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Regeneration, Soils and Associates of Three Subspecies of *Sclerocarya birrea* in Tanzania

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Abstract: This study examined soil properties, regeneration biology and vegetation associates of the 3 subspecies of *Sclerocarya* namely; *birrea*, *caffra* and *multifoliolata* in Tanzania. The plotless sampling technique was used to obtain 100 mature trees, 1 from an on-farm and another from a wild environmental setting; for each of the 3 subspecies. A total of 600 mature trees were sampled and 40 soil samples were collected for analysis both of the 2 settings (on-farm and wild environment). Seedlings and saplings, as well as species associates were also inventoried. Results show that most of the basic soil properties were not influenced by the subspecies, although a more robust soil sampling is suggested. Most populations originated from coppicing and sprouting than from seed sources. Interestingly, there was no single species associate associated with all the 3 *Sclerocarya* subspecies but associates of 2 subspecies were found.

Key words: Sclerocarya, regeneration, sampling, soils, Tanzania

INTRODUCTION

Much of the available knowledge on *Sclerocarya birrea* is based on subspecies *caffra*. Analysis of the available information on sclerocarya biology and use conclude that much is known about the fruit and its uses including policy, marketing and processing propositions but information on the species' natural populations is fragmentary and this is for all the subspecies. Little is known about the regeneration ecology of this species in its natural habitat (Akinnifesi *et al*., 2008; Helm and Witkowski, 2008; Gouwakinnou *et al*., 2009) while its influence on soils and species composition around its habitat is old and scant (Hall *et al*., 2002). Studies are needed to understand the recruitment nature of the species which grows in areas with frequent disturbances (Helm and Witkowski, 2008). In the 1990s, large numbers of unimproved seedlings of *Sclerocarya birrea* were distributed to farmers as one of the efforts to establish the tree on farms, as an agroforestry species in Southern Africa. This early enthusiasm was short-lived as graft-take became, as low as 10% and low survival and growth were reported on farmers' fields (Mhango and Akinnifesi, 2001). So, recruitment of new individuals for the species remains natural both in the wild and on farms. Natural regeneration is an important process in perpetuation of plant communities in their natural habitats, as well as sustainable utilisation (Tesfaye *et al*., 2010).

Natural regeneration of tree species takes place either through seeds or vegetative means mainly through root or coppice sprouting. But, it is known that on tropical mainland, especially in the dry forests >90% of all tree species have >50% of their seeds killed by predators or fruit fungi between fruit set and seed germination. All these factors together with nutrient relations and herbivory; control the growth and reproduction from seeds (Harper *et al*., 1965; Malaisse, 1978; Hutchings, 1986; Janzen and Vazquez-Yanes, 1991; Chidumayo, 1993, 1997; Grundy *et al*., 1993). Therefore, the main form of

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natural vegetation regeneration is through root suckering and stump coppicing. These usually occur following disturbances imposed on the natural communities, such as logging and land clearing (Mugasha, 1978). After establishment seedlings and saplings pass through a difficult transition to establish into the tree layer due to top kill through browsing and fire (Higgins *et al*., 2000; Blondel and Midgley, 2001; House *et al*., 2003; Hanan *et al*., 2008) needing time to establish structures, such as lignotubers to be able to re-sprout to their previous size (Hoffmann, 1998; Hoffmann and Solbrig, 2003). Saplings, also need a minimal disturbance for them to recruit into the canopy layer where there is less damage (Lehmann *et al*., 2009). Hence, disturbances affects and shape population structure and status of a species, since it determines the amount of trees attaining the mature reproductive stage (Higgins *et al*., 2000; Hanan *et al*., 2008).

While regeneration determines adult population structure for a species, species associates and soil properties are also important habitat components with influences on performance of species. *Sclerocarya birrea* is found in mixed deciduous woodland and wooded grassland in most case reported to be associated with *Lannea* and *Combretum* sp. (Mbuya *et al*., 1994; Van Wyk and van Wyk, 1997; Ruffo *et al*., 2002). The different subspecies are reported to be associated with different vegetation and species types (Hall *et al*., 2002). The available information is based on generalised vegetation reviews and it is suggested that localised variations are possible (Shackleton *et al*., 2001). For the case of Tanzania where all the subspecies occurs, researchers do not know if there is an overlap of the associates.

On the other hand, information on soils where the species occur is restricted to general texture (Hall *et al*., 2002). Sandy texture is the most common although sandy loam and loam are also mentioned. There is scant information about pH (commonly from 4.8-6.2 and occasionally alkaline) (Morrison *et al*., 1948; Vollesen, 1980) and soil fertility is said to be generally poor (Ohler, 1985) with a few exceptions (Trapnell, 1953).

