Coppicing ability of dry miombo woodland species harvested for traditional charcoal production in Zambia: a win–win strategy for sustaining rural livelihoods and recovering a woodland ecosystem

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Abstract The miombo woodland is one of the most extensive woodlands in Africa, supporting livelihoods based on biomass fuel for millions of rural people. However, there are growing concerns about the sustainability of harvesting for biomass fuel (mainly charcoal). Thus, the aim of this study was to examine whether regeneration by coppice is a viable option for sustainably managing miombo woodlands for biomass fuel production. We tested the hypotheses that (1) species, stump diameter, stump height and time since cutting significantly affect the number of sprouts per cut stump (coppice density) and mean sprout height (shoot vigour) and (2) higher coppice density reduces shoot vigour due to competition among coppice shoots in a given stump. In an inventory in areas that were harvested for charcoal production by the local people, 369 stumps of 11 species were recorded with mean coppice stumps ranged from 6 to 84. The mean coppice density ranged from 5 to 8 shoots per stump while the mean height of coppice shoots ranged from 46 to 118 cm with

marked interspecific variations. Stump size was significantly and positively correlated with coppice density for some of the species, but not with shoot vigour for the majority of the species. However, shoot vigour was significantly positively correlated to time since cutting of trees for nearly half of the species. Coppice density had a significant negative correlation with shoot vigour for two species, and a positive correlation for one species. In conclusion, the results provide evidence about the importance of coppice management as a win–win strategy for sustaining charcoal-based rural livelihoods and recovering the miombo woodland ecosystem.

Keywords African woodlands · Charcoal production · Forest management · Regeneration · Resprouting ability

Introduction

African dry forests and woodlands play an important role in provision of ecosystem services, biodiversity conservation and rural livelihoods (Chidumayo and Marunda 2010). The miombo woodland is one of the most extensive woodlands, naturally distributed in central and southern Africa with an estimated area of 2.4–2.7 million km² (Deweese et al. 2010; Kutsch et al. 2011). The woodlands are major sources of biomass fuel (firewood and charcoal) for household consumption and income for a large proportion of rural households. For example, biomass fuel accounts for 76 and 85 % of the national energy budgets in Zambia and Mozambique, respectively (Shackleton and Clarke 2007; Syampungani et al. 2009). Charcoal business is a lucrative local economy, generating an annual income of about US\$ 350 million in Tanzania (Mugo and Ong 2006), about US\$ 30 million in Zambia and an average

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annual income of about US\$ 250–300 per family in Mozambique where 150,000 families are engaged in charcoal production (Frost 1996). In Malawi and Kenya, 92,800 and 500,000 people, respectively, owe their livelihoods to the charcoal business (Falcão 2008).

There are, however, concerns about the impacts of harvesting for biomass fuel and clearing for agriculture on woodland ecosystem products and services (Syampungani et al. 2009; Chirwa et al. 2014; Jew et al. 2016). Most wood fuels are sourced from natural forests and woodlands; thus, lack of sustainable dry forest and woodland management will eventually lead to degradation and deforestation. Often, the discourse about woodland management in many parts of Africa, including Zambia, focuses on regulatory mechanisms without regard for the forest-based livelihood system of the rural poor. Regulatory policies are not based on strong evidence about the recovery potential of the woodlands although silvicultural systems based on disturbance-recovery knowledge (Geldenhuys 2010) could be developed to maintain trade-offs between woodland recovery and sustainable forest-based livelihoods. For example, coppice management for fuel wood and charcoal could be a possible option because most tropical dry forest and woodland species have the ability to coppice vigorously following cutting (Luoga et al. 2004; Kaschula et al. 2005; Ky-Dembele et al. 2007; Mostacedo et al. 2009; Dayamba et al. 2011; Lèvesque et al. 2011). Furthermore, the coppices, with an already well-established root system, grow rapidly compared with newly established seedlings (Grundy 1995), greatly contributing to the rapid recovery of disturbed woodland ecosystems.

As a result, coppice management, though an age-old silvicultural practice worldwide, has regained increasing attention recently in response to the growing demand for wood fuels, diversification of forest-based livelihoods and nature conservation (Dayamba et al. 2011; Matula et al. 2012; Ferraz-Filho et al. 2014). Understanding factors that influence the coppicing ability of trees have, thus, attracted the interest of researchers and managers aiming at developing adaptive management strategies. Several studies have shown that the probability of coppicing, the number of coppices produced by a cut stump (i.e., coppice density) as well as subsequent coppice growth and development are influenced by factors, such as parent tree age, cutting season (Babeux and Mauffette 1994), and tree size and site quality (Keyser and Loftis 2015). In addition, tree species also vary in their coppicing ability (Handavu et al. 2011).

