses in the understorey (Putz & Redford, 2010; Ratnam et al., 2011; Oliveras & Malhi, 2016). Tropical woodlands are dominated by C4 grasses. The C4 photosynthetic pathway makes them tolerant to higher temperatures and drought but less tolerant to shade compared to C3 grasses (Ratnam et al., 2011; Oliveras & Malhi, 2016). We will use the term "woodland" in this article to follow regional convention and to highlight that tropical rainforests and Afromontane forests are not discussed here. For information on the dense mountain, coastal and mist forests of South Africa, we refer to other studies (e.g. Mensah et al., 2017b, 2017a; Ngubeni, 2015; Seifert et al., 2014; Vermeulen, 2009). The term "forest" is, however, retained when referring to data from FAO's forest resources assessments and collected through remote sensing, as they are based on the FAO definition for forest which specifies a minimum canopy cover of 10% (FAO, 2012). There is no internationally accepted definition for woodland (Putz and Redford, 2010) and we define it as vegetation characterised by trees – woody plants able to reach a minimum height of 5 m (FAO, 2012) – with tree crown cover between 10%

(FAO, 2012) and 60% (Hirota et al., 2011; Kutsch et al., 2011), and an understory where C4 grasses are present.

The largest extent of forest and woodland is found in the northern areas of southern Africa, which receive a higher amount of precipitation, such as Angola and Zambia (Tab. 1). Namibia, Botswana and South Africa, with their predominantly semi-arid climate, have a relatively small forest area. This article focuses on the woodland resources of southern Angola, western Zambia, northern Namibia, and northern Botswana, where most SASSCAL projects took place (Fig. 1). Plantation forestry in the SASSCAL countries is briefly discussed with most information originating from South Africa, which has the largest commercial forestry industry in the region.

Woodland composition

Most of Zambia and Angola are characterised by Miombo woodlands (Fig. 1). In southern Angola and south-western Zambia, woody species diversity gradually declines and Miombo is replaced by more open and drier Mopane and *Baikiaea* woodlands (FAO, 2000; Scholes et al., 2002; Timberlake & Chidumayo, 2011). Further south, in Namibia and Botswana, the canopy cover of the *Baikiaea* woodlands decreases, progressively more species of the legume subfamily Caesalpinioideae (formerly Mimosoideae) appear, and the open woodlands gradually

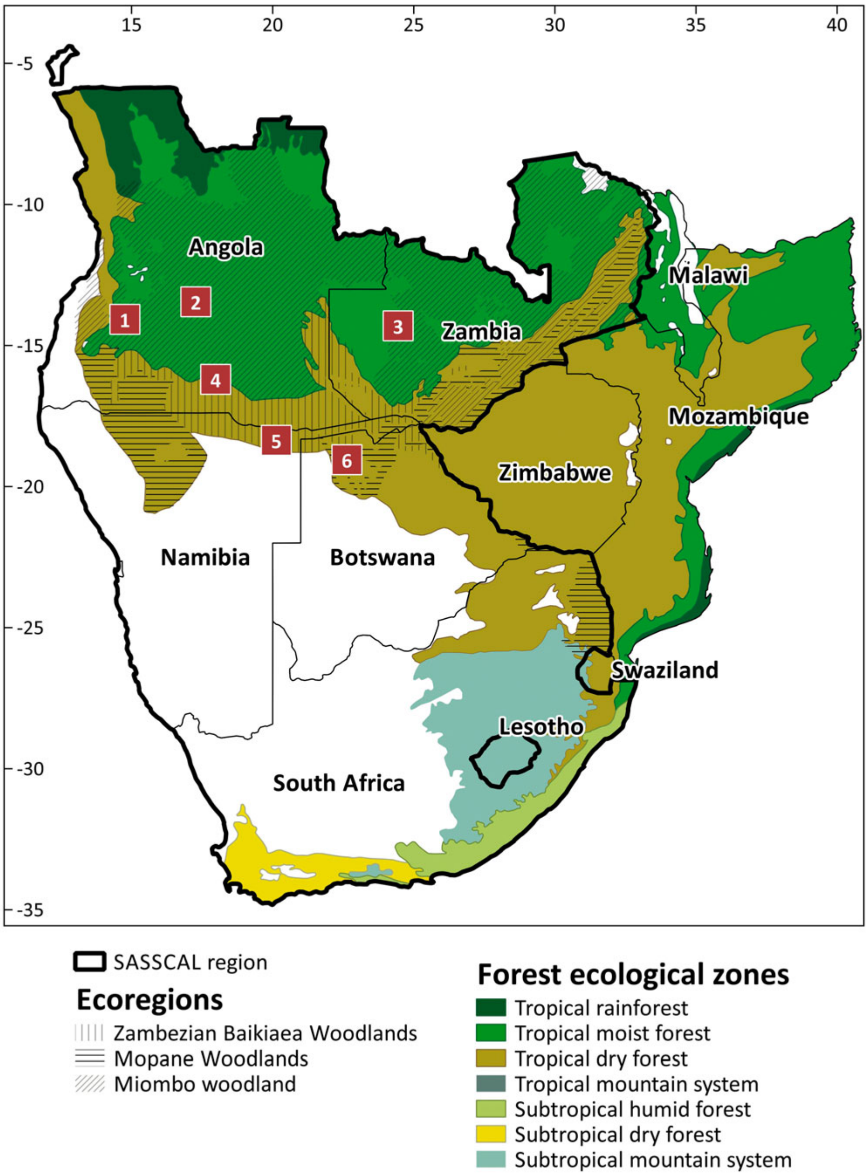

Figure 1: Forest ecological zones in the SASSCAL countries according to FAO (2000) with indication of ecoregions according to WWF (Olson et al., 2001). The numbers 1 to 6 indicate the locations of the forest inventories summarised in Table 2: 1. Huíla, 2. Bié, 3. Western Province, 4. Cuando Cubango, 5. Kavango's, and 6. North-West Province.

