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Population Structure and Regeneration Status of *Vitellaria paradoxa* (C.F.Gaertn.) Under Different Land Management Regimes in Uganda

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Abstract: *Vitellaria paradoxa* is an ecologically and economically important tree in the dry savanna woodlands of Africa contributing immensely to livelihoods and amelioration of microclimate in areas where it occurs. Despite its importance, this tree is currently considered threatened by the World Conservation Union. This has been mainly due to over exploitation of this tree and agricultural encroachment. Despite its red list status, there is no clear understanding of its population structure and regeneration status under different land management regimes. In this study, we assessed the population structure and regeneration status of *V. paradoxa* under old fallows, young fallows and current fields. The specific objectives were: to determine the density of seedlings, saplings and mature *V. paradoxa* to examine the size class distribution and regeneration status of *V. paradoxa*. We hypothesised that its density is not influenced by land management regime. We measured thickness of all mature trees, saplings and seedlings in 50×50 plots. The population structure was described using densities, size class distributions and their slopes. Generalised linear model analysis was used to compare the density of each size class under different land management regimes. Seedling density was influenced by land management regime while sapling and mature tree densities were not. Young fallows registered high seedling density compared to old fallows and current fields. Size class distribution and regeneration status were influenced by land management regime. Young fallows had more stable populations with better regeneration compared to old fallows and current fields. This study confirms that land management regimes can influence the population structure and regeneration status of *V. paradoxa*.

Key words: Seedlings, size class distribution, fallows, shea butter tree, density, savanna

INTRODUCTION

Vitellaria paradoxa (C.F. Gaertn.), commonly known as the shea butter tree is an iconic fruit tree in the dry savanna woodlands of Africa (Boffa, 1999). It is a major component of the woody flora of Sudanian regional centre of endemism (White, 1983) contributing immensely to local livelihoods, amelioration of micro-climate and nutrient recycling through the decaying of its leaves and fine roots (Dianda *et al*., 2009). It covers an almost unbroken belt approximately 6000×500 km from Senegal to the northern parts of Uganda (Sanou *et al*., 2006). It is a tree species of priority for African genetic resources (FAO, 1988) because of its significant economic potential for livelihood improvement (Teklehaimanot, 2004; Sanou *et al*., 2004). The fruit pulp can be eaten by both humans and animals while the butter extracted from the seed kernel may be used for local consumption, manufacturing body care products as well as pharmaceutical and confectionery industries (Kelly *et al*., 2004a; Lamien *et al*., 2007). Shea butter products are increasingly becoming popular globally and it is envisaged that as the demands grows there will be need for sustainable management of the shea butter tree (Teklehaimanot, 2004). When aggregated Africa has a potential of exporting about 263,000 metric ton of shea products annually however, only about 150,000 metric ton of dry shea kernels are currently exported (Lovett, 2000). The free on board value of shea export is estimated to be ranging in $37.5-45 million annually (ibid).

Despite its economic and ecological importance, the population of this tree species has reduced for instance (Djossa *et al*., 2008a) reported 5 trees ha^{-1} of this species in West Africa compared to 15 trees ha^{-1} reported by Ruyssen. Chevalier reported a density of 230 trees ha^{-1} in the Sudanian savannas which has reduced to 11 trees ha^{-1} (Nikiema *et al*., 2001). According to the World Conservation Union, *V. paradoxa* is considered a

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threatened tree species, i.e., it is vulnerable to extinction in the near future. This has mainly been due to over exploitation for timber, firewood, charcoal production and agricultural encroachment due to increasing population pressure.

The current decline in the population of *V. paradoxa* has triggered research on this tree species in the recent years (Bayala *et al*., 2008; Kelly *et al*., 2007; Lamien *et al*., 2007). However, it is noticeable that understanding variation of *V. paradoxa* population structure with land management regimes at a wide geographical scale has not been extensively investigated.