Although tree species in the miombo woodland of south-central and eastern Africa are known to coppice following disturbances (Grundy 1995; Mwabumba et al. 1999; Luoga et al. 2004), inadequate information on the influence of stem sizes on coppicing ability makes it difficult for forest managers to effectively develop management strategies

(Handavu et al. 2011). Because coppices are a potential source of regeneration for a variety of woodland species, models that quantify coppicing responses of tree species harvested for wood fuel are needed to adequately describe and predict early stand dynamics. Thus, this study was conducted with the aim of identifying factors that influence the coppicing ability of dry miombo woodland species that were harvested for charcoal production in southern Zambia. We tested the hypotheses that (1) species, stump diameter, stump height and time since cutting have significant effects on the number of sprouts per cut stump (coppice density) and mean sprout height (shoot vigour); and (2) higher coppice density reduces shoot vigour due to competition among coppice shoots in a given stump.

Materials and methods

Study area

The study was conducted in Choma District of southern Zambia, which lies between 26°30' and 27°30' longitude and 16° and 17°45' latitude at an altitude of 1400 m above sea level (Fig. 1). The district falls within Agro-ecological Zone II, which receives an annual rainfall of less than 1000 mm. The climate is characterized by three distinct seasons, namely, hot dry season (August to October), rainy season (November to April) and the cool dry season (May to July). The mean annual temperature ranges from 14 to 28°C (Environmental Council of Zambia 2000). The natural vegetation in the study site is classified as dry miombo woodland with poor floristic composition. The dominant tree species of the dry miombo woodland are *Brachystegia spiciformis* Benth., *Brachystegia boehmii* Taub., and *Julbernardia paniculata* (Benth.) Troupin. Other species include *B. floribunda* Benth., *Faurea saligna* Harv., *Marquesia macroura* Gilg, *Parinari curatellifolia* Planch. ex Benth, *Pericopsis angolensis* (Baker) Meeuwen and *Pterocarpus angolensis* DC. Most of these species are used for firewood and charcoal production by the local people.

Inventory of coppices

We selected three charcoal regrowth sites that were up to 4 years old since cessation of charcoal production. On each site, plots were fixed along line transects that ran across sites. Circular sample plots, each with 20 m radius, were established along transects. On each sample plot, observations were made on coppiced stumps, and species were identified in situ. The number and height of shoots were recorded on 369 stumps of the identified woody species. In addition, diameter and height of each stump were measured. The diameter of cut stems was measured at the cut

Fig. 1 Map of the study area

surface, and resprout shoot heights were measured from their origin at the base.

Statistical analyses

For each species recorded during the inventory, descriptive statistics were computed for number of coppice stumps, coppice density and shoot vigour. Linear regression models were developed to predict coppice density and shoot vigour using stump diameter, stump height and time since harvesting for charcoal production as descriptor variables. Backward elimination of non-significant descriptor variables ($\alpha = 0.05$) was conducted to simplify the final predictive model for each species. Before fitting the regression models, coppice density was square-root-transformed, whereas shoot vigour was natural-logarithm-transformed. A correlation analysis was used to examine the relationship between coppice density and shoot vigour. All statistical analysis was performed with Minitab 17.0 statistical software (Minitab Inc., State College, PA, USA).

Results

A total of 11 species were recorded in coppice regrowth stands that were harvested by the local people for charcoal production. The number of coppice stumps ranged from 6

to 84 depending on the species; *J. paniculata* (Benth.) Troupin had the least and *B. spiciformis* had the most, followed by *Pseudolachnostylis maprouneifolia* Pax (Table 1). The mean diameter of stumps ranged from 10 to 23 cm; and nearly half of the species had a mean stump diameter less than 15 cm. However, the maximum stump diameter was more than 40 cm for some of the species (*P. maprouneifolia*, *P. curatellifolia*, *B. spiciformis*, *Terminalia mollis* M.A. Lawson and *Faurea speciosa* Welw.). The mean stump height ranged from 39 to 62 cm; however, the maximum stump height was more than 1.0 m for all species except *B. boehmii*, *J. paniculata* and *Terminalia sericea* Burch. ex DC.