Table 1: Area of forest and forest loss in southern Africa and the SASSCAL countries based on FAO (2015) and (in grey) Hansen et al. (2013) with forest including woodland.

Country	Land area (1000 ha)	Forest area with canopy cover >= 10% (1000 ha)	Forest cover (% of land area)	Forest area with canopy cover >= 25% (1000 ha)	Planted forest area (1000 ha)	Forest loss 2000 – 2015 (1000 ha)	Forest loss within forest area 2000 – 2015 (%)	Forest loss 2000 – 2012 (1000 ha)	Forest gain 2000 – 2012 (1000 ha)
SASSCAL									
Angola	124670	57856	46	63357	125	1872	3.2	1932	64
Botswana	56673	10840	19	54	0	1695	15.6	6	0
Namibia	82329	6919	8	13	0	1113	16.1	13	0
South Africa	121447	9241	8	7125	1763	0	0.0	953	831
Zambia	74339	48635	65	31616	64	2499	5.1	1316	18
SASSCAL total	**459458**	**133491**	**29**	**102164**	**1952**	**7179**	**5.4**	**4219**	**913**
Other southern African									
Lesotho	3035	49	2	12	17	-7	-14.3	0	0
Malawi	9428	3147	33	2216	419	420	13.3	129	10
Mozambique	78638	37940	48	37141	75	3248	8.6	2155	145
Swaziland	1720	586	34	595	135	-68	-11.6	75	60
Zimbabwe	38685	14062	36	2411	87	4832	34.4	387	49
Other total	**131506**	**55784**	**42**	**42373**	**733**	**8425**	**15.1**	**2746**	**264**
Southern Africa TOTAL	**590964**	**189275**	**32**	**144537**	**2685**	**15604**	**8.2**	**6965**	**1177**

Figure 2: Miombo in the Serenje National Forest, Central Province, Zambia, at the end of the rainy season. The road connects a larger illegal settlement within the woodland with Zambia's Great North Road (Photo: D. Parduhn).

change into semi-arid scrublands (Burke, 2002; Scholes et al., 2002; Chirwa et al., 2014). In southern Botswana and northern South Africa, Mopane and Combretaceae woodlands are found south of approximately 19° S (Timberlake & Chidumayo, 2011; Chirwa et al., 2014). The woodlands form part of the revised Miombo ecoregion, an extension of White's Zambezian regional centre of endemism that is characterised by semi-deciduous woodland composed of trees of the legume subfamily Detarioideae (previously Caesalpinioideae) (Timberlake & Chidumayo, 2011; LPWG, 2017). The following sections give more details about the species and structural composition of the different woodland types, except for the Combretaceae woodlands where no SASSCAL activities took place and for which we refer to the work of Shackleton and Scholes (2011), amongst others. Basal area (BA) is used as a proxy for wood volume and biomass; it is the sum of the cross-sectional areas of tree stems at DBH (diameter at breast height, or 1.3 m) in a stand.

Miombo woodland

Miombo sensu stricto, or true Miombo (Fig. 2), is a woodland characterised by three genera of the Detarioideae (formerly Caesalpinioideae): *Brachystegia*, *Julbernardia* and, to a lesser extent, *Isoberlinia* (Timberlake & Chidumayo, 2011; Chirwa et al., 2014). There are two types of Miombo: wet Miombo (annual rainfall > 1000 mm, canopy height > 15 m), and dry Miombo (rainfall < 1000 mm, canopy height < 15 m) (White, 1983; Frost, 1996). Many authors (e.g. Chirwa et al., 2014; Frost, 2000) cite the work of White (1983) to indicate that *Brachystegia boehmi, Brachystegia spiciformis* and *Julbernardia globiflora* are the dominant trees in dry Miombo woodlands. However, in the dry Miombo of southern Angola, *Julbernardia paniculata* and *Brachystegia bakeriana* are the only species of the Miombo genera and they reach their southern limit at a latitude of approximately 16° S (Revermann et al., in press; Baptista, 2014).

