JUNE 2014

VOLUME 83 (2)

TANZANIA JOURNAL OF FORESTRY and NATURE CONSERVATION

ISSN 1956 – 0315

Published by
Faculty of Forestry and Nature Conservation
Sokoine University of Agriculture
Morogoro, Tanzania

Tanzania Journal of Forestry and Nature Conservation, Volume 83(2), June 2014

COMPARISON OF THE SUBSPECIES OF *SCLEROCARYA BIRREA*BY SEX AND ENVIRONMENT

Woiso[1]*, D. A., Agea[2], J. A., Okia[2], C. A., Kimondo[3], J. M., Abdallah[4], J.M., Shemdoe[5], R. S., Mwang'ingo[1], P. and Teklehaimanot[6], Z.

*Corresponding author: email - dinusandrew@yahoo.com
[1]Department of Biological Science, Sokoine University of Agriculture, P. O. Box 3038, Morogoro, Tanzania
[2]College of Agriculture and Environmental Sciences, Makerere University, P.O.Box 7062, Kampala, Uganda
[3]Kenya Forestry Research Institute, P.O Box 20412-00200, Nairobi, Kenya
[4]Department of Forest Economics, Sokoine University of Agriculture, P. O. Box 3010, Morogoro, Tanzania
[5]Institute of Human Settlements, Ardhi University, P. O. Box 35176, Dar es Salaam, Tanzania
[6]School of Environment, Natural Resources and Geography, Bangor University, Bangor, Gywnedd, LL57 2UW, UK

ABSTRACT

A comparison of stand parameters between wild and on farm populations of the 3 subspecies of *Sclerocarya birrea* was done. Using plot-less sampling technique, 100 trees from six populations were measured for diameter at breast height (Dbh), branching height, height and crown diameter. There was significant (p<0.001) difference in Dbh, branching height and tree height between the three subspecies and between the populations. For all subspecies and populations, male trees were taller than female trees although the difference was not significant. While *S. birrea* subspecies *birrea* and *caffra* had trees in the wild taller than those on farm, the opposite was observed among trees of *S. birrea* subspecies *multifoliolata*. The mean crown sizes of male and female trees differed significantly (p<0.001) between the three subspecies and within a population. There were positive correlations (p> 50) between altitude and tree diameter, branching height, tree-height and crown diameter. Tree size was not found to increase due to farmers' selection pressure and farming practices in Tanzania, probably because they are not retained purposely for their fruits as is the case in other countries in southern Africa.

Key words: *Sclerocarya birrea*, Tanzania, population, habitat, gender

INTRODUCTION

Out of the 250,000 higher plant species in the world, less than 1% has been domesticated as food plants and of these, about 50% are fruit trees (Leakey and Tomich 1999). In Tanzania, about 326 indigenous plants have been described as edible (Ruffo *et al.* 2002) but few, if any of these species have been domesticated through deliberate tree improvement programmes (Akinnifesi *et al.* 2006). Domestication aims at promoting the cultivation of indigenous fruit trees (IFTs) with economic potential as new cash crops, and provides incentive to subsistence farmers to plant trees that contribute towards achieving the Millennium Development Goals (MDGs) of poverty reduction and enhancement of food and nutritional security (Leakey *et al.* 2005a).

Sclerocarya birrea (A. Rich.) Hochstis a dioecious plant with three subspecies namely *birrea*, *caffra* and *multifoliolata*. The occurrence of these subspecies is restricted, with its highest diversity in Tanzania which is the only country where all the three subspecies co-exist (Kokwaro and Gillet 1980; Shackleton 2002; Kaduet *et al.* 2007; Teklehaimanot 2008). Ethno botanical studies carried out in the late 1980s and early 1990s identified *S. birrea* as one of the five top priority woodland tree species important for research and development in Africa (Magembe and

Seyani 1992). A recent identification of priority wild fruit tree species for domestication in East Africa ranked *S. birrea* as number one in Tanzania (Teklehaimanot 2005).

To date, research on *S. birrea* in Tanzania is relatively limited despite being the most diverse area for the species. Elsewhere in Eastern and Southern Africa, studies on domestication, growth, genetic diversity, fruit production, phenology, use, post-processing waste handling and traditional knowledge are reported (Khonje *et al.* 1999; Shackleton *et al.* 2002, 2008; Akinnifesi 2004, 2006; Leakey *et al.* 2005b; Karin and Nontokozo 2006; Kadu *et al.* 2007; Muok *et al.* 2007; Kleiman *et al.* 2008; Hillman *et al.* 2008; Mghomba 2008; Teklehaimanot 2008; Moyo *et al.* 2010; Ndifossap *et al.* 2010).

Despite *S. birrea* being a top ranking wild fruit tree for domestication in Tanzania, it remains scantly studied. The species is important because of its potential as a cash crop for its fruit can be processed into numerous commercial products already in the market regionally and globally (Akinnifesi 2008). Tanzania is privileged to have all the three subspecies available as field study material for comparison. Understanding stand parameters of the subspecies/populations can shed light on important areas for germplasm collection and tree improvement. According to Hall *et al.* (2002), population studies on *S. birrea* are important, for among other reasons, understanding the male to female ratio which is essential in understanding its pollination success and also as a management tool for accelerated domestication.

It is noteworthy that although inventory studies provide crucial information and tool for sustainable management of any species, *S. birrea* remains little inventoried not only in Tanzania, but also across its ecological range (Hall *et al.* 2002; Shackleton 2002; Chirwa & Akinnifesi 2008). Most of the inventory information available is largely based on records of occurrence or wholesome vegetation assessments (Hall *et al.* 2002; Shackleton *et al.* 2003). Few inventories of *S. birrea* subspecies *caffra* in South Africa and Namibia (DFID 2003; Nghitoolwa *et al.* 2003) and *S. birrea* subspecies *birrea* in Benin (Gouwakinnou *et al.* 2009) have been reported but no formal inventory has ever been carried out for *S. birrea* subspecies *multifoliolata.* Against this background, this study was carried out to compare stand parameters for the three subspecies growing on farm and in the wild environmental setting as well as male and female trees. In this study, environmental setting refers to on farm environment where farming activities take place and wild environment where no farming activity is taking place. The parameters studied were diameter at breast height (Dbh), branching height, tree height (to the top of crown) and crown size. Spatial distribution by sex and population was also studied.

