Forest Ecology and Management 373 (2016) 1–8

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Annual diameter growth of *Pterocarpus angolensis* (Kiaat) and other woodland species in Namibia

Sam Van Holsbeeck [a,*], Vera De Cauwer [b], Maaike De Ridder [c], Esther Fichtler [d], Hans Beeckman [c], Jan Mertens [a]

[a] Ghent University, Department of Applied Bioscience, V. Vaerwyckweg 1 Camp. Schoonmeersen, 9000 Ghent, Belgium
[b] Faculty of Natural Resources & Spatial Sciences, Namibia University of Science and Technology, Private Bag 13388, Windhoek, Namibia
[c] Wood Biology Service, Royal Museum for Central Africa, Leuvensesteenweg 13, 3080 Tervuren, Belgium
[d] Georg-August-University Göttingen, Crop Production Systems in the Tropics, Grisebachstr. 6, 37077 Göttingen, Germany

ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 13 April 2016
Accepted 13 April 2016

Keywords:
Tree rings
Growth rate
Mean diameter increment
Pterocarpus angolensis
Forest management

ABSTRACT

Pterocarpus angolensis DC. (Kiaat) is one of the most preferred timber species that occurs in most southern African countries, including Namibia. In Namibia, the species mainly occurs across the five regions in the north-eastern part of the country where commercial timber harvesting has taken place since the 1940s. Information about the growth rates of the species is currently lacking, yet this information is required to determine a sustainable harvesting regime in Namibia. Therefore, more data about diameter increment is needed. This study aims to (1) determine annual diameter increment of *P. angolensis* in order to assist in planning for sustainable harvesting levels in the northern regions of Namibia, (2) compare growth of *P. angolensis* with other woodland species (*Burkea africana*, *Baikiaea plurijuga*, *Terminalia sericea* and *Schinziophyton rautanenii*) and (3) compare *P. angolensis* growth rates found in northern Namibia with those found in other countries within its distribution range. A total of 111 increment cores and 73 stem discs were collected for tree-ring analysis. The results showed that the average diameter increment of *P. angolensis* was higher in the Kavango regions (0.71–0.80 cm yr^{-1}) than in neighbouring regions (0.35–0.41 cm yr^{-1}). The northern Namibian growth rate is estimated as 0.50 cm yr^{-1} and lies within the growth range reported for southern Africa. Growth rates of *P. angolensis* were more than 0.10 cm yr^{-1} lower than rates of *T. sericea* and *S. rautanenii*, but 0.10 cm yr^{-1} higher than *B. africana* and *B. plurijuga*. Age–diameter relationships of *P. angolensis* may be a good indicator of tree age if a sufficient number of samples are obtained. Our results revealed a rotation cycle of 95–100 years to reach the minimum harvesting diameter of 45 cm in the Kavango regions. This rotation cycle should be a good guideline for sustainable management of this species. This study suggests that simple ring counting on increment cores and stem discs with additional diameter data can provide valuable information on growth rates and rotation cycles. Additional data and work on older trees (>100 years) is required to complete the age–diameter framework.

1. Introduction

Pterocarpus angolensis DC. (Fabaceae) also known as Kiaat, Transvaal teak or bloodwood tree is one of the most integral African savannah trees used in timber production (Mendelsohn and Obeid, 2005). In Namibia, *P. angolensis* is situated in the north-eastern regions of the country where woodland is the most dominant vegetation type (Mendelsohn and Obeid, 2005). The species has been harvested on a commercial scale since the 1940s (Mendelsohn and Obeid, 2005), and is not only favoured by wood importers but also by carvers for sculptures, which has resulted in increased illegal logging of existing populations (Barnes, 2010). This illegal logging mostly supports local sawmilling industries (Pröpper et al., 2010). From a forestry point of view, forests dominated by *P. angolensis*, *Baikiaea plurijuga* Harms (Fabaceae) and *Burkea africana* Hook (Fabaceae) are economically valuable wood stock (Chakanga, 2000).

In Namibia, land clearing for crop farming is largely responsible for the decline in forest area. Although recent values are unavailable,

* Corresponding author at: Steenweg op Vilvoorde 401, 1745 Opwijk, Belgium.
E-mail addresses: samvanholsbeeck@gmail.com (S. Van Holsbeeck), vdecauwer@nust.na (V. De Cauwer), maaike.deridder@africamuseum.be (M. De Ridder), efichtl@gwdg.de (E. Fichtler), hans.beeckman@africamuseum.be (H. Beeckman), jan.mertens@ugent.be (J. Mertens).

http://dx.doi.org/10.1016/j.foreco.2016.04.031
0378-1127/

a total of 4% of the land was cleared between 1943 and 1996 (Mendelsohn and Obeid, 2005; Pröpper et al., 2010). Poor soil fertility means that soil nutrients are generally depleted after a few growth seasons and hence farmers must continue to clear new areas (Pröpper et al., 2010). Every year, 34% of the Kavango regions in the north-eastern corner of Namibia are burnt to encourage the growth of new grass for cattle or to clear fields (Mendelsohn and Obeid, 2005). Unfortunately, many fires burn out of control due to wind and some areas are burnt every three years on average (Mendelsohn and Obeid, 2005). Annual fire disturbance may cause eventual tree mortality, limited recruitment, decreasing growth, accelerated nutrient loss and finally reduced soil fertility (Geldenhuys, 1977; Mendelsohn and Obeid, 2005; Verlinden and Laamanen, 2006).