SASSCAL forest inventories were performed in Miombo areas of similar mean annual rainfall (950–1100 mm) and thus at the border of dry and wet Miombo. They show that stem density, maximum DBH, and BA increased from western Angola to western Zambia, with the BA in Huíla only half of that recorded in Bié (Tab. 2). The study area in Huíla is the most populated, with approximately 58 persons per km^2 compared to less than 6 persons per km^2 for the other five study areas (Linard et al., 2012). Its low BA is, amongst other reasons, the result of human interventions. The most common species in the Angolan Miombo areas were *J. paniculata* and *B. spiciformis*, which in combination contributed to 36% and 45% of the BA in Bié and Huíla, respectively. In Huíla, *Brachystegia longifolia* was another important canopy tree, representing 13% of both stems and BA. In Bié, *Erythrophleum africanum* was as common as the two aforementioned species, contributing 14% of the total BA. Important timber species such

Table 2: Structural composition of typical woodland types in the SASSCAL region based on forest inventory data for trees with minimum diameter at breast height (DBH) of 10 cm. Only living trees were measured. Multiple stems were measured except for location 6. The location numbers are indicated in Figure 1.

Location number	1	2	3	4	5	6
Forest type	**Miombo**	**Miombo**	**Miombo**	***Baikiaea***	***Baikiaea***	**Mopane**
Country	Angola	Angola	Zambia	Angola	Namibia	Botswana
Province/Region	Huíla	Bie	Western	Cuando Cubango	Kavango W/E	North-West
Mean annual rainfall (mm)	1000	1100	950	700	550	450
Number of plots	107	35	60	24	114	15
Stem density (ha^{-1})	277	370	480	87	116	162
Basal area (m^2.ha^{-1})	7.1	11.4	13.9	8.1	5.6	5.2
Mean DBH (cm)	17.9	17.7	18.3	39.3	29.9	18.8
Maximum DBH (cm)	31.1	39.6	44.5	65.3	52.8	39.6
Maximum height (m)		13.6	22.1	12.6	12.0	9.2

as *Pericopsis angolensis* and *Pterocarpus angolensis* had a low occurrence (< 0.6% BA).

In the Zambian Miombo, inventories showed that the most common species recorded were *J. paniculata* and *Brachystegia boehmii*, together contributing 49% of the total BA. Other important canopy species were *Guibourtia coleosperma* (10% BA) and *Cryptosepalum exfoliatum* subsp. *pseudotaxus* (6% BA). Timber species such as *Pericopsis angolensis, Pterocarpus angolensis* and *Burkea africana* are present but not abundant (1–3% BA). Tree height at the Zambian sites reached on average a maximum of 22 m, remarkably high for Miombo woodland with mean annual rainfall of 950 mm, while the BA was much higher than in a study of Chidumayo (1987a) for the same area (7.9 $m^2.ha^{-1}$).

Baikiaea woodland

The *Baikiaea* woodlands are characterised by the species *Baikiaea plurijuga* (Fig. 3), an important timber tree whose northern boundary in Angola is at a latitude of 16° S (Baptista, 2014; Revermann et al., 2015). Forest inventories in southern Angola and Namibia (Tab. 2) show, however, that the species is less dominant than in the eastern parts of the *Baikiaea* woodland (Childes & Walker, 1987; Mitlöhner, 1993; De Cauwer et al., 2016). In fact, the contribution of *B. plurijuga* to the total number of stems (3–11%) and total BA (5–14%) is similar to that of the other co-dominant species, *B. africana, Pterocarpus angolensis,* and *Schinziophyton rautanenii,* which contributed up to 18%, 10%, and 34% respectively of the total BA in the *Baikiaea* study areas. Forest inventories over larger areas show that *B. africana* is the most dominant canopy tree (23% BA) in the western *Baikiaea* woodlands, followed by *B. plurijuga* (De Cauwer et al., 2016). Several authors therefore refer to these woodlands as *Burkea* (Frost, 1996; Burke, 2002), Burkeo-Pterocarpetea (Strohbach & Petersen, 2007) or *Baikiaea-Burkea* (Stellmes et al., 2013) woodlands. De Cauwer et al. (2016) argue that *B. africana* is an early succession and non-differentiating species, and

Figure 3: *Baikiaea* woodlands: (a) overview during the growth season and (b) *Baikiaea plurijuga* with one historically felled stem in the Mashare area of Kavango East, northern Namibia (Photos: R. Revermann and V. De Cauwer).

Figure 4: Mopane woodland in the Seronga area, Okavango panhandle, Botswana. *Colophospermum mopane* can be seen in both its (a) shrub form and (b) tree form. (Photos: R. Revermann).

propose the name *Baikiaea-Pterocarpus* woodlands.

E. africanum was still very common at the Angolan *Baikiaea* site with 10% of the total BA, but this decreased to 1% at the Namibian site. Total stem densities and BA in the *Baikiaea* woodlands were much lower than in Miombo, but the average DBH was higher (Tab. 2). BA for the Namibian *Baikiaea* site was also lower than the BA of 8–10 $m^2.ha^{-1}$ in areas with similar rainfall (480–650 mm) of the Combretaceae woodlands (Shackleton & Scholes, 2011), although the latter BA is based on a stem diameter at height 0.05 m instead of DBH.