The regeneration mode for the 3 subspecies has never been compared and especially taking into account the wild and farm environment where it occurs. Researchers, also do not know whether the species which despite its valuable ecological role in the wild (Hall *et al*., 2002; Shackleton *et al*., 2002; Helm and Witkowski, 2008) and which grows in association with crops on farms, influence the basic soil properties around its habitat. Although, there is a general literature about the species' vegetation associates; it has been suggested that local variation are possible (Shackleton *et al*., 2001). All the 3 subspecies occur in Tanzania and present a unique opportunity to study and compare the respective habitats. If this knowledge is acquired, it can be an important supplement in sustainable use and conservation initiatives for the species (Helm and Witkowski, 2008). Given this background, researchers studied and compared the basic soil properties, regeneration status and species associates for the 3 subspecies of *Sclerocarya birrea*.

MATERIALS AND METHODS

Study area and sampling technique: The study was carried out in 3 sites each representing one of the 3 subspecies of *Sclerocarya birrea*. The sites and the respective subspecies are Holili (3.4° South; 37.6° East); located in Rombo District, Northern Tanzania close to Kenyan border (subspecies *birrea*); Kiegea (6.8° South; 37.7° East), located in Morogoro District, East-Central Tanzania (subspecies *caffra*) and Malinzanga (7.8° South; 35.7° East); located in Iringa District, Southern Tanzania nearby Ruaha National Park (subspecies *multifoliolata*). In each site 2 environmental settings (wild and on-farm) were sampled and at each site condition one sampling plot was established for survey, hence in total 6 different populations were studied. The 2 sampling plots in each village were at least 1 km apart.

Researchers established study plots containing 100 sclerocarya trees at each site using the plotless sampling technique described by Cottam and Curtis (1956) and Williams *et al*. (1969). This method has been described, used and modified over time to suit various field conditions and specific objectives of surveys (Ludwig and Reynolds, 1988; Sparks *et al*., 2002; Sheil *et al*., 2003). The method is superior for it saves time, energy and money while attaining higher levels of accuracy, especially where trees are sparsely distributed and unevenly scattered (Lessard *et al*., 1994).

To begin sampling in each site, 1 mature sclerocarya tree (≥10 cm dbh) located in the centre of a randomly identified area was used as a starting point. The 99 nearest other mature trees (nearest neighbor) to the starting trees were then included in each population. This involved moving progressively outward from the starting tree, so that the sample was expanded by adding more individuals but kept compact, until it included 100 mature individuals. This means that the diameters of the plots varied depending on the sclerocarya stocking density, i.e., variable plot size sampling.

Soil studies: The soil in each environmental condition (on-farm and wild areas) was characterized to get an overall status of soil basic properties. Soils were collected under and away (10 m) from 5 randomly selected *Sclerocarya birrea* trees per environmental condition. To do this, at each sampling location, a trench was dug to expose the soil horizon. Soil was collected at depths of 0-20 and 20-40 cm, excluding the top litter layer. This made a total of 40 samples per subspecies (10 samples under trees and away from trees, hence 20 samples from on-farm and wild environmental setting). The samples were put into a black polyethene bag with labels made by cutting pieces from cardboards indicating location and depth of sample collection included inside the bags. They were transported to Sokoine University Soil Science Department Laboratory for analysis. Properties analysed include pH (1:2.5 solid to liquid ratio), organic carbon, total nitrogen, available phosphorus and exchangeable bases (calcium, magnesium, potassium and sodium). Soil texture was analysed to classify the soils into various percentage proportions of sand, silt and clay.

Mode and intensity of regeneration: The area occupied by the 100 sclerocarya trees was divided into 20×20 m^2 grids. About 10% of the grids were randomly selected for regeneration study. A total of 26 and 3 plots in Holili on-farm and wild environments; 3 plots for each in Kiegea sites and 24 and 6 plots for each in on-farm and wild environments in Malinzanga were surveyed. The number of plots was a function of the area covered by the 100 trees. To assess the natural regeneration, the numbers of saplings and seedlings were enumerated in each of the selected sample grid. Seedlings (<1 m tall) and sapling (<10 cm dbh but ≥1 m tall) were categorized, as either arising from seed or stumps (coppices) or roots (sprouts).

Associated tree species: Associated neighboring woody species (≥10 cm dbh) encountered close (within 20 m radius) to each mapped sclerocarya tree was identified and enumerated. The data was used to generate absent-present species list number of associated species stems per hectare and diversity indices (Species Richness and Simpsons' Index) of the associated species. Species Richness is a measure of the number of different kinds of species present in a particular area. However, diversity depends not only on richness but also on evenness. Evenness compares the similarity of the population size of each of the species present. A community dominated by 1 or 2 species is considered to be less diverse than 1 in which several different species have a similar abundance. As species richness and evenness increase, so diversity increases. Simpson's Diversity Index is a measure of diversity which takes into account both richness and evenness. Simpson's Index (D) measures the probability that 2 individuals randomly selected from a sample will belong to the same species. The value of D ranges between 0 and 1 where 0 represents infinite diversity and 1 no diversity. That is the bigger the value of D, the lower the diversity. This is neither intuitive nor logical, so to get over this problem, D is sometimes subtracted from 1 to give Simpson's Index of Diversity 1-D.