MATERIALS AND METHODS

Study site

Three sites namely Holili in Rombo district, Kilimanjaro region, Kiegeya in Morogoro urban district, Morogoro region and Malinzanga in Iringa rural district, Iringa region were used (Figure 1). The three sites are located at least 400 km and at most 1100km from each other by road. The sites were selected in such a way that each covered one of the three subspecies of *S. birrea*. *S. birrea* subspecies *caffra* was found in the northern part of the country (Holili); *S. birrea* subspecies *birrea* in the east-central part of the country (Kiegeya) and *S. birrea* subspecies *multifoliolata* in the southern part of the country (Malinzanga).

Holili lies at latitudes 3° $21^{'}3$ $6^{''}$S and longitude $37^{\circ}36^{'}$ 43"E. The mean rainfall ranges from 500mm in the lowlands to over 2000mm in areas over 1600 m.a.s.l. Mean temperature is 21.7^{o}C but ranges from 10.2^{o}C to 43.7^{o}C. The hot season lasts between October and March. Holili (part of the Taita-Taveta vegetation) is covered by mainly arid and semi-arid land vegetation, grassland, woodlands and shrub lands with savanna species (*Acacia sp, Commiphora sp*.). Where the groundwater table is high, riverine/permanent wetland vegetation types occur with *Acacia xanthophloea, Milicia excelsa, Albiziasp, Ficus sp.* etc. (Krhoda 1998).

Malinzanga village is located near Ruaha National Park in Iringa region in the Southern highlands zone of Tanzania. The village is located at latitude $6^{\circ}41'24''$ S and longitude $37^{\circ}44'\ 53''$ E. It receives a mean annual rainfall of 650mm with mean temperatures ranging from 8^{o}C to 30^{o}C. May to September is the driest period in the area. The vegetation of Malinzanga site is dominated by *Acacia* woodland/bushland, *Acacia/Commiphora* bushland, *Brachystegia* woodland, *Commiphora–Combretum* bushland, *Acacia tortilis* thorn scrub, and *Acacia* induced woodland modified by human activities, *Hyphaene* and *Acacia tortilis* riparian vegetation, *Combretum* woodland and riparian *Acacia-Ficus* vegetation (MBOMIPA 2006)

Kiegeya is a village located approximately 20 km north of Morogoro municipality. The village is located at latitude $7^{\circ}35'\ 45''$S and longitude $34^{\circ}59'\ 20''$E. The mean annual rainfall ranges from 600mm in the lowlands to 1200mm in the highlands. Mean temperatures vary greatly with altitude ranging from 17.5^{o}C in the high elevations to 31.3^{o}C in river valleys. Kiegeya has fairly open woodland, though considerable parts of it, particularly on ridges and in valleys, would be better classified as wooded grassland. *Brachystegia, Isoberlinia* and elements of the miombo are present, but admixed with species more characteristic of Gillman's bushland and thicket. Many of the trees are leafless during the dry season but other species lose their leaves until the flush begins, and the thickets contain a number of evergreen elements. Fires burn the grasses, usually in June, July and August, but the fires being early, tend to be very patchy, with many areas left unburnt (Welch 1960).

.

Sampling and data collection

This study was comparative by design. At each of the study villages, *S. birrea* trees were sampled in two environmental settings, i.e. an on farm population and a wild population. At each environmental setting, one sampling plot was established for survey, hence two plots per village and six plots for the whole study. In selecting a sample, a variable-size plot sampling which is also referred to as nearest neighbour tree technique or plot-less sampling as described by Cottam and Curtis (1956) and Williams *et al.* (1969) was adopted. The method is believed to suit various field conditions and specific objectives (Ludwig and Reynolds 1988; Sparks *et al.* 2002; Sheil *et al.* 2003). It is also superior in saving time and money while attaining higher levels of accuracy especially for sparsely distributed trees with Dbh of ≥ 10 cm. Even in populations which are unevenly scattered, plot-less sampling remains valuable and biases are insignificant (Lessard *et al.* 1994).

To arrive at a study sample in each population, a mature *Sclerocarya* tree (≥ 10 cm Dbh) was first located roughly at the centre of the selected variable size plot. From this tree, progressive outward movement was made by adding more individuals but keeping the sample compact until 100 individuals were included. For each tree included, Dbh, height to the top of crown and height to the first branch were measured. Crown diameter was derived by measuring two diameters perpendicular to each other through the crown's vertical projection.