Mopane woodland

Mopane woodlands are strongly dominated by the species *Colophospermum mopane,* which structurally can occur either as a tree up to 20–25 m tall (Geldenhuys & Golding, 2008) or a shrub (Fig. 4). The distribution range of Mopane woodland (Fig. 1) covers areas with an annual rainfall of 400 to 700 mm (Chirwa et al., 2014) and has distinct boundaries; there is no gradual transformation towards Miombo and *Baikiaea* woodlands. The distribution range of the species *C. mopane* is larger as it includes scrubland, which is not discussed here, and is mainly influenced by frost, minimum temperature, dry season length, and a preference for clay-rich soils (Fraser et al., 1987; Burke, 2006; Stevens et al., 2014). The species represented 79% of all woody species in a forest inventory in Botswana, where it mainly occurs as a small tree (Fig. 4), contributing up to 81% of the BA (Tab. 2). The only other canopy tree species were *B. plurijuga* and *Acacia erioloba* with 11% and 7% of the BA, respectively.

Woodland resources use

Wood for local use

Wood is a major woodland resource for both local and commercial users in the region. Local users mainly collect (dead) firewood, a primary source of domestic energy (Shackleton & Clarke, 2007; Chirwa et al., 2014), and to a lesser extent harvest standing trees for construction purposes. For example, SASSCAL Task 311 showed that villagers living close to the Chobe Forest Reserve in northern Botswana rely heavily on woodland resources, especially firewood from *B. plurijuga*, and earn cash from selling wood as poles. The soft wood of *S. rautanenii,* called Mungongo in Botswana and Manketti in Namibia, is used for dug-out canoes, the main form of transport in the Okavango area, but also as fuel. A study in Cusseque, central Angola, showed that total annual consumption of wood amounted to 484 kg per capita, of which 78% was for firewood and the remainder for house construction (Kissanga Vicente da Silva Firmino, 2016). The most important species used for construction in Cusseque were *Bobgunnia madagascariensis, G. coleosperma,* and *J. paniculata*, the latter also an important tree for fuel, together with *Brachystegia* spp. (Kissanga Vicente da Silva Firmino, 2016). Uses of poles in construction include outside walls, roofs, fences, window frames, furniture, granaries, and coffins. Domestic tools such as hoe and axe handles, pestles and mortars, cooking sticks, and slingshots are also made from local wood. For each purpose, only the most suitable tree type is targeted. The most preferred timber species for local use is *Pterocarpus angolensis,* which has the widest distribution range of all southern African timber trees (De Cauwer et al., 2014). Its wood is regionally referred to as Kiaat (Namibia and South Africa), Mukwa (Zambia) or Girassonde (Angola) (Fig. 5). Kiaat has a medium density (620 kg·m^{-3}), is known for its stability (ITTO, 2017) and is used for the manufacturing of furniture, decking, doors, bowls, and other woodcrafts (Moses, 2013). Other timber species used for construction depend on the area, such as the much harder wood of *Pericopsis angolensis* (Mubanga) in central Zambia, and *B. plurijuga* in southern Zambia (Mukusi), northern Botswana (Mokusi) and northern Namibia (Zambezi teak).

Wood of natural woodlands and plantations for commercial use

Commercial users harvest specific tree species to produce charcoal and timber. Most charcoal is harvested by rural dwellers and then sold in nearby towns or in the regions' capitals, especially in Lusaka and Luanda, where it constitutes the most affordable source of energy (Gumbo et al., 2013, Parduhn & Frantz, 2018). The commercially most important indigenous timber species of the SASSCAL region are *Pterocarpus angolensis, B. plurijuga, G. coleosperma* and *Pterocarpus tinctorius*. SASSCAL Task 035 highlighted the extent of the cross-border trade and showed that at least 15,229 m^3 of Zambian timber and 15,547 m^3 of Angolan timber were exported via Namibia between 2010 and 2014. Trade routes between Namibia, Angola and Zambia were identified, with final markets in South Africa and China (Fig. 6). The most traded wood was that of *Pterocarpus angolensis* (Fig. 5), followed by Zambezi teak (*B. plurijuga*). Only the merchantable logs are traded, which is approximately 28% of the utilisable timber wood volume for Kiaat (Moses, 2013), with the remaining harvested wood being underutilised. Even then, the timber use value of Kiaat, estimated at ZAR 485, for a tree of harvest size, surpasses the carbon value (Moses, 2013).

The wood of *G. coleosperma* is known under the tradename of Rosewood or local names Ushivi (Namibia), Musivi (Angola), and Muzauli (Zambia), and its harvest is on the rise (IRDNC, 2015a). Demand for the wood of *P. tinctorius* (synonym *P. chrysothrix* is used in Zambia), locally named Mukula and known as Padouk outside the SASSCAL region (ITTO, 2017), started fairly recently, driven by the Chinese market. The consequent rates of harvesting and the limited knowledge on the growing stock caused the Zambian government to impose a moratorium on the harvesting and trade of *P. tinctorius* in 2014 (Phiri et al., 2015).

Plantation forestry is much less important than in other regions of the world. The area covered by plantations accounts for about 1.95 million ha in the SASSCAL region, representing only 1.5% of the total forest cover and 0.4% of the total land area (Tab. 1). Comparative values for the European Union and United States of America are 29% and 30% respectively (Forestry South Africa, 2017). Most of the planted forest area in the region, approximately 1.22 million ha, is situated in South Africa (Forestry South Africa, 2017), with the remaining area being in Angola and Zambia (FAO, 2015).