RESULTS

Soil basic properties: There were in total 6 populations studied: 3 on-farm and 3 in the wild. There were differences in soil characteristics between the sites where each subspecies of *Sclerocarya* occur but also between Wild (W) and on-Farm (F) sites, as well as between soils collected under and away from the trees. The differences between soils under and away from trees indicate that *Sclerocarya birrea* influences soil properties, especially organic matter composition and soil pH. However confounding factors, such as presence or absence of other associated species and human practices may influence the findings. Results for various soil parameters analyzed in the laboratory are shown in Table 1and 2. For subspecies *caffra* habitat in Kiegea which is in central part of the country, soils under the trees were slightly acidic (pH6.75±0.10 to 6.35±0.27) whereas the habitat for subspecies *birrea* in Holili in the North and subspecies *multifoliolata* habitat in Malinzanga in the South of the country were slightly alkaline with pH8.40±0.32 to 7.03±0.16 and 7.64±0.1 to 7.06±0.05, respectively (Table 1). Away from the trees, the soils in Holili remained slightly alkaline while in Kiegea and Malinzanga the soils were slightly acidic (Table 2). The habitats for subspecies *birrea* and *multifoliolata* are both on a higher altitude at 879.81±3.54 and 954.20±1.07 m.a.s.l., respectively than the habitat for subspecies *caffra*, 520.43±1.07 m.a.s.l.

Mean and standard error for organic matter (%), total Nitrogen (N%), exchangeable bases (N, P, K, Na) and soil texture are in Table 1 and 2. Results show that soils in the wild population had more percent organic carbon than those on-farm with a slight exception of soils in Malinzanga. Distinctive pattern was missing in terms of percen total nitrogen and amount of exchangeable bases with the exception of potassium (K^+) which was observed to be higher in the area where subspecies *caffra* occurs. Therefore, the influence of *Sclerocarya birrea* on soil nutrients properties was not seen.

All soils had a higher percentage of sand. Population of subspecies *caffra* were found on soils with the highest sand proportion, 80% for wild environment and

Table 1: Soil properties for the 6 populations under both Wild (W) and on-Farm (F) conditions for samples collected under the trees

		Study subspecies/site					
		S. birrea		*S. caffra*		*S. multifoliolata*	
Items	Soil depth (cm)	Holili F	Holili W	Kiegea F	Kiegea W	Malinzanga F	Malinzanga W
Soil pH (1:2:5-H_2O)	0-20	8.40±0.32	7.34±0.09	6.75±0.10	7.44±0.12	7.64±0.16	7.20±0.12
	20-30	7.37±0.11	7.03±0.16	6.73±0.04	6.35±0.27	7.16±0.24	7.06±0.05
Organic carbon (%)	0-20	1.09±0.13	1.40±0.15	1.16±0.02	1.22±0.09	1.82±0.16	0.70±0.03
	20-30	0.67±0.18	0.97±0.24	1.14±0.01	0.93±0.06	0.54±0.07	0.93±0.11
Total nitrogen (%)	0-20	0.11±0.01	0.08±0.02	0.12±0.01	0.15±0.01	0.18±0.01	0.12±0.02
	20-30	0.13±0.01	0.14±0.01	0.12±0.01	0.14±0.01	0.06±0.03	0.08±0.01
Ca^{2+} (cmol$^+$ kg^{-1})	0-20	3.80±1.21	1.12±1.36	3.34±0.61	4.34±0.15	7.50±.0.27	0.94±0.02
	20-30	2.73±1.02	3.60±0.92	3.21±0.33	4.05±0.22	1.17±0.62	2.62±0.84
Mg^{2+} (cmol$^+$ kg^{-1})	0-20	1.47±0.71	1.28±0.54	2.39±0.28	2.36±0.15	2.93±0.33	2.39±0.71
	20-30	3.69±1.12	1.29±0.19	1.95±0.16	2.48±0.47	2.55±0.51	1.79±0.28
K^{1+} (cmol$^+$ kg^{-1})	0-20	0.13±0.03	0.30±0.01	0.25±0.0.1	0.72±0.03	0.09±0.01	0.32±0.01
	20-30	0.07±0.01	0.23±0.01	0.50±0.22	0.67±0.01	0.13±0.02	0.25±0.03
Na^{1+} (cmol$^+$ kg^{-1})	0-20	0.32±0.04	0.31±0.01	0.32±0.04	0.39±0.03	0.31±0.02	0.36±0.01
	20-30	0.84±0.08	0.27±0.01	0.29±0.05	0.37±0.01	0.27±0.04	0.35±0.05
Clay (%)	0-20	23.16±1.05	17.65±1.31	17.48±1.06	17.01±1.92	31.21±1.23	29.32±2.66
	20-30	27.23±2.11	15.14±1.26	15.29±1.11	15 27±0.81	19.06±2.17	19.46±1.74
Silt (%)	0-20	7.11±0.94	7.81±0.76	1.03±0.21	3.11±0.28	9.39±1.89	7.08±0.94
	20-30	9.47±1.23	9.38±0.75	1.62±0.33	5.42±1.07	5.72±0.30	5.25±2.08
Sand (%)	0-20	70.06±1.66	76±0.06	84.32±0.88	82.11±1.29	60.63±0.65	64.18±1.27
	20-30	64.17±2.91	76±0.32	82.03±1.08	78.39±0.99	76.14±1.08	76.43±0.82
USDA class		SCL	SL	LS	LS	SCL	SL