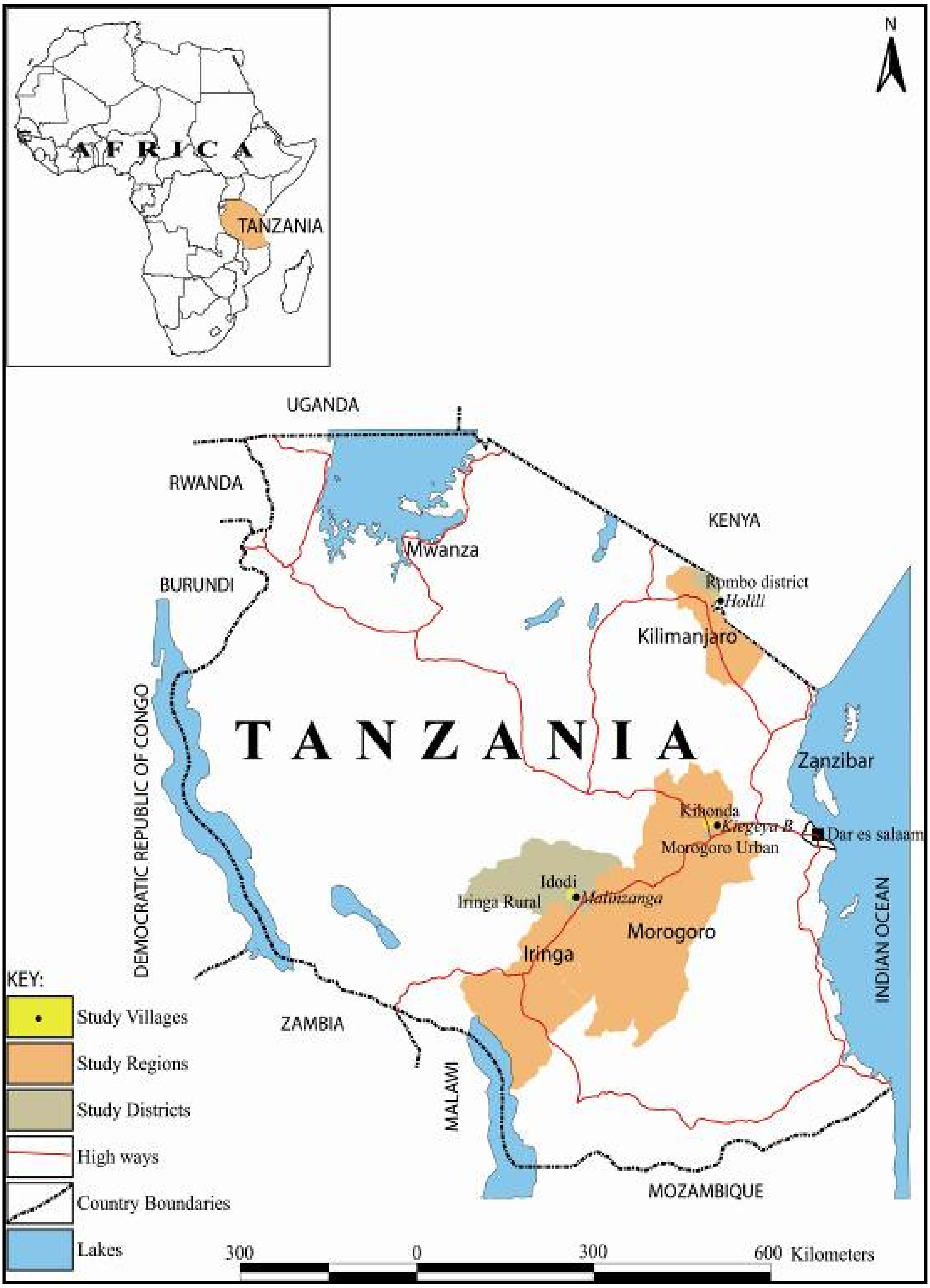


Figure 1: Map of Tanzania showing location of the three study sites: Holili, Kiegea and Malinzanga villages.

The mean of the two crown measurements was then used as crown diameter value for each tree. Also, the studied trees were identified in terms of sex. Trees which produced fruits were regarded as female and those without fruits regarded as males. Female trees may not fruit in certain seasons for a variety of reasons. To deal with this irregularity, the sex of the study trees was assessed for 3 consecutive fruiting seasons.

Data analysis

Excel Spread Sheet and Minitab were used to process and analyze the data into graphs and tables. Dbh was summarized into eight classes (10.0-20.0; 20.1-30.0; 30.1-40.0; 40.1-50.0; 50.1-60.0; 60.1-70.0; 70.1-80.0; >80.0 cm); branching height into five classes (<1.5; 1.6-3.0; 3.1-4.5; 4.6-5.0; 5.1-7.5 m); tree height into four classes (<5.0; 5.1-10.0; 10.1-15.0; 15.1-20.0 m); and crown diameter into seven classes (<2.0; 2.1-5.0; 5.1-8.0; 8.1-11.0; 11.1-14.0; 14.1-17.0; >17.0 m).

The sizes of the tree parts were described using mean and standard error of the mean. Comparison of the subspecies was done using one-way ANOVA while independent t-test was used to test differences between the on farm and wild populations and tree sex. Correlation was used to examine the relationship between diameter, height and crown-size. The sites for different subspecies were in different locations, but comparison was done assuming that the biophysical environments for the species have a lot of similarities. The similarities were assumed based on studies which report that the species is found in dry, low rainfall and poor-rocky soil areas (Hall *et al.* 2002).

The nearest neighbour distance (meters) for each pair of trees was calculated using Arc View. To determine the tree distribution pattern, the Clark and Evans (1954) technique was used. The technique assumes that in a population with N individuals with known density d and nearest neighbour distance r from pair or neighbour trees, the mean observed distance is represented as $ro = \sum r/N$. The mean distance which would be expected if the population was randomly distributed, re, has a value equal to $re = 1/2\sqrt{d}$. The degree to which the observed distribution approaches or departs from random expectation with respect to the distance to nearest neighbour is expressed as a ratio $R = ro/re$. According to Clark and Evans (1954), R has a limited range: $0<R<2.1491$. When $R = 0$, there is a situation of complete aggregation; when $R = 2.1491$, there is completely uniform distribution pattern and when $R = 1$, the distribution pattern of individuals is said to be random.

RESULTS

Tree size parameters

Diameter at breast height (Dbh)

The Dbh of the sampled trees varied significantly ($p<0.001$) between subspecies and environments (Table 1a). Overall, the mean diameter was 32.87 ± 0.67, 28.87 ± 0.70 and 39.96 ± 1.27 cm for *S. birrea* subspecies *birrea*, *S. birrea* subspecies *caffra* and *S. birrea* subspecies *multifoliolata* respectively. For on farm populations, Dbh ranged from 11 to 122 cm while among the wild populations, it ranged from 10 to 92 cm. The mean Dbh of on farm and wild populations of the subspecies *S. birrea* is shown in Table 1b. For both environments, subspecies *S. birrea* subspecies *multifoliolata* had the highest mean Dbh. *S. birrea* subspecies *multifoliolata* and *S. birrea* subspecies *birrea* growing on farm had higher mean Dbh of 48.64 ± 1.88 cm and 37.56 ± 0.75 cm respectively compared to their respective wild trees which had mean Dbh of 31.29 ± 1.19 cm and 28.18 ± 0.89 cm respectively. In the case of *S. birrea* subspecies *caffra*, wild populations had higher mean Dbh (30.08 ± 0.84 cm) than on farm trees (27.66 ± 1.10 cm). Independent t-test showed significant ($p<0.001$) difference in Dbh between on farm and wild populations. Further analysis showed that most of the trees on farm were in the Dbh class of 20 to 50 cm while most of the trees in the wild fell in the Dbh class of 10 and 40 cm (Table 1c). Results also showed that male individuals had larger Dbh than female trees in almost all Dbh classes for each subspecies. There was a significant ($p < 0.001$) difference between male and female trees in terms of Dbh in all subspecies.