The commercial timber plantations in South Africa account for about 1% of the country's total surface area and mainly consist of exotic species of three genera: *Pinus* (a softwood), and *Eucalyptus* and Australian *Acacia* (both hardwoods). Only 0.3% of the plantation area is based on other species, such as exotic *Quercus* species or the indigenous Yellowwood (*Podocarpus latifolius*) (Forestry South

Figure 5: Wood of *Pterocarpus angolensis*, locally called Kiaat, Mukwa and Girrasonde (Photos: P. Nichol and V. De Cauwer).

Africa, 2016). Most industrial forestry is situated in the high rainfall zones of eastern South Africa, where there is limited scope for expansion because of priority given to other land uses. However, a growing population and an emphasis on renewable, carbon-friendly commodities compel the sector to investigate alternative woodland resources, specifically in dryland situations (du Toit et al., 2018). Most plantations in Angola and Zambia are also based on exotic tree species. SASSCAL

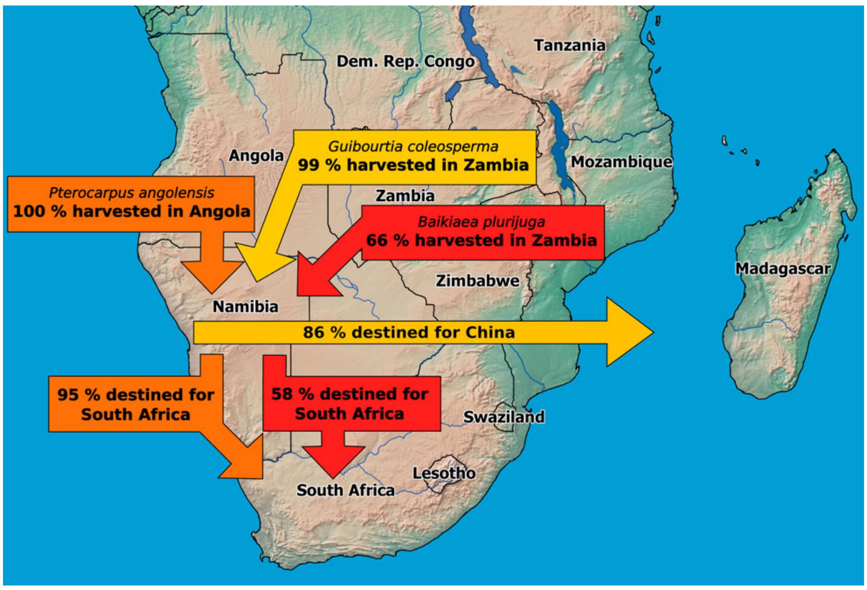

Figure 6: Trade routes of important timber species in south-western Africa (IRDNC, 2015b).

Figure 7: Examples of non-wood forest products: (a) edible caterpillars and (b) mushrooms collected in Zambian Miombo woodland (Photos: D. Parduhn).

Task 037 found that households in the Serenje District of central Zambia start to include timber from pine and eucalypts into their livelihood strategies. A few trial plantations with indigenous species (e.g. Kiaat) were established during colonial times (Groome et al., 1957; Piearce, 1979). The plantations in Angola are mainly composed of *Eucalyptus* species and were either planted during colonial times or very recently. SASSCAL Task 173 trialled the use of *Eucalyptus urograndis*, amongst others, along contour lines to combat erosion in Moxico province, Angola.

Non-wood forest products

A range of fruits, wild vegetables, medicinal and other products are extracted from the region's woodlands, providing an important source of nutrition and cash income (Shackleton & Gumbo, 2010). In the *Baikiaea* woodlands, the fruits of especially *Sclerocarya birrea* (Marula), *G. coleosperma*, *Dialium englerianum*, *Strychnos* spp. (Monkey orange), and *Grewia* spp. are directly eaten or used to make alcoholic beverages. The seeds of *Bauhinia petersiana* (Mogose) and *S. rautanenii* yield good quality oils. The oil yields for *S. rautanenii* are high (60%) and comparable to those of sunflower and peanut oils (45–55%), indicating their potential for the commercial production of cold-pressed (virgin) oil. *B. petersiana* oil yields are lower (19%) but comparable to those of soybean oil (17–22%) (Yeboah et al., 2017). SASSCAL Task 335 also demonstrated the presence of 73–80% unsaturated fatty acids in *B. petersiana* and *S. rautanenii*, comparable to good quality oils like olive oil, which has about 72% unsaturated fatty acids. The presence of α-eleostearic acid (α-ESA) was also detected in *S. rautanenii* oil. Studies have shown that α-ESA is a tumour suppressing agent and can inhibit breast cancer (Tsuzuki et al., 2004; Grossmann et al., 2009), thus demonstrating the potential suitability of the oil as a health food supplement.