Table 2: Soil properties for the 6 populations under both Wild (W) and on-Farm (F) conditions for samples collected away from the tree

		Study subspecies/site					
		S. birrea		*S. caffra*		*S. multifoliolata*	
Items	Soil depth (cm)	Holili F	Holili W	Kiegea F	Kiegea W	Malinzanga F	Malinzanga W
Soil pH (1:2:5-H_2O)	0-20	7.04±0.61	7.42±0.21	6.48±0.06	6.81±0.33	6.35±0.48	6.11±0.04
	20-40	7.10±0.17	7.17±0.08	6.73±0.04	6.27±0.14	6.12±0.05	6.01±0.07
Organic carbon (%)	0-20	0.66±0.25	0.91±0.22	1.09±0.06	1.28±0.11	0.61±0.20	0.51±0.16
	20-40	0.61±0.08	0.59±0.24	0.86±0.05	0.75±0.37	0.44±0.12	0.51±0.07
Total nitrogen (%)	0-20	0.15±0.01	0.13±0.04	0.09±0.02	0.11±0.01	0.10±0.04	0.14±0.01
	20-40	0.12±0.02	0.10±0.01	0.09±0.01	0.09±0.02	0.11±0.07	0.09±0.01
Ca^{2+} (cmol$^+$ kg^{-1})	0-40	4.11±1.68	4.36±0.97	3.15±1.02	3.68±0.44	2.74±0.61	1.89±0.11
	20-40	3.54±0.82	2.86±1.73	3.06±0.61	3.39±0.27	2.21±0.33	1.09±0.28
Mg^{2+} (cmol$^+$ kg^{-1})	0-20	2.08±0.14	1.11±0.10	2.39±0.28	2.36±0.15	2.93±0.33	2.39±0.71
	20-40	1.96±0.15	1.35±0.11	2.16±0.21	2.48±0.47	2.55±0.51	1.79±0.28
K^{1+} (cmol$^+$ kg^{-1})	0-20	0.13±0.03	0.28±0.02	0.20±0.02	0.63±0.08	0.06±0.01	0.19±0.11
	20-40	0.15±0.01	0.31±0.01	0.33±0.06	0.34±0.15	0.04±0.01	0.08±0.01
Na^{1+} (cmol$^+$ kg^{-1})	0-20	0.37±0.02	0.22±0.04	0.14±0.01	0.45±0.13	0.19±0.05	0.42±0.08
	20-40	0.12±0.03	0.18±0.01	0.16±0.01	0.15±0.16	0.12±0.01	0.25±0.04
Clay (%)	0-20	26.09±0.85	22.14±1.31	16.11±2.11	17.27±2.02	28.06±0.77	30.91±0.47
	20-30	27.52±3.43	13.22±1.08	14.45±1.32	23 61±1.47	21.31±1.48	24.12±2.03
Silt (%)	0-20	6.32±0.43	8.05±0.31	3.14±0.17	2.92±0.11	12.02±0.36	10.53±1.76
	20-40	6.71±0.58	6.11±0.23	1.42±0.41	2.35±0.10	9.18±1.06	4.12±1.16
Sand (%)	0-20	76.11±2.07	71.93±0.27	86.13±0.09	86.13±0.56	64.03±1.19	72.39±1.43
	20-40	70.35±1.48	69±0.12	83.13±1.18	79.21±1.09	73.32±2.65	70.08±0.67
USDA class		SCL	SL	LS	LS	SCL	SL

83% sand for on-farm environment. Using USDA (US Department of Agriculture) classification, soils in Holili (subspecies *birrea*) and Malinzanga (subspecies *multifoliolata*); on-farm and wild soils resembled each other, i.e., sandy clay loam (scl) for on farms soils and sandy loamy (sl) for wild soils. The soils in Kiegea (subspecies *caffra*) were loamy sand (ls).