Table 1a: Comparison of stand parameters between the different subspecies of *Sclerocarya birrea*

Stand parameters	*S. birrea*	*S. caffra*	*S. multifoliolata*
Tree diameter (cm±se)	32.87±0.67	28.89±0.70	39.96±1.27
Branching height (m±se)	2.73±0.07	2.69±0.07	2.61±0.08
Tree height (m±se)	7.02±0.16	7.35±0.20	9.06±0.20
Crown diameter (m±se)	8.52±0.24	5.96±0.20	9.91±0.26

Table 1b: Comparison of stand parameters between on farm and wild environments for all subspecies

Site/sub-species	**Mean** ±SE			
	Diameter (cm)	Branching height (m)	Height (m)	Crown diameter (m)
S. multifoliolata farm	48.64±1.88	2.91±0.12	10.07±0.27	10.67±0.34
S. multifoliolata wild	31.29±1.19	2.31±0.11	8.05±0.25	9.52±0.51
S. caffra farm	27.66±1.10	2.33±0.09	5.60±0.20	5.51±0.29
S. caffra wild	30.08±0.84	3.06±0.10	9.10±0.24	6.42±0.26
S. birrea farm	37.56±0.75	2.47±0.08	6.72±0.19	9.10±0.28
S. birrea wild	28.18±0.89	2.99±0.10	7.31±0.25	7.95±0.38

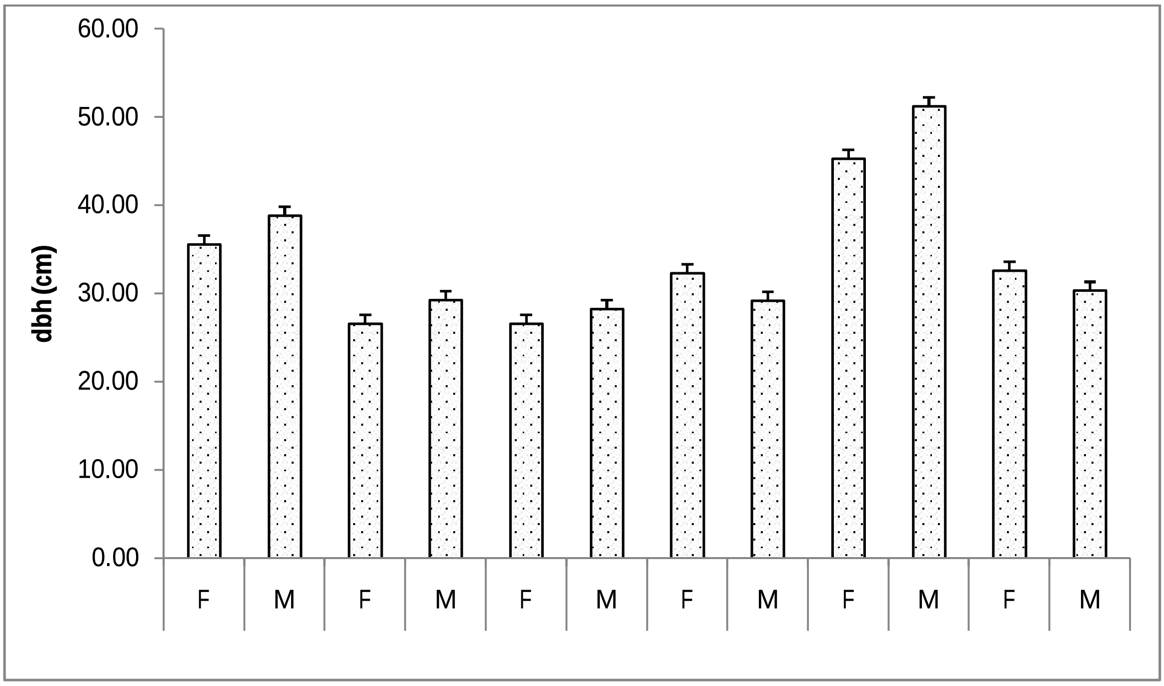


Figure 2: Mean diameter at breast height (Dbh) for on farm (1) and wild (2) female (F) and male (M) trees each of the three subspecies of *Sclerocarya birrea*

Branching height
Wild populations of *S. birrea* subspecies *birrea* and *S. birrea* subspecies *caffra* had higher mean branching heights of 2.99±0.10and 3.06±0.10 m respectively than their corresponding on farm populations which had mean branching heights of 2.47±0.08 &2.33±0.09 m respectively (Table 1 b). On farm *S. birrea* subspecies *multifoliolata* populations branched at a mean higher height of 2.91 ± 0.12 m than those of the corresponding wild populations (mean of 2.31 ± 0.11 m).

Table 1c: Dbh classes by sex, sub-species and population (M: *multifoliolata*, B: *birrea*, C: *caffra*, FP: on farm population and WP: Wild population)

	Number of Females						Number of Males					
Dbh (cm)	MFP	MWP	BFP	BWP	CFP	CWP	MFP	MWP	BFP	BWP	CFP	CWP
<10	0	0	0	0	0	0	0	1	0	0	0	0
10.1-20.0	0	6	10	1	1	6	1	11	15	11	0	11
20.1-30.0	5	10	16	10	8	23	5	21	27	24	7	26
30.1-40.0	11	14	9	14	22	12	10	20	11	33	30	13
40.1-50.0	17	8	3	1	8	1	18	5	3	5	20	6
50.1-60.0	8	1	1	0	2	0	7	2	3	0	2	2
60.1-70.0	1	0	0	1	0	0	3	0	2	0	0	0
70.1-80.0	1	0	0	0	0	0	6	0	0	0	0	0
>80	2	0	0	0	0	0	5	1	0	0	0	0

Comparison of the three subspecies (Table 1a) shows that *S. birrea* subspecies *birrea* branched at the highest point (2.73 ± 0.07 m). The shortest branching height (2.61 ± 0.08 m) was observed in *S. birrea* subspecies *multifoliolata*. There was a significant ($p<0.001$) difference in mean branching height between on farm and wild populations for each subspecies. However, there was no significant difference in the branching heights between the three subspecies.