The mean coppice density ranged from 5 to 8 shoots per stump, depending on the species; *F. speciosa* and *P. curatellifolia* had the highest density, *T. sericea* the lowest (Table 2). The coppice density was as high as 20 shoots per stump for some species (*F. speciosa* and *Swartzia madagascariensis* Desv.). A significant positive relationship between coppice density and stump diameter was found for three species: *Albizia antunesiana* Harms, *B. spiciformis* and *C. molle*; coppice density had a significant positive relationship with stump height for *T. sericea* only (Table 2). The number of shoots per stump increased with increasing stump diameter and height for these species, though the strength of relationship was generally weak [R^2 (adj) < 50 %; Fig. 2]. The relationship between coppice

Table 1 Species, number of coppice stumps recorded (n), and stump size distribution of trees cut for charcoal production

Species	n	Stump diameter (cm)		Stump height (cm)	
		Mean	Range	Mean	Range
<i>Albizia antunesiana</i> Harms	34	12.3	5–25	50.1	15–122
<i>Brachystegia boehmii</i> Taub.	15	10.9	5–29	41.0	12–90
<i>Brachystegia spiciformis</i> Benth.	84	18.1	4–51	53.0	1–125
<i>Combretum molle</i> Engl. & Diels	40	12.2	6–26	49.7	11–132
<i>Faurea speciosa</i> Welw.	29	15.7	4–57	40.2	10–106
<i>Julbernardia paniculata</i> (Benth.) Troupin	6	23.3	11–40	42.7	18–70
<i>Parinari curatellifolia</i> Planch. ex Benth	32	16.3	6–47	44.5	10–100
<i>Pseudolachnostylis maprouneifolia</i> Pax	55	12.0	3–44	51.4	7–135
<i>Swartzia madagascariensis</i> Desv.	29	12.3	4–35	51.8	12–160
<i>Terminalia mollis</i> M.A. Lawson	29	14.9	5–54	61.9	10–156
<i>Terminalia sericea</i> Burch. ex DC.	16	10.0	6–17	39.4	11–81

Table 2 Coppice density (number of coppice shoots per stump) of miombo woodland species after cutting for charcoal production

Species	Coppice density (no. of shoots/stump)			
	Mean	SD	Minimum	Maximum
<i>A. antunesiana</i> ^a	6	3	1	15
<i>B. boehmii</i> ^d	6	2	3	10
<i>B. spiciformis</i> ^a	6	3	1	17
<i>C. molle</i> ^{a,c}	6	3	2	12
<i>F. speciosa</i> ^c	8	4	4	20
<i>J. paniculata</i> ^e	5	1	2	9
<i>P. curatellifolia</i> ^d	8	4	4	18
<i>P. maprouneifolia</i> ^c	6	3	2	15
<i>S. madagascariensis</i> ^c	7	3	2	20
<i>T. mollis</i> ^d	7	2	3	11
<i>T. sericea</i> ^b	5	2	1	9

SD standard deviation

^a Species for which significant ($p < 0.05$) relationships were found between coppice density and stump diameter^b Significant relationship between coppice density and stump height^c Significant relationship between coppice density and time since cutting^d No significant relationships were observed^e This species was not included in the analysis due to few coppice stumps and mostly very young shoot

density and time since cutting of the tree species for charcoal production was significant for *C. molle*, *F. speciosa*, *P. maprouneifolia* and *S. madagascariensis*. The number of shoots per stump decreased over time for all these species, except *F. speciosa* which had more shoots per stump over time (Fig. 3).

The mean height of coppice shoots ranged from 46 to 118 cm, depending on the species; *T. sericea* had the highest, *P. curatellifolia* the lowest (Table 3). The mean height of coppice shoots reached as high as 4.0 m for some species,

such as *A. antunesiana*, *C. molle* and *T. sericea*. There were no significant relationships between mean height of coppice shoots and stump size for all species except *F. speciosa* (Table 3). For *F. speciosa*, the mean height of coppice shoots increased with increasing stump diameter (Fig. 4). Nearly half of the species had a significant positive relationship between mean height of coppice shoots and time since cutting of trees for charcoal production (Table 3). For all the species with a significant relationship, mean height of coppice shoots were increased over time (Fig. 5).