Natural regeneration of *Sclerocarya birrea*: *Sclerocarya birrea* regenerate both sexually and asexually through seeds and coppicing from stumps or sprouting from roots. Analysis of number of seedlings and saplings from seeds and vegetative regeneration (coppices and root sprouts) was conducted for each subspecies under both environmental conditions on-farm and wild conditions. With the exception of *S. caffra*, number of surviving seedlings and saplings was significantly higher under wild condition ($p<0.001$) from both seeds and vegetative regeneration as shown in Table 3. The on-farm environment for subspecies *caffra*

Table 3: Seed and vegetative regeneration per hectare for *Sclerocarya birrea* populations under 2 environmental settings

Population	Environment	Coppice seedlings	Coppice saplings	Seed seedlings	Seed saplings	Total
S. birrea	On-farm	8.65±3.080	1.92±1.330	2.88±1.600	8.65±3.080	22.12±5.250
	Wild	91.67±30.05	58.33±22.05	16.67±8.330	8.33±8.330	175.00±14.43
S. caffra	On-farm	216.67±44.10	75.00±14.43	83.33±22.05	41.67±16.67	416.67±91.67
	Wild	50.00±28.87	33.33±22.05	25.00±14.43	8.33±8.330	116.67±16.67
S. multifoliolata	On-farm	7.29±3.830	2.08±1.440	1.04±1.440	4.17±1.940	14.58±3.960
	Wild	41.67±15.37	20.83±13.57	12.50±13.57	8.33±5.270	83.33±12.36

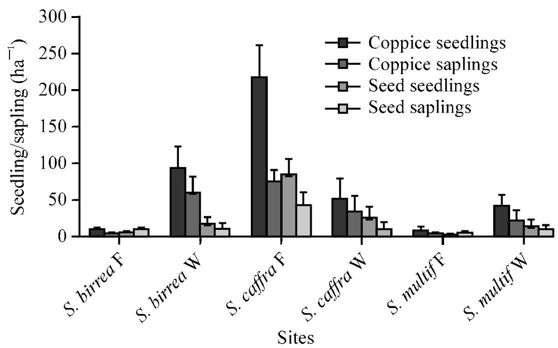

Fig. 1: Regeneration status of the subspecies of *Sclerocarya birrea* in numbers ha^{-1} under on-Farm (F) and Wild (W) environments

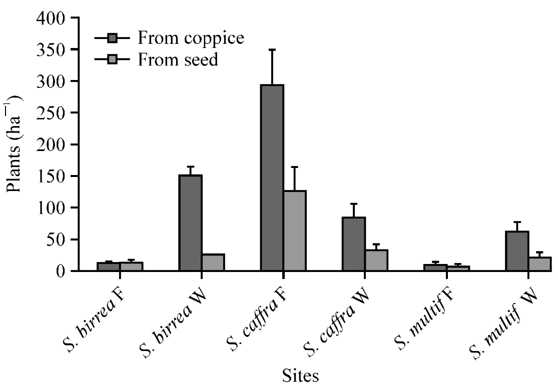

Fig. 2: Nature of natural regeneration for the subspecies of *Sclerocarya birrea* in each of on-Farm (F) and Wild (W) environments

had exceptionally the most abundant number of seedlings and saplings (416.67±91.67 seedlings and saplings ha^{-1}) while the on-farm environment for subspecies *multifoliolata* had the least seedlings and saplings abundance (14.58±3.96 plants ha^{-1}) (Fig. 1). Normally, researchers would expect more regenerants from the wild population (Gouwakinnou *et al*., 2009).

Analysis to compare the modes of regeneration showed that vegetative seedlings and saplings were more than those from seeds. The difference was similar for each subspecies with the exception of the on-farm population for *S. birrea* where regeneration from seeds (11.54±3.73) which was slightly more than from vegetative sources (10.58±3.15) but the difference was not significant (Fig. 2).

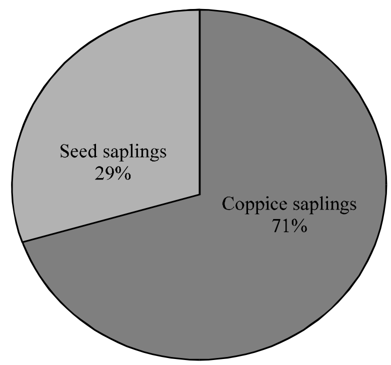

Fig. 3: Percentage of saplings originating from seeds and coppice for *Sclerocarya birrea* populations

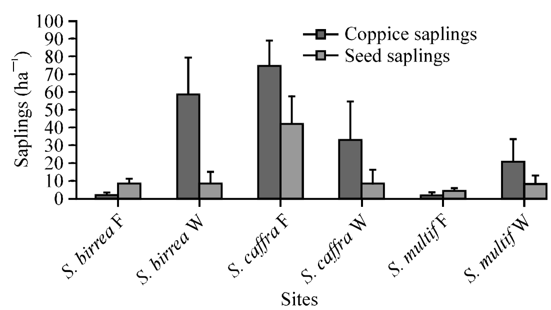

Fig. 4: Number of saplings ha^{-1} by source (seeds or coppices) for each of the subspecies of *Sclerocarya birrea*