Assessment of branching height by sex showed that with the exception of *S. birrea* subspecies *birrea*, female trees had longer clear boles than male trees (Figure 3). Female trees of S. *birrea* subspecies *multifoliolata* and S. *caffra* had higher mean branching height (2.70±0.14 and 2.75±0.12 m respectively). Female trees of *S. birrea* subspecies *birrea* had smaller mean branching height (2.65± 0.10 m) than male trees.The most dominant branching height class was 1.6 – 3.0m followed by 3.1-4.5m for all subspecies (Table 1d). *S. birrea* subspecies *multifoliolata* had trees in all branching height classes while *S. birrea* subspecies *birrea* did not have any trees with branching height less than 1.5 m (Table 1d). *S. birrea* subspecies *caffra* also had trees in all branching height classes as shown in Table 1d.

.

Tree height

Generally, all the three subspecies had individual tree heights ranging from 5 to 20 m (Table 1e). Majority of *S. birrea* subspecies *multifoliolata* trees had heights ranging from 10 to 15 m followed by those between 15 and 20m. For *S.birrea* subspecies *caffra*, most trees were in the height class of <5m and 10 – 15 m. Most of the *S. birrea* subspecies *birrea* trees in the height class of 5 – 10 m and were distributed more or less evenly by sex and environmental setting. The minimum and maximum heights were2.5m and 16.3m for *S. birrea* subspecies *birrea*; 3m and 15.8m for *S. birrea* subspecies *caffra*; and 2mand 17.2m for *S. birrea* subspecies *multifoliolata* respectively.

Table 1a and 1b shows the mean and standard error of tree height from the two environmental settings, i.e. on farm and wild settings. Mean height was highest for *S. birrea* subspecies *multifoliolata* (9.06±0.20 m) followed by *S. birrea* subspecies *caffra* (7.35±0.20 m) while *S. birrea* subspecies *birrea* had the least mean height of 7.02±0.16 m. Wild populations of *S. birrea* subspecies *caffra* and *birrea* had higher mean tree heights (9.10±0.24 m and 7.31±0.25 m respectively) than their respective populations growing on farm which had mean heights of 5.60±0.20 m and 6.72±0.19 m respectively

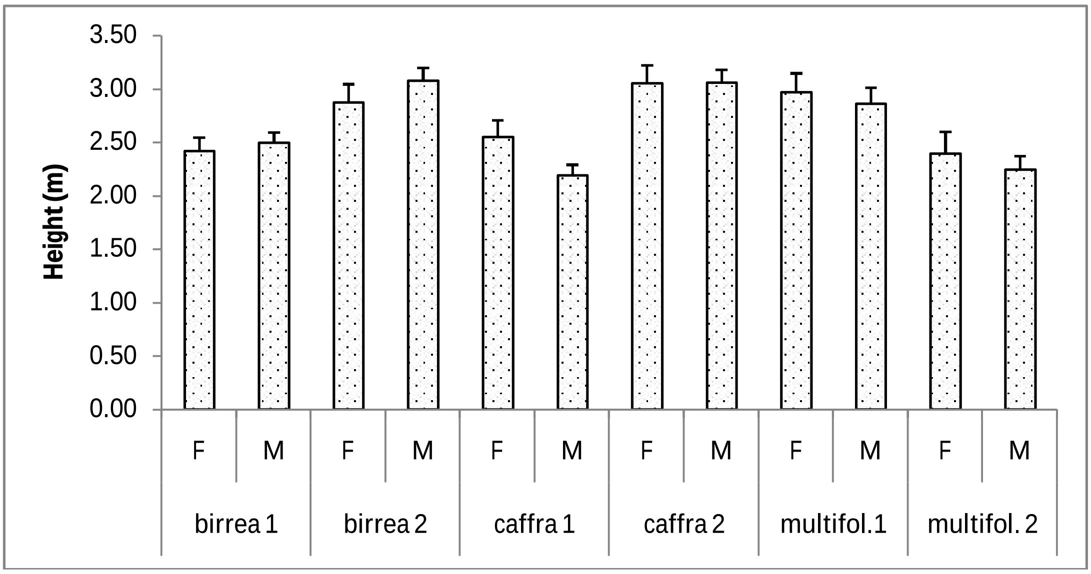


Figure 3: Mean and error bars of branching height for males (M) and female (F) trees on farm (1) and in the wild (2) environments for the subspecies *birrea*

Table 1d: Branching height by sex, sub-species and population (M:*multifoliolata*, B: *birrea*, C: *caffra*, FP: on farm population and WP: Wild population)

	Number of Females						Number of Males					
Br.ht (m)	MFP	MWP	BFP	BWP	CFP	CWP	M FP	M WP	BFP	BWP	CFP	CWP
>1.5	3	9	2	0	0	0	2	11	7	1	0	0
1.6-3.0	24	20	27	18	35	26	34	40	46	46	51	31
3.1-4.5	11	7	9	7	5	13	10	8	8	14	7	19
4.6-5.0	4	2	0	1	1	1	7	2	0	9	1	8
5.1-7.5	3	1	1	1	0	2	2	0	0	3	0	0

For *S. birrea* subspecies *multifoliolata,* the on farm trees had higher mean height (10.07±0.27 m) than the trees in the wild (8.05±0.25 m). ANOVA and t-test confirmed that with the exception of *S. birrea* subspecies *birrea*, the differences between mean tree heights were significant ($p<0.001$) between the subspecies and between the two environmental settings. For all subspecies and environments, male trees were taller (7.92±0.14m) than female trees (7.63±0.18m) although the difference was not significant.