More so, there is little information on its regeneration status (Djossa *et al*., 2008b). Most of the studies that have attempted to investigate *V. paradoxa* populations have been done in West Africa (Odebiyi *et al*., 2004; Djossa *et al*., 2008a; Raebild *et al*., 2007). Understanding the population and regeneration of *V. paradoxa* in Eastern Africa where *nilotica* sp. is endemic has not attracted the attention of researchers. It is only Okullo (2004) who attempted to investigate its population in Northern Uganda.

In this study, we assessed the population structure and regeneration status of *V. paradoxa* under different land management regimes in the *Vitellaria* savannas. The specific objectives were: to determine the density of seedlings, saplings and mature individuals of *V. paradoxa* under different land management regimes; to examine the size class distribution and regeneration status of *V. paradoxa* under different land management regimes. We hypothesised that density of seedlings, saplings and mature *V. paradoxa* does not vary with land management regime. We envisage that the findings will help inform management decisions in the dry savanna woodlands of Africa.

MATERIALS AND METHODS

Study sites: The study covered the districts (highest level of local government in Uganda) of Moyo (3°37' 41N, 31° 45'13E), Nakasongola (1°18' 32N, 32°27' 23E), Lira (2°14' 6N, 32°54'35E) and Katakwi (1°53' 28N, 33°57' 58E) which are part of the area commonly referred to as the shea belt by traders of shea butter products (Fig. 1). The shea belt in Uganda covers an area of 29,726 km^2 mainly covering North-West, North and North-East of the country (Ferris *et al*., 2001). The mean annual rainfall of these districts ranges between 500-1600 mm and they experience bimodal rainfall regime (NEMA, 1995). The terrain is generally flat with some plateaus in certain districts. The soils are mainly sandy, loamy and clay with Ph ranging between 5.5-6.8 (Nabalegwa *et al*., 2006; NEMA, 2000). The vegetation is dominated by savanna woodlands with *Acacia*, *Combretum*, *Vitellaria*, *Annona, Erythrina*, *Albizia* and *Terminalia* tree species as the most common (Katende *et al*., 2000).

Studied species: *V. paradoxa* is a characteristic tree species in the savanna woodlands of Africa (Hall *et al*., 1996). It is endemic to the African savanna North of the equator (Maranz *et al*., 2004).

It belongs to the family sapotaceae within the genus Vitellaria (with only a single species worldwide). There two subspecies, i.e., *V. paradoxa* ssp. *paradoxa* and