Results show that there were more saplings from vegetative than seed regeneration. This indicates that stump coppicing and root sprouting contributes to the sapling and eventually adult population than seedling from seeds. The source of 71% of all saplings was vegetative from roots and stumps (Fig. 3). When the subspecies were compared against each other, the pattern was the same (more coppice and root sprout saplings than seed saplings) with the exception of on-farm population of *S. birrea* where vegetative saplings and seed saplings were 1.92±1.33 and 8.65±3.08 ha^{-1}, respectively and *S. multifoliolata* where vegetative saplings and seed saplings were 2.08±1.44 and 4.17±1.94 ha^{-1}, respectively. Figure 4 compare the 2 sources of saplings for each subspecies and the 2 environmental conditions. It implies

Table 4: Distribution of species associated with *Sclerocarya birrea* in Southern, East-Central and Northern parts of Tanzania

	S. multifoliolata		*S. caffra*		*S. birrea*	
Species	Wild	On-farm	Wild	On-farm	Wild	On-farm
Acacia brevispica				1		
Acacia gerrardii var. gerrardii			1	1		
Acacia mellifera sp. *melifera*			1			
Acacia nigrescens	1				1	1
Acacia nilotica					1	1
Acacia senegal			1	1		1
Acacia senegal var. leiorhachis	1	1				
Acacia tortilis sp. *tortilis*	1	1				1
Acacia xanthophloea	1					
Albizia amara			1	1	1	
Azanza garckeana					1	
Azadarachta indica	1					
Balanites aegyptiaca						1
Boscia salicifolia					1	1
Combretum apiculatum			1			
Combretum collinum sp. *binderanum*			1			
Combretum fragans				1		
Combretum molle			1	1	1	1
Combretum zeyheri	1	1				
Combretum zeylanica			1	1		
Cordyla densiflora	1					
Crossopteryx febrifuga					1	1
Dalbergia melanoxylon			1	1	1	1
Delonix elata	1					
Euphorbia tirucalli	1					
Grewia microcarpa				1		
Lannea fulva					1	1
Lannea humilis					1	1
Lannea stuhlmannii						
Leucaena glauca				1		
Lonchocarpus capassa	1	1				
Maerua angolensis				1		
Markhamia lutea	1					
Markhamia obtusifolia			1			
Pteleopis myrtifolia			1	1		
Steganotaenia araliacea	1					
Sterculia africana					1	
Strychnos henningsii			1			
Strychnos mitis	1					
Terminalia brownii					1	1
Terminalia sericea			1	1		
Terminalia spinosa						1
Vitex payos	1					
Vitex strickeri			1			
Xeroderris stuhlmannii	1		1	1		
Zanthoxylum chalybeum			1			
Ziziphus mucronata				1		

that for on-farm environment seed sources perform better than coppices or root sprouts with the exception of subspecies *caffra*.

Associated tree species of *Sclerocarya birrea*: Throughout the study sites 47 different species were found to be in association with *Sclerocarya birrea*. The abundance per hectare for each species is provided in Table 4. *Acacia mellifera* subspecies *binderanum* which was associated with subspecies *multifoliolata* and *Dalbegia melanoxylon* (the African black wood) which was associated with subspecies *birrea* were the most abundant species (saplings included) each with 126 trees ha^{-1}.

Table 5: Abundance and diversity of species associated with *Sclerocarya birrea* subspecies on-Farm (F) and Wild (W) settings

	S. multifoliolata		*S. caffra*		*S. birrea*	
Species	Wild	On-farm	Wild	On-farm	Wild	On-farm
Stems (ha^{-1})	668.00	322.00	447.00	29.00	518.00	45.00
Simpson's index (D)	0.11	0.12	0.11	0.03	0.12	0.08
Species richness	14.00	13.00	15.00	4.00	13.00	13.00

Species presence and absence pattern in the 3 populations is presented in Table 4. The genus *Acacia* was represented by many species and was found in all the three study subspecies, although through different species. There were no a single species found to be commonly associated with all the 3 subspecies. However, some species were found to associate both with subspecies *multifoliolata* and *caffra* while others were associated with subspecies *caffra* and *birrea*. However, there was no connectivity of distribution for *Acacia nigrescens* and *Acacia tortilis* sp. *tortilis*. The 2 species were found to associate with subspecies *multifoliolata* in the South and subspecies *birrea* North skipping subspecies *caffra* at the Eastern-Central part of the country.