Crown diameter

Generally, most of the sampled trees fell under crown diameter-class of 2 to 14 m (Table 1f). While *S. birrea* subspecies *multifoliolata* had many trees with big (> 11m) crown diameter, *S. birrea* subspecies *caffra* had few trees with crown size in this category. Many trees of *S. birrea* subspecies *caffra* had small (<5m) crown diameter. The population of *S. birrea* subspecies *birrea* had a generally normal distribution of crown diameter compared to the other subspecies. Most of its trees had crown diameters falling in the 5–11 m class (Figure 5). Mean crown diameter was 8.52±0.24 m for *S. birrea* subspecies *birrea*, 5.96±0.20 m for *S. birrea* subspecies *caffra* and 9.91±0.26 m for *S. birrea* subspecies *multifoliolata* (Table 1a and 1b). *S. birrea* subspecies *multifoliolata* trees had the largest crown diameter while *S. birrea* subspecies *caffra* had the smallest crown diameter.

Table 1e: Total height by sex, sub-species and population (M: *multifoliolata*, B: *birrea*, C: *caffra*, FP: on farm population and WP: Wild population)

	Number of Females						Number of Males					
Height (m)	MFP	MWP	BFP	BWP	CFP	CWP	MFP	MWP	BFP	B WP	CFP	CWP
<5	1	2	21	0	8	5	0	5	26	2	4	5
5.1-10.0	23	28	17	21	30	35	27	44	33	48	52	45
10.1-15.0	19	8	1	6	3	2	24	11	2	22	3	6
15.1-20.0	2	1	0	0	0	0	4	1	0	1	0	2

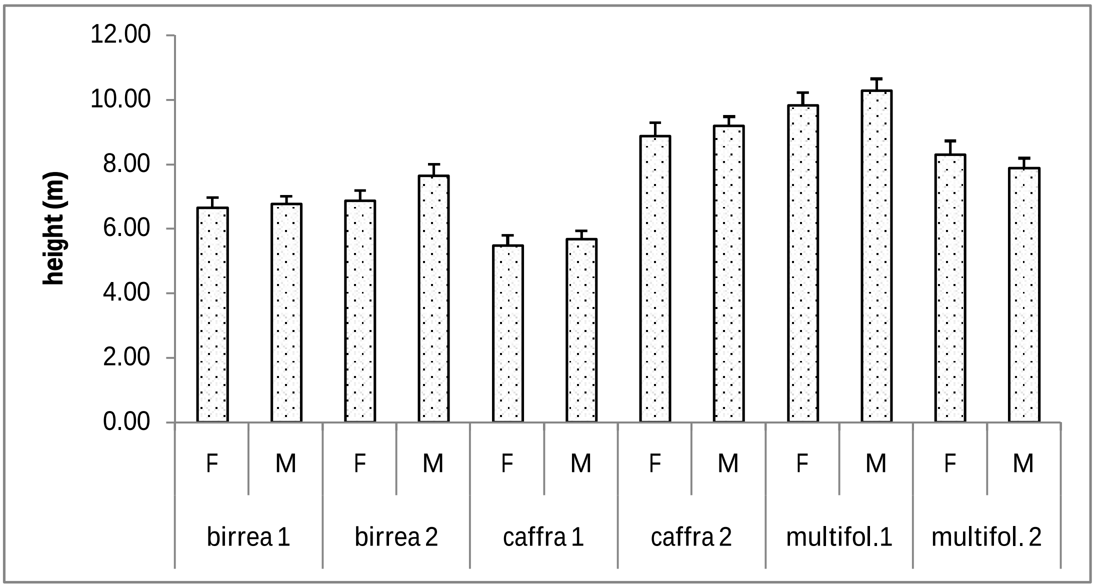


Figure 4: Mean and error bars of tree height for males (M) and female (F) trees on farm (1) and in the wild (2) environments for the subspecies *birrea*

On farm populations of *S. birrea* subspecies *multifoliolata* and *birrea* had larger mean crown diameters (10.67±0.34 m and 9.10±0.28 m respectively) than their respective wild populations (9.52±0.51 m and 7.95±0.38 m respectively) while wild populations of *S. birrea* subspecies *caffra* had larger mean crown diameter (6.42±0.26 m) than on farm trees (5.51±0.29 m). Table 1b and Figure 8 show mean crown diameter for wild and on farm populations for the three subspecies. There was significant (p<0.001) difference in mean crown sizes between the three subspecies with *S. birrea* subspecies *multifoliolata* having the largest crown. However, there was no significant difference in the mean crown diameter between the on farm and wild populations. On the other hand, means of crown sizes of male and female trees differed significantly (p<0.001) between subspecies and within similar environmental setting. Female trees had small crown size than male trees except in wild populations of *S. birrea* subspecies *caffra* and *multifoliolata* (Figure 6).

Relationship between altitude and Dbh, branching height, tree height and crown diameter

There were positive correlations between altitude and four tree parameters (Dbh, branching height, tree height and crown diameter) (Table 2). Although altitude had positive correlation with each of the tree size parameter, the relationship was weak except for crown diameter where it showed a moderately strong ***r*** value of 0.41, implying that trees growing in higher altitude are likely to have bigger crown diameter.

Table 1f: Crown diameter by sex, sub-species and population (M:*multifoliolata*, B: *birrea*, C: *caffra*, FP: on farm population and WP: Wild population)

	Number of Females						Number of Males					
Crown (m)	MFP	MWP	BFP	BWP	CFP	CWP	MFP	MWP	BFP	BWP	CFP	CWP
<2	0	0	2	0	0	3	0	0	6	1	0	3
2.1-5.0	1	3	16	5	5	6	0	10	28	25	1	10
5.1-8.0	8	9	17	18	14	18	12	21	17	25	18	14
8.1-11.0	23	11	2	2	11	9	15	12	5	18	27	14
11.1-14.0	10	9	1	1	9	5	13	11	5	4	11	13
14.1-17.0	2	5	1	1	2	1	11	7	0	0	2	3
>17	1	2	0	0	0	0	4	0	0	0	0	1