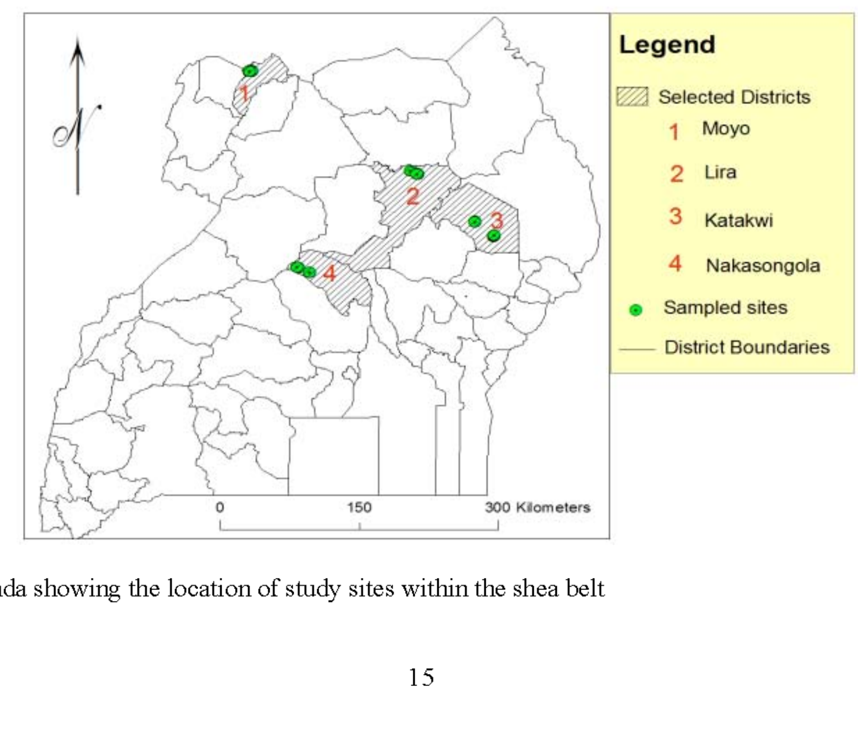

Fig 1: Map of Uganda showing the location of study sites within the shea belt

V. paradoxa ssp. nilotica (Henry *et al*., 1983; Hall and Hindle, 1995). There is no definite distinction between the two subspecies based on leaves, flowers, fruits or morphology of mature individuals. The difference is in terms of origin of which *V. paradoxa* ssp. nilotica occurs in eastern Africa through south Sudan, northern Uganda, western fringe of Ethiopia and north eastern parts of Democratic Republic of Congo while *V. paradoxa* ssp. paradoxa ranges from eastern parts of Central African Republic westwards to Senegal (Hall *et al*., 1996). *V. paradoxa* ssp. *paradoxa* ismainly found between 100-600 m above sea level (masl) while *V. paradoxa* ssp. *nilotica* between 650-1600 masl (Bouvet *et al*., 2004).

V. paradoxa is a long lived (maturing in 10-20 years) deciduous, compact crowned tree with a height of 7-25 m (Sanou *et al*., 2006). The bole is short on average ranging between 3-4 m but in some instances, 8 m and diameter is usually <1 m (Hall and Hindle, 1995). Large sized trees are mostly found in land under cultivation while small sized trees are found in forests and fallows (Djossa *et al*., 2008a).

It reproduces mainly sexually and most often it is insect-pollinated (Cardi *et al*., 2005). It flowers in the dry season (Von Maydell, 1986). Peak flowering season in Uganda is January to February (Okullo *et al*., 2004). Fruiting of *V. paradoxa* may start at 10 years of age and attains full fruit production between 20 years to >50 years (Okullo *et al*., 2004). Ripening of fruits takes place during the rainy season and there is still little evidence on occurrence of fruiting cycles (Lovett, 2000). *V. paradoxa* is intolerant to shade and therefore open sites especially plains are conducive for this species. It preferably grows on colluvial soils that are deep with free drainage and predominantly sandy-clay top soils (Hall *et al*., 1996).

Land-use practices within the shea districts of Uganda: Subsistence agriculture, charcoal burning, livestock rearing and *V. paradoxa* fruit collection/processing are the major activities supporting the livelihoods of the local communities.

They practice subsistence agriculture characterised by two land management regimes; continuous cultivation with annual crops such as sorghum (*Sorghum bicolour* (L.) Moench), Millet (*Eleusine coracana* (L.) Gertn.), Beans (*Phaseolus vulgaris* L.), Maize (*Zea Mays* L.), Ground nuts (*Arachis hypogaea* L.) and fallow system where land that was previously under cultivation is left over a period without any farming activity to allow it regain soil fertility (Okullo, 2004). In each land management regime *V. paradoxa* and other trees of economic importance are retained by farmers. The duration of the fallow period is based on size of land and household needs. Fallow periods of 1-5 and 5-10 years are common (District Environment Officers pers.com). Short fallows are common in areas with high population densities while long fallows in areas that are sparsely populated.

Areas that have been under long fallows are characterised by more dense woody vegetation than under short fallows and continuous cultivation. Land under continuous cultivation has mainly very little woody vegetation apart from economically important trees such as *V. paradoxa*.

Sampling design: Sampling was done in four districts (lowest local government units in Uganda) that have sizeable areas of *V. paradoxa* stands. One site was selected in each district based on presence of fallow land and current crop fields covered by *V. Paradoxa*. These make up the two most dominant land management regimes in the *Vitellaria* savanna farming system (Boffa, 1999; Lovett and Haq, 2000; Okullo *et al*., 2004). These land management regimes formed the treatments for this study. Fallow land was further categorised as old or young on the basis of length of fallow period. Old fallows were sites not cultivated for over 10 years while young fallows were not cultivated for 3-6 years. The current fields were areas covered by annual crops (at the time of study).