The highest 4 and lowest 15 species richness for the associates was with subspecies *multifoliolata*. The populations of subspecies *multifoliolata* were the only ones which showed considerable difference in species richness between on-farm and wild conditions. For subspecies *birrea* and *caffra*, species richness were more or less the same between the different environmental conditions (Table 5) where wild population of subspecies *caffra* had a richness of 14 while all the other populations had a richness of 13. Sorensen's Index (D) showed that the associates for on-farm populations of *S. birrea* and *S. multifoliolata* were more diverse than the others with indices of 0.03 and 0.08, respectively. The populations with higher diversity had the least abundances (<50 individuals ha^{-1}) compared to the least diverse populations which had over 300 individuals ha^{-1}. The wild population associated to subspecies *caffra* had the highest abundance with 668 individuals ha^{-1}.

DISCUSSION

Soil basic properties: The soil classes, clay loam, sandy loam and loamy clay, observed across all the populations have been mentioned in other reports on soils found in *Sclerocarya birrea* habitats (Hall *et al*., 2002). The results shows low levels of organic matter content and exchangeable bases and total Nitrogen (N) ranging from 0.1-0.14% and are in line with other studies (Werger and Coetzee, 1978; Shackleton *et al*., 2000; Hall *et al*., 2002). Reports on studies from similar vegetations shows that top soil organic matter is about 1% and on average Ca^{2+} = 2076; Mg = 1.08; Potassium = 0.84 and Sodium = 0.08 (Stromgaard, 1989 ; Chidumayo, 1993). The absence of *Brachystegia* and *Julbernardia* species, as associates of *Sclerocarya birrea* in this study is related to the level of pH, slightly acidic and slightly alkaline (Chidumayo, 1993). Contrary to expectation, soils in on-farm condition for subspecies *multifoliolata* had more organic carbon than the respective wild condition. In the respective site, farmers do not burn the farm residues in this area and perhaps the reason for the high level of organic carbon on farms. Farmers in Kiegea (*S. caffra*) practices burning during land preparations while in Holili they do not burn but carryout brick curving/mining on farms subjecting the land to erosion by wind and runoff. Subspecies *birrea* and *multifoliolata* sites had soils which were slightly alkaline, especially under the trees and the results are in line with literature where it is pointed out that some sclerocarya populations in Tanzania are found in alkaline soils (Hall *et al*., 2002), although those studies were based on subspecies *caffra*. Since, soils under the trees were the ones with alkaline properties unlike those away the trees, it is possible that the alkaline conditions reported by Hall *et al*. (2002) are caused by the trees and not vice versa. The influence of sclerocarya on soil nutrients was not observed and this may be because researchers compared with samples around 10 m away from the trees which were randomly distributed and rather close to each other. Researchers suggest a comparison with samples taken from isolated trees and >10 m away from the particular trees.

Regeneration: Subspecies *caffra* populations showed the highest regeneration both from seeds and vegetative means compared to subspecies *birrea* and *multifoliolata*. This difference in regeneration vigour is directly proportional to the abundance of parent stock. In areas where there were more adult trees per hectare regeneration was also high. The number of adult stems per hectare is as shown in Table 6, in the results study. With exception of the site for subspecies *caffra*, regeneration was higher in the wild environment for both subspecies *birrea* and *multifoliolata* relative to the on-farm environment. Several to 100 of seedlings were observed under mother trees but almost all of them did not survive to the next year due to mortality. The cause of mortality of on-farm seedlings is mainly tillage or intentional removal by farmers. Mild fires in the wild could influence regeneration by breaking the hard marula seed nut, as well as initiating sprouting by damaging of roots, although this needs a long term monitoring study. A study on subspecies *birrea* found more germination on-farms but fewer saplings compared to the wild environment and attributed it to intentional removal by farmers to reduce competition with cultivated crops (Gouwakinnou *et al*., 2009). On farm population of subspecies *birrea* had a slightly high proportion of regeneration from seeds. Gouwakinnou *et al*. (2009) reported more favourable seed germination on farmlands in Benin and attributed it to damage of seeds in the wild. Sexually reproduced seedling are important in the future because farmers can use them as root stock for grafting and therefore should be encouraged to retain them.

Table 6: Stand population density in stems ha^{-1} for the different subspecies and site condition

Population	Site condition	Sampled area (ha)	Stems (ha^{-1})
S. birrea	On-farm	66.15	1.5
	Wild	5.88	17.0
S. caffra	On-farm	4.91	20.4
	Wild	6.83	14.6
S. multifoliolata	On-farm	58.79	1.7
	Wild	11.70	8.5

Several factors are reported to influence survival and proliferation of young plants in African vegetations. Seeds and seedlings suffer high rates of mortality from various environmental problems, such as grazing animals, fires, uprooting during farming, fungi, insect pests and diseases. Janzen and Vazquez-Yanes (1991) reports that on tropical mainland especially in the dry forests, >90% of all tree species have >50% of their seeds killed by allelopathy, predators or fruit fungi between fruit set and seed germination. After germination while young the seedling will need to survive destruction from fire and grazing animals. To be able to do this, it needs a strong underground food reserve to enable vigorous resprouting when favourable conditions returns. Under these conditions saplings are better equipped due to well developed root systems of the parent tree.