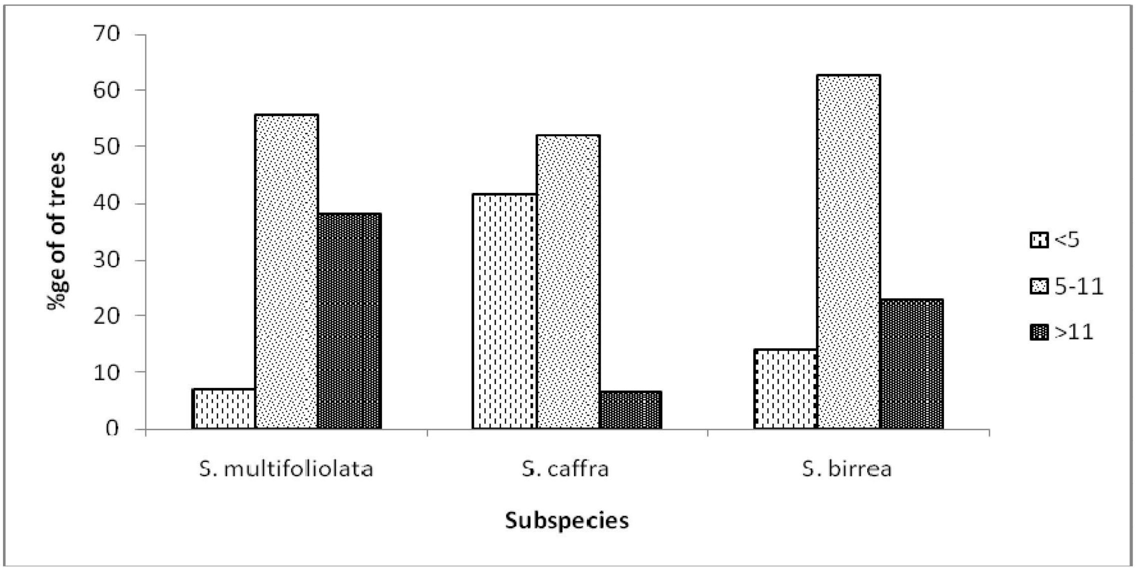


Figure 5: Percentage of population of the subspecies of *Sclerocaryabirrea* in different crown diameter classes

Tree diameter had a moderately strong correlation with tree height (***r*** = 0.60) and crown diameter (***r*** = 0.66). Moderate (***r*** = 0.53) correlation was observed between tree height and crown diameter as well as between branching height with tree height (***r*** = 0.50).

Number of stems per hectare

With the exception of the *S. birrea* subspecies *birrea* population, which occurs in east-central Tanzania, the number of stems per hectare (stems ha^{-1}) of wild populations was higher than the populations on farmland areas. The densest population was that of *S. birrea* subspecies *birrea* on farms with 20.4 stems ha^{-1}. The least dense was that of *S. birrea* subspecies *caffra* growing on farmland with 1.5 stems ha^{-1} (Table 3).

Spatial distribution of trees by sex

Results showing the spatial distribution of female and male trees for each population are presented in plate 1**,** while Table 4 shows the tree density ***(d)***, observed nearest neighbour distance ***(ro)***, expected nearest neighbour distance ***(re)*** and measure of degree to which the observed distribution approaches or departs from random expectation ***(R)*** for all the sites.

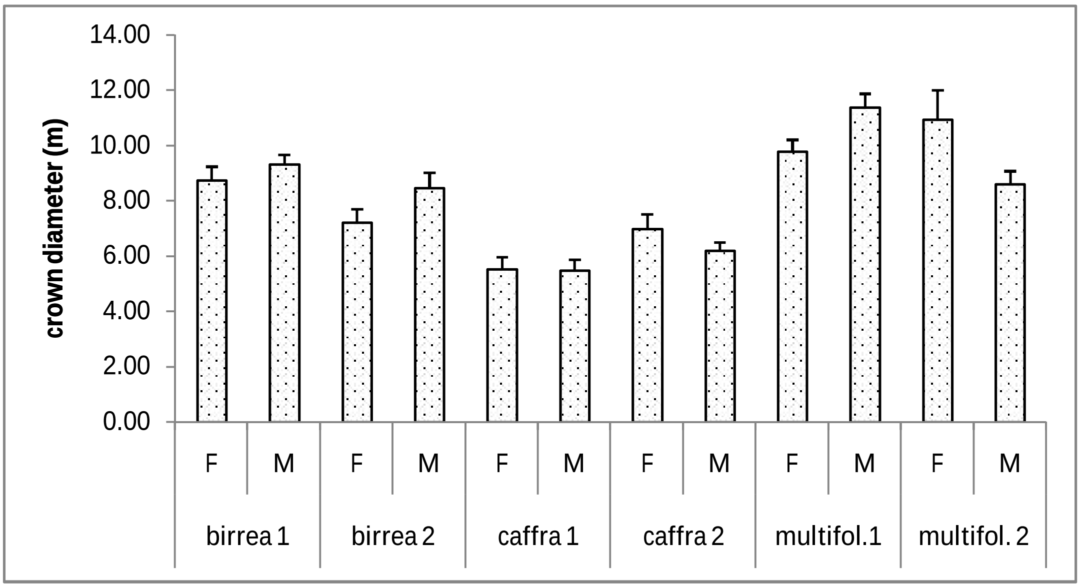


Figure 6: Mean crown diameter and standard error of mean for males (M) and female (F) trees on farm (1) and in the wild (2) environments for the subspecies *birrea*

Table 2: Correlation between tree size parameters(diameter, branching height, tree height and crown diameter) of *Sclerocarya birrea*

	1	2	3	4	5
1. Site altitude	-	0.289**	0.289	0.127*	0.412**
2. Diameter		-	0.289**	0.601**	0.664**
3. Branching height			-	0.498**	0.243**
4. Tree height				-	0.531**
5. Crown diameter					-

*** p< 0.001; * p < 0.01*

Table 3: Density in stems ha^{-1} by subspecies and population

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

The observed nearest neighbour distance ***(r$_o$)*** for *S. birrea* subspecies *birrea*, (on farm and in the wild respectively) was shorter (12.80 ± 0.90 m and 13.60 ± 1.09 m) than that for *S. birrea* subspecies *caffra* (32.37 ± 2.45 m and 11.71 ± 0.77 m) and *S. birrea* subspecies *multifoliolata* (35.23 ± 3.26 m and 14.11 ± 1.17 m).