Within each land management regime, four sample plots each of 50×50 m were established using systematic random sampling (Chazdon *et al*., 2005). The first plot was randomly located (Johnson and Bhattacharyya, 2001) while subsequent plots were established systematically at least 100 m apart. This allowed the plots to be considered as individual sampling units (Sanou *et al*., 2006). Generally, old fallows, young fallows and current fields were encountered but in Nakasongola, only old and young fallows were encountered.

Data collection: Individuals of *V. paradoxa* were measured (cm) for either stem diameter (saplings and mature trees) or root collar diameter (seedlings/resprouts) following Rondeux (1999). Sapling diameter was determined at the point of first branching while mature trees were measured at breast height (at 1.3 m high) using vernier callipers. Individuals with stem Diameters at Breast Height (DBH) $\geq$ 10 cm were considered mature trees, those with DBH 6 $\leq$ 10 cm as saplings while those with collar diameter of 0.1 $\leq$ 5 cm as seedlings (Rondeux, 1999). Plot assessments were conducted in 2008 between October and December when the rainy season ends in most areas of the shea belt of Uganda.

Data analysis

***V. paradoxa* population density under each land management regime:** Density was calculated as the total number of *V. paradoxa* ha^{-1} in each size class (seedlings/resprouts, saplings and mature trees) under each land management regime following (Djossa *et al*., 2008a). The average number of individuals of *V. paradoxa* and standard deviation under each land management regime were derived to compare densities of each size class. A generalized linear model analysis in GenStat ($p<0.05$) was applied to determine whether land management regime influenced the density of each size class under the different land management regime.

***V. paradoxa* population structure and regeneration status:** The size class distribution under each land management regime was analysed following (Condit *et al*., 1998). Diameter sizes (cm) of measured individuals were grouped into the following size classes (Lykke, 1998): 1, 2, 3-4, 5-6, 7-8, 9-10, 11-13, 14-16, 17-19, 20-23, 24-27, 28-31, 32-35, 36-39, 40-43, 44-47, 48-51, 52-55, 56-59, ≥ 60. All individuals ≥ 60 cm DBH were grouped in a 10 cm wide class. This categorisation balances samples across size classes since number of individuals declines with increasing diameter (Condit *et al*., 1998). The size class distributions were generated using the number of individuals in each size class (Ni) and the class midpoints.

The number of individuals in each size class (Ni) was natural log (ln) transformed and plotted against the class midpoints to display graphically the size class distributions under the different land management regimes (Condit *et al*., 1998; Mwavu and Witkowski, 2009; Venter and Witkowski, 2010). The Log transformation was used to standardise densities of the different size classes. The regression of the size class distributions was calculated with class midpoints as the explanatory variable and number of individuals ln (Ni+1) per class as the dependent variable (Lykke, 1998).

The addition of 1 to Ni was necessary to cater for situations where a class had 0 individuals (Mclaren *et al*., 2005). The slopes of the regressions were used as indicators of the population structure (Obiri *et al*., 2002) under each land management regime. The slope values were derived using LINEST function in excel and interpreted based on the types of size class distributions (Everard *et al*., 1994; Mwavu Witkowski, 2009). Negative slopes indicate regeneration since there are more individuals in the small classes compared to the large classes (Obiri *et al*., 2002). Flat distributions with a slope of 0 indicate equal numbers of individuals in the small or regenerating classes and large size classes or mature trees and positive slopes indicate poor regeneration with more trees found in larger classes than in smaller size classes. Steepness of the slope was used to further describe the regeneration status as steep negative slope indicates better regeneration than shallow negative slopes (Lykke, 1998; Venter and Witkowski, 2010).