Coppice density and shoot vigour were significantly correlated for only three species (Table 4). For *B. spiciformis*, the mean height of coppice shoots increased with increasing coppice density, whereas the mean height of coppice shoots decreased with increasing coppice density for *P. maprouneifolia* and *S. madagascariensis*. However, the correlation between coppice density and mean height of coppice shoots was generally weak, particularly for *B. spiciformis* ($r = 0.252$) and *P. maprouneifolia* ($r = -0.283$) compared with *S. madagascariensis* ($r = -0.439$).

Discussion

All the species recorded in the present study produced 5–8 shoots per stump on average with a mean height of 46–118 cm for coppice shoots, which is an indication of their ability to resprout once they are cut. This resprouting is typical of most tropical dry forest species that have the ability to regenerate vegetatively, and coppice growth is an important species-specific trait that strongly influences regeneration by coppicing (Kaschula et al. 2005; Ky-Dembele et al. 2007). Resprouting is a key attribute of resilience and productivity of the woodland savannas (Shackleton 2001). The ability of most of the tropical dry forest species to coppice has been observed in studies of

Fig. 2 Relationships between coppice density and stump size for species that showed significant relationship. Models for coppice density were developed using square-root transformed data for all species presented, and the regression lines represent back-transformed values

Fig. 3 Relationships between coppice density and time since cutting for species that showed significant relationship. Models for coppice density were developed using square-root transformed data for all species presented, and the regression lines represent back-transformed values

many tropical dry forests, such as the South African savanna (Shackleton 2000; Kaschula et al. 2005) and the miombo ecoregion (Luoga et al. 2004; Syampungani and Chirwa 2011; Chirwa et al. 2014) and Sudanian savanna-woodlands of West Africa (Ky-Dembele et al. 2007; Dayamba et al. 2011) because most tropical dry forest

species generally have extensive vertical and horizontal root systems that facilitate recuperation after cutting (Mistry 2000). However, the observed inter-specific difference in the number of coppice stumps in the present study could be related to their initial stocking density in the stand and the preference of the local people.

Table 3 Coppice growth (mean height of coppice shoots per stump) of miombo woodland species after cutting for charcoal production

Species	Mean	SD	Mean height (m)	
			Minimum	Maximum
<i>A. antunesiana</i> ^a	1.04	0.96	0.11	4
<i>B. boehmii</i> ^b	0.98	0.32	0.4	1.47
<i>B. spiciformis</i> ^a	0.98	0.45	0.17	2.48
<i>C. molle</i> ^a	1.15	0.83	0.3	4
<i>F. speciosa</i> ^c	0.97	0.51	0.22	2.4
<i>J. paniculata</i> ^d	0.5	0.22	0	1
<i>P. curatellifolia</i> ^c	0.46	0.27	0.14	1.16
<i>P. maprouneifolia</i> ^a	0.79	0.4	0.1	1.8
<i>S. madagascariensis</i> ^a	1.09	0.79	0.24	3.9
<i>T. mollis</i> ^b	0.87	0.79	0.07	3.7
<i>T. sericea</i> ^a	1.18	0.92	0.15	4

SD standard deviation

^a Species for which significant ($p < 0.05$) relationships were found between mean shoot height and time since cutting^b No significant relationships were observed^c Significant relationship between mean shoot height and stump diameter^d This species was not included in the analysis due to few coppice stumps and mostly very young shoot **Fig. 4** Relationships between shoot vigour (mean height of coppice shoots) and stump diameter for a species that showed significant relationship. The model for shoot height was developed using natural logarithm-transformed data, and the regression lines represent back-transformed values

Coppice density (Fig. 2) and shoot vigor (Fig. 4) were also observed to have a significant relationship with stump size and time since cutting for some of the species. Our findings agree with previous studies (Shackleton 2000; Luoga et al. 2004) in the eastern and southern African woodland savannas where the influence of species, plant size/age, stump height and the percentage of stand removed on the resprouting ability was observed. The influence of species on coppicing ability may be attributed to the fact that there is a trade-off between storage and growth when trees are allocating resources, which, in turn, may vary among species. Consequently, resprouting is more