In the Miombo woodlands, rural dwellers harvest bark to make beehives and ropes (preferably from *Brachystegia boehmii* and *Cryptosepalum exfoliatum* subsp. *suffruticans*), and a wide range of edible products. Depending on the season, households collect fruits from trees (e.g. *Uapaca kirkiana*, *Anisophyllea boehmii*, *Parinari curatellifolia*), mushrooms (Fig. 7), roots (e.g. *Rhychosia insignis/munkoyo*), tubers (e.g. chikanda harvested from three orchidioid genera *Disa*, *Satyrium* and *Habenaria* (Veldman et al., 2017)), as well as wild vegetables (e.g. wild spinach from the *Amaranthus* genus, and *Corchorus olitorius*/Wild okra (Velempini et al., 2003)). They are used for both home consumption and sale, sometimes after processing such as the extraction of oil from *P. curatellifolia* kernels. Honey collected from wild bees is a major source of cash income in the Miombo woodlands (Shackleton & Gumbo, 2010). In contrast to temperate regions, nectar is mainly collected not from herbaceous plants but instead from trees, mainly of the genera *Brachystegia*, *Julbernardia*, *Cryptosepalum*, *Erythrophleum*, *Bobgunnia*, and *Pterocarpus* (Gröngröft et al., 2015). A small number of households collect a variety of caterpillar species as well as termites. The insect with the highest commercial value in Zambia is an edible caterpillar (Fig. 7) belonging to the moth family Saturniidae, commonly known as Ifishumi (Bemba) and Vinkhubala (Nyanja) (Kachali, unpublished). Bush meat for home consumption is also of importance to most households, with field mice (imbeba) being most popular, followed by cane rats (*Thryonomys* sp./insengele), and wild hares (katili). The roots, bark or leaves of almost all local trees are used for medicinal purposes.

In the Mopane woodlands, *C. mopane* has many economic uses. It provides good quality firewood, construction material, medicines, fodder for game and domestic animals, and young bark for ropes, and it is a food plant for Mopane worms (Madzibane & Potgieter, 1999; Mannheimer & Curtis, 2009). The Mopane worm (*Imbrasia belina*) is the caterpillar of another moth of the Saturniidae, which feeds primarily on the leaves of *C. mopane*. The caterpillars are dried before consumption or sale in both rural and urban centres and provide an important source of protein (61% of dry matter) for the indigenous people (Headings & Rahnema, 2002).

Threats

The rates of deforestation in Africa are lower than in other areas of the tropics. Deforestation is most prevalent in the tropical rainforests, but also in the dense tropical moist and dry forests (Hansen et al., 2013). About 3,246 km^2 of forest were lost per year in the SASSCAL region during the period 2000–2012, compared to an annual gain of merely 700 km^2 (Tab. 1). Deforestation in the region is mainly driven by clearing for agricultural purposes and expansion of settlements. Small farmers play a more important role in African deforestation than in south-east Asia and Latin America (Pröpper et al., 2010; Rudel, 2013; Parduhn & Frantz, 2018), although clearing for cash crops like tobacco also takes place. Subsistence agriculture in Miombo woodland is mainly through shifting cultivation (Fig. 8), resulting in a mosaic landscape with tree stands in different stages of succession (Chirwa et al., 2014). After clear-felling, regeneration is quick, especially through coppicing of remaining stumps, with many of the key Miombo tree species well represented (Luoga et al., 2004; Chirwa et al., 2014; Syampungani et al., 2016). However, reaching compositional similarity takes many decades (McNicol et al., 2015) and thus old growth Miombo is not common (Chidumayo, 1987b; Dewees et al., 2011). In the *Baikiaea* woodlands, farmers remain on the same fields and use short fallow periods, resulting in permanent clearings (Pröpper et al., 2010). Natural regeneration of important timber and fruit species appears problematic, especially for *Pterocarpus angolensis*, *Strychnos cocculoides*, and *G. coleosperma* in the *Baikiaea* woodlands of northern Namibia and southern Angola, and for *B. plurijuga* in Zambia (De Cauwer, 2016; DFSC, 2001; Kabajani, 2016).

While the extent of woodland degradation is difficult to assess, it is estimated that woodland degradation, including by fire, is a much larger contributor to carbon emissions than deforestation (Bombelli et al., 2009). Next to fire, the major drivers of woodland degradation in the region are slash and burn agriculture and unsustainable harvest of woodland resources (Chidumayo, 2013; Chirwa et al., 2014; Kamwi et al., 2015; Kissanga Vicente da Silva Firmino, 2016; Schelstraete, 2016). Large elephant populations can be an additional driver of woodland degradation in and near national parks of the region (Ben Shahar, 1998; Edkins et al., 2008). Wood is the main woodland resource that is unsustainably harvested (Chidumayo, 2013), although quantitative data are often too limited to assess sustainability levels (see section 5). A study in southern Angola showed that the wood biomass used by the local population of 1085 inhabitants corresponded to an area of approximately 6 hectares of Miombo woodland per year (Kissanga Vicente da Silva Firmino, 2016). In Zambia, wood harvesting for charcoal is often done in conjunction with agricultural expansion or shifting cultivation and therefore is not the primary source of woodland degradation (Parduhn & Frantz, 2018). However, when urban centres are within trading distance, woodland degradation does occur as harvesters target large canopy trees and specific tree species (e.g. Brachystegia spp.) (Zweede et al., 2006; Chidumayo, 2013; Gumbo et al., 2013; Pröpper et al., 2015). Depending on species and tree size, harvest of other woodland resources, especially bark or root fibres, can lead to tree mortality and hence forest degradation (Geldenhuys, 2004; Vermeulen, 2009; Shackleton et al., 2010; Ngubeni, 2015). Roads, and especially tar sealed roads, are the major vectors along which both deforestation and degradation takes place, especially in formerly "pristine" areas (Schneibel et al., 2013; Kamwi et al., 2015). Climate change is likely to accelerate the rate of woodland degradation in large parts of the southern African region because of increasing temperatures and changing fire regimes, especially in the areas where summer rainfall is projected to decrease (Hewitson, 2006; Enright et al., 2015; De Cauwer et al., 2016; Munalula et al., 2016). Increasing evapotranspiration caused by rising temperatures, increased fire frequency, and an increasing frequency of droughts will cause more plant stress (Munalula et al., 2016), a decrease in tree growth (Fichtler et al., 2004; Trouet et al., 2006; Therrell et al., 2007), decreasing tree recruitment (Enright et al., 2015), and ultimately a potential increase in tree mortality (Allen et al., 2010) and changing distribution ranges of tree species (Thuiller et al., 2006; De Cauwer et al., 2014). SASSCAL Task 033 showed that periods of drought and higher fire incidences in the Zambezi region of Namibia caused locals to rely even more on woodland resources, although food aid was more important still as a coping mechanism (Kamwi et al., 2015).