RESULTS AND DISCUSSION

Population densities under different land management regimes: Seedling density was high in the young fallows compared to old fallows and current fields, respectively. Density of saplings was generally low under old fallows, young fallows and current fields. Mature tree density was relatively high under all the three land management regimes. Land management regime significantly influenced seedling density ($p<0.00$) but not sapling and mature tree densities (Table 1).

Population structure and regeneration of *V. paradoxa* under different land management regimes: The old fallows showed inverse J-shaped size class distribution across all sites except in Moyo (Fig. 2). Similarly, all young fallows had inverse J-shaped size class distribution across all sites.

There were many individuals in the smallest diameter classes and the number gradually declined in the middle and larger diameter classes in fallows. Current fields had flat size class distributions in all the sites. There were more individuals in the larger diameter classes than in the small diameter classes. The old and young fallows generally had negative slopes of the size class distributions. Within current fields the slopes of the size class distribution were positive with more trees in larger size classes than in smaller ones. Young fallows had steeper slopes (more negative) across all the sites than old fallow and current fields, respectively (Table 2).

Population densities under different land management regimes: The young fallows had the highest seedling density followed by old fallow and current fields respectively. This corroborates Djossa *et al*. (2008a) findings in Benin where *V. paradoxa* seedling density in current fields was low compared to other land uses. This could be probably because of the farmers' ignorance of the importance of protecting *V. paradoxa* seedlings when cultivating. It may also be attributed to excessive cultivation of land that has the effect of inhibiting regeneration of seedlings (Kelly *et al*., 2004b). Seedling density was low in old fallows compared to young fallows across all the sites studied except in Nakasongola. This is

Table 1: Seedling, sapling and mature tree density ha^{-1} within the old fallow, young fallow and current fields across studied sites

	Districts											
	Katakwi			Lira			Moyo			Nakasongola		
Land management regime	Seedlings	Saplings	Mature trees	Seedlings	Saplings	Mature trees	Seedlings	Saplings	Mature trees	Seedlings	Saplings	Mature trees
Old fallow	142±100	3±4	15±4	280±176	2±4	19±3.83	126±94.80	3±3.83	36±8.64	54±26.40	3±3.83	42±13.00
Young fallow	257±171	9±18	26±10	398±200	0±0	20±8.64	438±314.00	0±0.00	38±7.66	8±13.47	5±7.57	15±6.83
Current field	34±32	0±0	19±4	164±104	4±4	27±6.00	14±14.05	0±0.00	33±6.83	-	-	-