successful for species or trees that have larger reserves to support regrowth (Knox and Clarke 2005). Additionally, the size of the tree at the time of cutting tends to influence the resprouting ability of many African savanna species (Luoga et al. 2004) and other hardwood species (Keyser and Loftis 2015). The influence of the size or rather age of the tree at the time of cutting may be attributed to physiological changes to which the capacity for rejuvenation by vegetative means depend upon (Yamada et al. 2001; Bond and Midgley 2003). In the present study, there was an increasing tendency of resprouting ability with larger stump diameter for some species, in agreement with other observations elsewhere within the tropics (Mwavu and Witkowski 2008; Lèvesque et al. 2011). Resprouting is influenced by the amount of food reserve accumulated in the stump, and/or the activity of underground buds, which in turn depends on stump diameter. Miura and Yamamoto (2003) showed that larger stumps have much more food reserves and/or more active underground buds, resulting in the production of more sprouts.

A positive relationship between stump height and coppice density was also found for *T. sericea*, which is consistent with several studies in the tropics and subtropics (Mishara et al. 2003). Within the southern African savannas, a number of studies reported the influence of stump height on resprouting ability of the Zimbabwean miombo (Mushove and Makoni 1993) and South African (Shackleton 2001) and Zambian (Handavu et al. 2011) miombo woodlands. This effect of stump height can be attributed to availability of more reserved food and dormant buds on longer stumps. Also, cutting too low on the stem of the tree might encourage fungal infection because of moisture from the ground or stump decay.

Although mean height of coppice shoots appeared to be increasing over time (Fig. 5), coppice density decreased over time for three of four species (Fig. 3). These results are an indication of competition for resources among coppice shoots, as also evidenced from the negative correlation between coppice density and mean height of coppice shoot, particularly for *P. maprouneifolia* and *S. madagascariensis* (Table 4). Generally, plants are capable of adjusting the relative sizes and distribution of their organs in response to changes in the supply of resources, which is in line with the resource optimization hypothesis (Ågren and Franklin 2003) or functional equilibrium theory (Brouwer 1983). Changes in allocation pattern are relatively strong when nutrient supply is highly varied. However, it should be noted that the strength of the relationship between coppicing ability (both coppice density and mean height of coppice shoots) and stump size as well as the correlation between coppice density and shoot vigor were generally weak in the present study. The range in stump diameter and height of the cut stumps sampled in the

Fig. 5 Relationships between shoot vigour (mean height of coppice shoots) and time since cutting for species that showed significant relationship. Models for shoot height was developed using natural logarithm-transformed data for all species presented, and the regression lines represent back-transformed values

Table 4 Species-wise correlation between coppice density and mean height of coppice shoots

Species	Coefficient (<i>r</i>)	<i>P</i> value
<i>A. antunesiana</i>	-0.119	0.498
<i>B. boehmii</i>	-0.352	0.198
<i>B. spiciformis</i>	0.252	0.021 ^a
<i>C. molle</i>	-0.301	0.059
<i>F. speciosa</i>	-0.286	0.132
<i>P. curatellifolia</i>	-0.192	0.291
<i>P. maprouneifolia</i>	-0.283	0.017 ^a
<i>S. madagascariensi</i>	-0.439	0.017 ^a
<i>T. mollis</i>	0.054	0.782
<i>T. sericea</i>	0.051	0.851

^a Correlation was significant

present study was narrow because the trees cut by the locals for charcoal production were sampled directly. A controlled experiment involving a wider stump diameter and height would likely provide a better prediction model.

Conclusion

Our findings provide evidence that woody species in the dry miombo woodlands are capable of resprouting after they are cut using the traditional harvesting technique for charcoal production. Based on the findings, the following conclusions can be drawn: (1) stump diameter and height

significantly affect coppice density (number of shoots per stump) with marked variation among species; (2) stump diameter and height have no effect on mean height of coppice shoots; however, mean height increases over time for half of the recorded species, which suggests high shoot vigour; and (3) coppice density is negatively correlated with shoot vigour, particularly for *P. maprouneifolia* and *S. madagascariensis*, suggesting possible competition among coppice shoots in a given stump. As a whole, the study provides additional evidence about the importance of coppice management as a win-win strategy for sustaining forest-based livelihoods and recovering woodland ecosystems. The results suggest that species and stump size are important aspects to be considered in the planning of harvesting for fuel wood and managing subsequent coppices. Further study is needed to determine consistent predictors of coppicing ability of miombo species using a wider size distribution of the trees to be harvested.

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