Regeneration of *P. angolensis* appears to be problematic in South Africa leading to a diminishing stock (van Daalen, 1991). For Tanzania, it has been found that *P. angolensis* regeneration was not sufficient for sustainability given present harvest intensities (Boaler and Sciwale, 1966; Schwartz et al., 2002; Caro et al., 2005). Both the low regeneration rate and the length of time it takes for seedlings to be recruited into populations mean that the species will not be able to supply the markets continuously in future years (Schwartz et al., 2002). Caro et al. (2005) concluded that *P. angolensis* has been driven to local extinction in Tanzania at a rapid rate due to wholesale removal, and very low recruitment has been observed in protected areas, suggesting that these populations might also be declining despite being protected (Schwartz et al., 2002; Caro et al., 2005).

Efforts to manage commercial plantations of *P. angolensis* in South Africa have been largely unsuccessful (van Daalen, 1991). Silvicultural problems occurred at all stages of the species' development (Boaler and Sciwale, 1966). There is a need for vigorous research programmes on sustainability of *P. angolensis* harvest and use. Scientific data on growth and fire behaviour are crucial and documentation must be distributed to support sustainable forest management (Geldenhuys, 1996).

Annual growth rings provide a strong basis for age determination of species and have important applications for forest ecology and sustainable management (Stahle et al., 1999). Stahle et al. (1999) indicated annual growth rings in indigenous *P. angolensis* forests of western Zimbabwe, and Trouet (2004) and Fichtler et al. (2004) have both described the annual nature of tree rings in *P. angolensis* and *B. africana* from the semi-arid regions of Namibia.

Currently, there is insufficient growth data available for *P. angolensis* to determine if logging is sustainable. In the past, several studies focused on the climate–growth relation of *P. angolensis* (Stahle et al., 1999; Shackleton, 2002; Fichtler et al., 2004; Therrell et al., 2007). Unfortunately, very few studies have been done with a silvicultural approach. Therrell et al. (2007) is an important exception and suggested that it would take more than 100 years for trees of this species to reach harvestable sizes of 35–40 cm in the distribution area (Therrell et al., 2007). This does not necessarily mean that rotation periods have to be this long. Our observations indicate difficulty in finding *P. angolensis* trees exceeding 100 years of age in Namibia, indicating that rotations of 100 years may not be possible. Within the Kavango regions of Namibia no studies on growth rate have yet been performed, except for measurements in permanent plots of a burning trial (Geldenhuys, 1977). In Namibia, the species is near its southern distributional limit and one could expect that annual growth would be lower than within more northern countries in the core distribution area, where growing conditions are more favourable. We aim to compare growth rates within different regions in north-eastern Namibia and determine suitable rotation cycles for application in sustainable management strategies.

The objectives of this study are (I) to estimate the annual growth of *P. angolensis* in Namibia, (II) to compare the growth of this species with other economically important species within the northern regions of Namibia, and (III) to compare the growth of *P. angolensis* in the northern regions of Namibia with other regions outside Namibia where *P. angolensis* occurs.

2. Material and methods

2.1. Study area descriptions

At three sites in the Kavango regions of northern Namibia, increment cores were taken from 109 trees of five different species during the dry season of 2014 (Fig. 1). For *P. angolensis* increment cores were collected in Hamoye (18°14′S, 19°43′E), Mashare (17°53′S, 20°12′E) and Divundu (18°7′S, 21°37′E) (SASSCAL, 2015). *Terminalia sericea* Burch. ex DC., *B. africana*, *B. plurijuga* and *Schinziophyton rautanenii* Hutch. ex Radcl.-Sm. were sampled only at Hamoye.

Stem discs from four additional study sites in four regions (Kavango West, Kavango East, Oshikoto and Zambezi) were also available (Fig. 1) (Fichtler et al., 2004; Moses, 2013). In Kavango West, three stem discs from individual *P. angolensis* trees were available from the Hamoye State Forest for the The Future Okavango (TFO) project. In Kavango East another 15 *P. angolensis* stem discs were available from two adjacent leasehold farms located about 205 km south of Rundu in the Karukuvisa District – Farm No. 1428 (19°08′54.36″S and 20°00′2.68″E) and Farm No. 1412 (19°16′36.36″S and 20°01′15.96″E) (Moses, 2013).

At two other sites in northern Namibia, Oshikoto region close to Ondangwa (17°56′S, 15°59′E) and Katima Mulilo, Zambezi region (17°30′S, 24°17′E), data regarding stem discs from four different species and 55 individual trees was released (Fichtler et al., 2004; Worbes, unpublished report).

Fig. 1 shows the complete sample collection and geographical location, and Table 1 lists the samples selected for further tree-ring analyses and includes a short description of differences between the sample sites.

All study areas are characterised by an annual dry season of 5–7 months with less than 50 mm precipitation, lasting from May to October.

The overall study design was based on random selection and accessibility. The influence of roads and the edge of the forest were minimised by establishing transects perpendicular to roads. Individual trees within these transects included trees in two different forest types, Community Forest and State Forest, if these forest types were present at the transect.

2.2. Tree species

All five species briefly described below are common in southern African woodlands and within the Kavango regions. *P. angolensis* is a medium sized to large tree growing up to 30 m in height under ideal conditions (von Breitenbach, 1973). In Namibia, height is reduced to 16 m due to the more arid conditions (Coates Palgrave, 2002). It is one of the best known, most widely used and most valuable timber species in southern Africa. Trees are deciduous and leaves are shed around June (Graz, 2004). The species is known to have a suffrutex or dieback stage where plants develop shoots that may reach heights of up to three metres each growing season (Graz, 2004). In the dry season, shoots die back to a depth of 2–36 cm below the surface protecting the meristem from fire damage. Shoots renew every year in order to prevent damage from the dry season fires. The suffrutex stage will last for a decade, although this may be extended to a length of 25 years by high