Figure 8: Fresh clearance of Zambian Miombo woodland for subsistence agriculture (Photo: D. Parduhn).

Both deforestation and woodland degradation affect the ability of the woodland to protect the soil, regulate the regional climate, serve as a carbon sink, and act as a safety net during droughts and wars (Chidumayo & Gumbo, 2010; Kutsch et al., 2011; Chidumayo, 2013). Woodland degradation also alters species composition, either by the survival of more fire-resistant species (De Cauwer, 2018) or by removal of species targeted for harvesting, such as *S. rautanenii* in Botswana, resulting in its listing as a threatened plant. The land-use changes and woodland degradation caused by a growing population make the region one of the world's most threatened with regard to biodiversity loss (Leadley et al., 2010). In addition, an emerging frontier of industrialised agriculture threatens large-scale conversions of dry forests and woodlands in southern Africa (Gasparri et al., 2016). Environmentally, this would be highly costly, including very negative trade-offs for biodiversity and carbon sequestration (Searchinger et al., 2015).

Woodland management

Forest and woodland monitoring

Sustainable woodland management requires knowledge of the area covered with woodlands (forest cover) and, if production of resources such as timber or carbon biomass is aimed at, information on the growing stock, total biomass and tree population dynamics. However, regional forest data are scant as no repeated national forest monitoring system is in place in any of the countries (Morales-Hidalgo, 2015). The exact forest coverage in the SASSCAL countries is also unknown. Tab. 1 lists forest cover per country based on different definitions and methodologies, each with their limitations. Data submitted to the 5- to 10-yearly forest assessment of FAO mainly consist of national desktop studies, as is the case for Angola, Botswana, Namibia, and South Africa that submitted data of low to medium quality (FAO, 2015). Desktop studies mainly concern extrapolations of outdated maps established with remote sensing, with inconsistent methods and definitions used between countries (Hansen et al., 2013; FAO, 2014b,a; De Cauwer, 2015). Zambia submitted data of good quality for forest cover as they are based on an Integrated Land Use Assessment (ILUA) project, which included repeated remote sensing surveys for the period 1990–2015 (FAO, 2014c). However, forest cover estimated with traditional optical remote sensing methods systematically underestimate the surface covered by dry tropical forest (Naidoo et al., 2016; Bastin et al., 2017). An important prerequisite for regional forest monitoring is, however, the availability of a consistent remote sensing database. The SASSCAL program explored other remote sensing methods with Tasks 032 and 033 using phenology and structural descriptors derived from long-term MODIS time series, while Task 205 used radar and LiDAR (Mathieu et al., 2018).

Estimates of the growing stock or total wood volume in the natural woodlands are often inaccurate or outdated as they are based on old forest inventories, not always covering the complete woodland area in a country (Zweede et al., 2006; De Cauwer, 2015). The most recent national forest inventory in the region appears to be in Zambia (Pohjonen, 2004), while a national forest inventory is being planned for Angola. Regional allometric equations are limited to specific species or sites (Abbot et al., 1997; Hofstad, 2005; Moses, 2013; Chidumayo, 2014), and sometimes pantropical models for aboveground biomass such as that of Chave et al. (2014) perform better than a model of another country in the region (De Cauwer, 2016). The compilation and expansion of regional datasets, especially for total biomass (including roots), is needed (Chirwa et al., 2014). Permanent sample plots allow one to derive information on woodland dynamics, especially tree growth, mortality, and regeneration (Phillips et al., 2003; Namaalwa et al., 2007), as well as the variables that influence them such as tree competition (Seifert et al., 2014). Data on tree regeneration, growth and mortality can also act as early warning for climate change (Allen et al., 2010). However, with the exception of the continuous monitoring of commercial plantations, few permanent sample plots are present in the region or their monitoring results have not been published for decades. Chidumayo (2013) recently assessed woodland degradation and recovery based on the data of permanent sample plots established in 1990 in Miombo woodland of central Zambia. The SASSCAL program established permanent sample plots in northern Namibia, while trees in the biodiversity observatories in Angola are measured and marked to allow continuous monitoring.