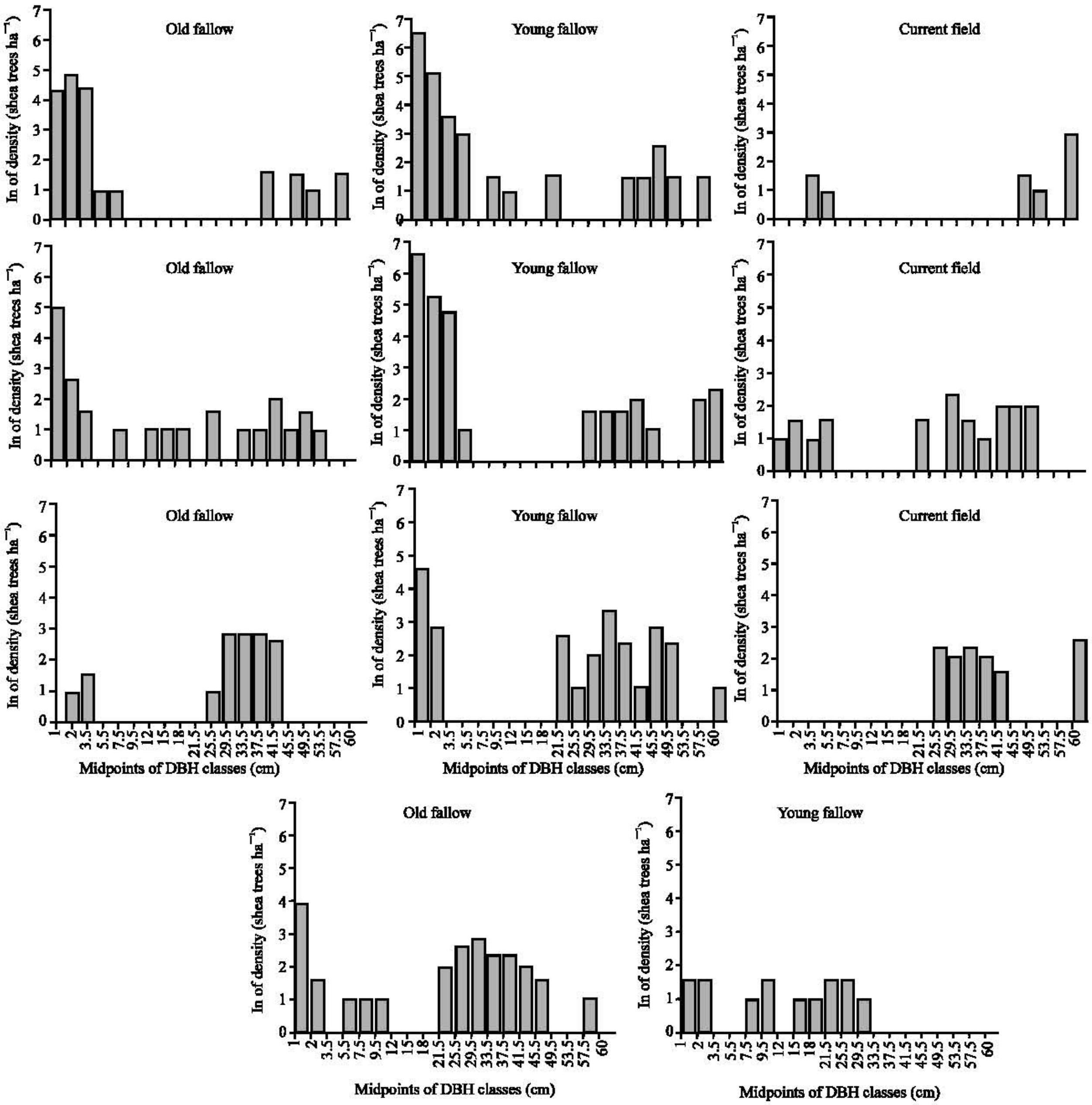

Fig. 2: Size class distributions of *V. paradoxa* in old fallow, young fallow and current fields across sites studied

probably because old fallows generally had dense tree and grass cover which may have impeded establishment of *V. paradoxa* seedlings through competition for growth resources and was potentially more susceptible to

Table 2: Slopes of the size class distributions of *V. paradoxa* under old fallow, young fallow and current fields across sites studied

Land management regime	Katakwi	Lira	Moyo	Nakasongola
Old fallow	-0.20587	-0.11434	0.014709	-0.03731
Young fallow	-0.42178	-0.49309	-0.0437	-0.03952
Current field	0.041261	0.011176	0.045326	

fire damage. According to Picasso, *V. paradoxa* is light demanding and therefore its seedlings could suffer from competition for basic growth requirements like light, water and nutrients in sites that have dense plant cover like most old fallows.

Generally *V. paradoxa* sapling density was very low in each of the land management regimes across all sites; suggesting that the *V. paradoxa* population risks degradation (Gijsbers *et al.* 1994). This finding is contrary to Lovett and Haq (2000) who found out that local people preferentially preserved significant saplings density of important tree species like *V. paradoxa* on their land as they cultivated. The low *V. paradoxa* sapling density in the fallows could be due to the uncontrolled incessant bush burning in the Vitellaria savannas of Uganda. According to Zida *et al.* (2007) and Peterson and Reich (2001), frequent fires can prevent sapling establishment in savanna woodlands. There was evidence of regular fires in the all fallows indicated by burnt barks of mature *V. paradoxa* trees.