A peculiar trend was observed for on-farm populations of subspecies *birrea* and *multifoliolata* succession of seedlings to saplings generation. The population of saplings from seeds was 4 times higher than that of their respective seedlings. A normal population structure is the 1 which shows an increasing continuum of abundance from seedling through saplings to adult size classes (Enquist and Niklas, 2001; Mwang'ingo, 2002; Rubin *et al*., 2006). The observed situation in this study was perhaps due to low survival of seedlings plus the longer time spent by the marula trees at the sapling state probably due to disturbances from browsing and tillage. The contribution to mature stand of marula trees was more from coppice regeneration because the abundance of coppice saplings was higher than seed saplings. This is also attributed to the higher capacity of reserving food in the roots compared to seedlings fresh from seeds. Saplings have an ability to re-sprout and grow faster, as well as manage some competition from other young stand generation.

Associated vegetation: Populations studied were located North towards the Sudano region, South towards the Zambezian region and central probably the interface of the Sudano-Zambezian vegetation regions. Species associates were different between the North and South location but associates of subspecies *caffra* at the centre of the country comprised of a mixture of associates of subspecies *birrea* from Northern Tanzania and *multifoliolata* from Southern Tanzania.

Out of the 16 species identified as associates of *birrea* in the North, 8 of them appear in the compiled list of associates of *birrea* in relation to drainage by Hall *et al*. (2002). The species are *Acacia nilotica*, *Albizia amara*, *Combretum molle*, *Balanites egyptiaca*, *Boscia salicifolia*, *Dalbegia melanoxylon*, *Lannea humillis* and *Terminalia brownii*. Associates of subspecies *caffra* identified at the central site were 23 and only 7 of them are listed in the compilation by Hall *et al.* (2002). Also, 5 species associated with subspecies *multifoliolata* in the South are known to be associates with subspecies *caffra* according to Hall *et al*. (2002). These are *Acacia nigrescens*, *Acacia tortolis*, *Lonchocarpus capassa*, *Xeroderris stuhmanii* and *Combretum zeyheri*. About 2 associate species of *Multifoliolata*, *Combretum zeyheri* and *Lannea humilis* in this study are also found in the compilation by Hall *et al*. (2002). Sharing of associates between the subspecies suggests a possibility of the species sharing habitats in Tanzania indicating a potential for exceptionally high genetic diversity. Kadu *et al*. (2006) found genetically distant characteristics between geographically proximate trees in Tanzania, more than in any of the other 6 countries he collected material for analysis. Conservation and management efforts need to be improved in Tanzania, since it may be a source of important and unique genotype for domestication and *ex situ* conservation in gene banks. This has also been suggested in the past (Hall *et al*., 2002; Kadu *et al*., 2006; Muok *et al*., 2007).

CONCLUSION

The soil classes, clay loam, sandy loam and loamy clay, observed across all the populations have been mentioned in other reports on soils found in *Sclerocarya birrea* habitats (Hall *et al*., 2002). The results shows low levels of organic matter content and exchangeable bases and total Nitrogen (N) ranging from 0.1-0.14% and are in line with other reports (Werger and Coetzee, 1978; Shackleton *et al*., 2000; Hall *et al*., 2002). There was no observed influence (probably with the exception of alkalinity) of *Sclerocarya birrea* trees on soil properties and in future sampling of soils away from the trees should be taken from a much distant points (15-20 m).

The present study found that regeneration from stem coppicing and root sprouting was more dominant than that from seeds. This suggestion is based on the assessment of the surviving young plants and should not imply less germination potential of marula seeds. This is because under mother trees several seeds were observed during the rain seasons but most did not survive to the next season, probably due to kill from weeding or drought. The contribution to mature stand of *Sclerocarya birrea* is thus more from vegetative regeneration than regeneration from seeds. To improve survival of seedlings from seeds and hence improve cross-breeding, management efforts need to step up to avoid damage due to farming practices, fire, drought, grazing and diseases. Sexually produced seedlings are also important to provide root-stock for grafting of marula.

RECOMMENDATIONS

Subspecies *caffra* populations showed the highest regeneration both from seeds and vegetative means compared to subspecies *birrea* and *multifoliolata*. This difference in regeneration vigour was directly proportional to the abundance of parent stock. In areas where there were more adult trees per hectare regeneration was also high. Therefore with the exception of the site for subspecies *caffra*, regeneration was higher in the wild environment for both subspecies birrea and *multifoliolata* relative to the on farm environment.

The species associated by the subspecies were overlapping to at least 2 subspecies. Associates of subspecies *caffra* comprised of a mixture of associates of subspecies *birrea* and *multifoliolata*. Sharing of associates between the subspecies suggests a possibility of the species sharing habitats in Tanzania indicating a potential for exceptionally high genetic diversity and thus calling for enhanced conservation efforts of this rather probable unique gene pool.

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