Another method to monitor tree growth over long periods of time is tree ring analysis. This is possible if trees have annual tree rings, as is the case in climates where there is a seasonal growth interruption because of cold temperatures or a lack of rainfall. Tree ring analysis was used by SASSCAL Task 038. It was illustrated that the mean stem diameter growth of *Pterocarpus angolensis* is 5.5 mm per year in northern Namibia and southern Angola. This is relatively high compared to growth in other parts of southern Africa (De Cauwer, 2016; Van Holsbeeck et al., 2016; De Cauwer et al., 2017). The biomass increment of *P. angolensis* in natural woodlands of northern Namibia and southern Angola is approximately 254 $kg.ha^{-1}.year^{-1}$ (De Cauwer, 2016). The sites with the highest productivity of *P. angolensis* in northern Namibia and southern Angola had a relatively lower temperature seasonality, consisted of very open woodland (canopy cover < 20% with stand BA between 5 and 10 $m^2.ha^{-1}$) and were situated on plains (De Cauwer et al., 2017). *Terminalia sericea* and *S. rautanenii* showed higher growth rates than *P. angolensis* in Namibia, while *B. africana* and *B. plurijuga* grew slower (Van Holsbeeck et al., 2016).

Regional woodland management systems

Systematic management of natural woodlands in the region is very limited (e.g. Dewees et al., 2011). Commercial timber harvesting in the region is mainly done by concessionaires. A selective harvesting system is employed, with felling of valuable timber species that have reached a minimum harvest size. Inspection for adherence to the conditions of the harvest permit is often missing because of a lack of resources in national forest agencies. Harvesting for charcoal production is mainly through clear felling, after which natural regeneration, mainly through coppicing, takes place (Shackleton & Clarke, 2007; Chidumayo, 2013).

Fire is one of the main problems that woodland managers in the region deal with. Every year, about 14% of the land area in the SASSCAL focus countries is burned (FAO, 2015). Most of this area is situated in the countries with the largest forest cover, Angola and Zambia, with 27% to 24% respectively of the land area burned on an annual basis in the period 2003–2012. The area burned annually in Namibia, Botswana, and South Africa was lower, varying between 7% and 4% respectively (FAO, 2015). A study in the Kavango-Zambezi Transfrontier Conservation Area also demonstrated that the area burned annually is high in the Angolan and Zambian, but also Namibian, parts of the conservation area, compared to Botswana and Zimbabwe where more effective fire management takes place (Pricope & Binford, 2012). Fire management of communal or state-owned woodlands is a responsibility of national forest agencies, although this is often shared with regional governments and communal forest managers. In South Africa, the government-funded job-creation program "Working on Fire" was established for implementing integrated fire management. Fire management includes both fire prevention (e.g. by establishing and maintaining firebreaks or applying early burning) and firefighting. The task is increasingly resource intensive, as the number of active fires shows a rising trend and poses an ever greater threat to the expanding population (Pricope & Binford, 2012; Schelstraete, 2016).

In Namibia, many woodland areas are managed by local communities under the Community-Based Natural Resource Management Program (CBNRM). The program aims to support and empower communities by transferring rights to manage and sell woodland resources to them. In Botswana, SASSCAL Task 311 found that the local communities support the transfer of Chobe Forest Reserve from state forest management to participatory or collaborative forest management. The communities argue that forest management regimes should be inclusive of all stakeholders, with clearly outlined roles and expectations from all parties, as it can promote a sense of ownership and hence improve protection of the reserve. However, such a collaborative approach may need an improved relationship between the stakeholders, particularly between woodland users and government officials.

Silviculture

Silviculture is the practice of tending a forest or woodland for specific purposes, for example timber, charcoal, bark and/or pole production, and includes interventions such as thinning, planting, pruning, and the use of rotations. It is rarely practised by forest managers in the SASSCAL region, except for in the commercial plantations. Hence, woodland management is restricted to the bare extraction of resources and thus can be rather compared to a mining operation where no actions are taken to invest in future woodland (Dewees et al., 2011). Cultivating indigenous fruit and timber tree species would improve food security and economic independence of local communities and it would reduce the pressure on natural forest and woodland resource stocks. SASSCAL Tasks 335 and 038 are involved in the cultivation of several indigenous tree species (De Cauwer et al., 2018).

Conclusion

Next to their important ecosystem regulating functions, the natural woodland ecosystems in the region provide an important contribution to the local and national economies. However, they are threatened by deforestation and woodland degradation, especially along roads and near population centres. Currently, woodland degradation caused by regular fires and the high dependence on wood for energy appears a bigger threat than deforestation, which is mainly caused by agricultural expansion of subsistence farmers. However, some studies predict that in the near future industrialised agricultural schemes may lead to large-scale conversion of formerly natural woodlands. Woodland managers need more data to assess the extent of forest loss and degradation, the value of the woodland resources, and the impact of climate change. Recurrent national forest inventories and access to more permanent sample plot data are therefore needed. Plantation forestry and silviculture are currently very limited and their expansion could assist in countering the trend of woodland loss.

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