The extremely low *V. paradoxa* sapling density in the current fields confirms studies done else where by Lovett (2000) where farmers were found to be only interested in mature productive *V. paradoxa* trees and therefore cut down saplings that interfered with their crop production. The low *V. paradoxa* sapling density across all studied sites under the different land management regime suggests that land owners may not be aware of the value of young individuals in sustaining *V. paradoxa* population. This may not immediately have a negative impact on the current adult population but will certainly in the long run be noticeable when the adult shea trees reach senesce and there are no young ones to replace them.

The density of mature trees was relatively high and similar under all the three land management regimes. This is contrary to studies done elsewhere (Djossa *et al.*, 2008a; Odebiyi *et al.*, 2004) where the density of mature *V. paradoxa* trees was highest in the current fields than under other land management regimes. Lack of significant variation in mature shea tree density across the different land management regimes may have been due to the fact that within the shea belt (especially where there are traditional conservation regulations), all productive mature *V. paradoxa* trees irrespective of the land management regimes are preserved (Lovett and Haq, 2000).

This therefore implies that mature shea tree densities are bound to be more or less similar in areas where this tree is considered important for conservation albeit the difference in land management regimes.

Population structure and regeneration under different land management regimes: Habitats that have abundant young individuals compared to adults have an inverse J-shaped size class distribution which is an indicator of a healthy and stable regenerating population (Condit *et al.*, 1998; Wilson and Witkowski, 2003). This was predominantly the case in the current study where all the young and old fallows had inverse J-shaped size class distributions with negative slopes across all sites except the old fallow of Moyo. This implies that *V. paradoxa* population and regeneration in all fallows is in a stable-healthy condition. However, the population within the current fields had flat size class distributions with positive slopes across all sites suggesting that there was no regeneration and the population was unstable and degraded (Everard *et al.*, 1994). The regeneration is therefore discontinuous (Poorter *et al.*, 1996) hence maintaining a relatively stable population of *V. paradoxa* in the current fields may be difficult (Lykke, 1998).

This is so because a stable population requires having more individuals in the smaller classes than larger ones (Condit *et al.*, 1998). The findings from this study corroborate findings of Kelly *et al.* (2004b) in Mali in which all fallows had more *V. paradoxa* individuals in the lower size classes compared to current fields. According to Kelly *et al.* (2004b), this could be due to the fact that farmers rarely protect seedlings that they encounter when cultivating crops or when they maintain the land under cultivation for a long time hence impeding shea tree regeneration.

The slopes of the regressions of the size class distributions were steeper (more negative) within the young fallows across all the sites except Nakasongola than the old fallows and current fields. This is contrary to studies done in West Africa (Kelly *et al.*, 2004b; Djossa *et al.*, 2008a) where old fallows had better regeneration of shea trees than the young fallows and current fields, respectively. This is probably because the climatic conditions in Uganda favour rapid establishment of vegetation, hence leaving land under fallow for a very long time may result into growth of more competitive vegetation that may impede regeneration of *V. paradoxa*. Because of this, the old fallows are bound to have poor regeneration of *V. paradoxa* than young ones where it experiences less competition for growth requirements.

CONCLUSION

This study confirms that land management regimes can influence the population structure and regeneration status of *V. paradoxa*. Young fallows support high seedling densities compared to old fallows and current fields. Although, land management regime may not have had any influence on the sapling and mature tree density the occurrence of extremely low density of *V. paradoxa* saplings across all sites suggest that land owners do not appreciate the importance of saplings in maintaining a stable population. This may have long-term consequences on the stability of *V. paradoxa* population and in the process may lead to its collapse and local extinction. Much as land owners preserve relatively high densities of mature *V. paradoxa* individuals irrespective of the land management regime; young fallows may maintain more stable-healthy populations and better regeneration compared to old fallows and current fields. There is thus need for the land owners in the shea belt of Uganda to be sensitised on the importance of preserving and protecting seedlings and saplings of *V. paradoxa* so as to maintain a stable population especially in the current fields where their density was dismal.

Sites targeted for conservation *V. paradoxa* should not be left under fallow for a long time to minimise establishment and growth of more competitive vegetation that may inhibit *V. paradoxa* regeneration.

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