Therefore, for *S. birrea* subspecies *birrea* where ***r$_o$*** for wild and on farm populations were more or less equal, the wild populations of *S. birrea* subspecies *multifoliolata* and *caffra* had r_o which was shorter than the on farm population. However, for both populations, the r_o values were close to r_e values hence resulting into R values of close to 1.00, implying that the distribution pattern for the populations was almost completely random. With the exception of *S. birrea* subspecies *caffra* population, one way ANOVA and independent t-test showed a significant ($p< 0.05$) difference for mean nearest neighbour distance and between the on farm and wild population

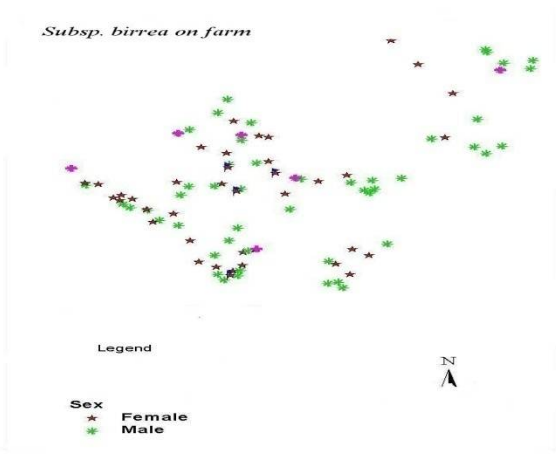
Population density by sex

The density of male and female trees of *S. birrea* subspecies *birrea* by subspecies and environmental setting is presented in Table 5. The density of male trees was significantly higher than that of female trees in all subspecies studied in both on farm and wild populations. The ratio of male to female trees was high for wild *S. birrea* subspecies *birrea* (27 males: 10 females) and low for on farm *S. birrea* subspecies *multifoliolata* (12 males: 10 females). *S. birrea* subspecies *caffra* had more or less equal number of male trees in both environmental settings (58 in the wild and 59 on farm) and so were the female trees, but the other subspecies had more male trees in the wild environment compared to the on farm environment.

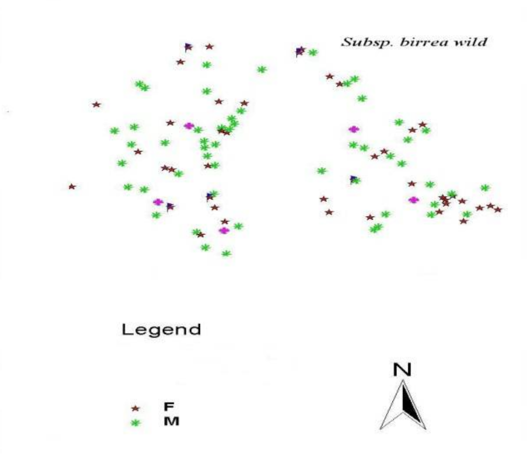
DISCUSSION

It was clear from the findings that *S. birrea* subspecies *multifoliolata* had the biggest trees in terms of diameter, height and crown size followed by *S. birrea* subspecies *birrea* and lastly by *S. birrea* subspecies *caffra*. While the reason for these variations could be genetical, seasonal fires in Kiegeya where *S. birrea* subspecies *caffra* occurs could probably have affected its growth. Fire, depending on frequency and intensity, tends to inhibit growth of woodland trees (Chidumayo 1988; Zolho 2005). For *S. birrea* subspecies *birrea* and *multifoliolata*, on farm tree populations had larger diameters, crown diameters and taller heights than wild trees and for *S. birrea* subspecies *caffra*, the situation was opposite. While on farm trees are expected to be bigger because of the care they receive through weeding and soil fertilization (McHardy 2003; Leakey *et al*. 2005), the present findings suggest that intraspecific competition could have influenced more sizes of trees of *S. birrea* subspecies *birrea*. This is because trees were relatively bigger where the population was less dense e.g. on farm population of *S. birrea* subspecies *birrea* which had the densest population but with the smallest tree. Of course, there might be other confounding factors such as human disturbance, site conditions and age of the trees which give room for further analysis. Gouwakinnou *et al.* (2009) observed that *S. birrea* trees on farm in Benin had Dbh twice the size of those in the wild, which were ten times denser than on farm trees.

Across all the subspecies and environments, male trees were bigger than female trees. There is scarcity of information from any previous study regarding differences in size between male and female trees. However, it is a common knowledge that female plants spend a lot of their food reserves for reproduction while among male trees, such reserves are made available for growth (Correia and Barradas 2000; Wheelwright and Logan 2004; Guangxiu 2009; Varga and Kytöviita 2010). This may perhaps explain the differences observed in this study. However, long term and wider coverage studies, particularly of *S. birrea* are necessary to make a concrete conclusion.

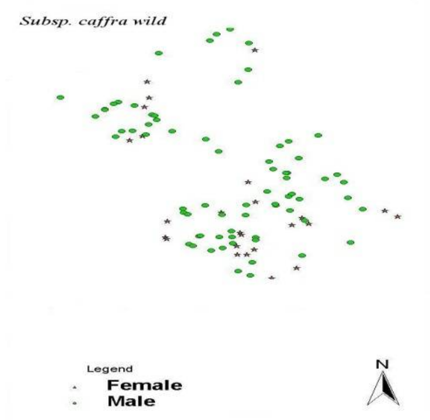


(Plot size = 66.15 Hectares)

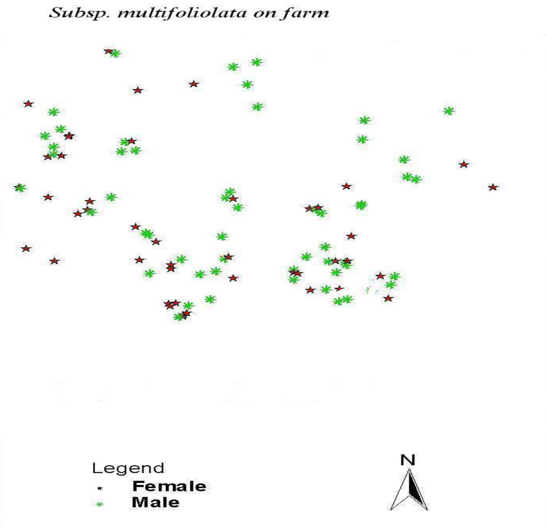


(Plot size = 5.88 Hectares)

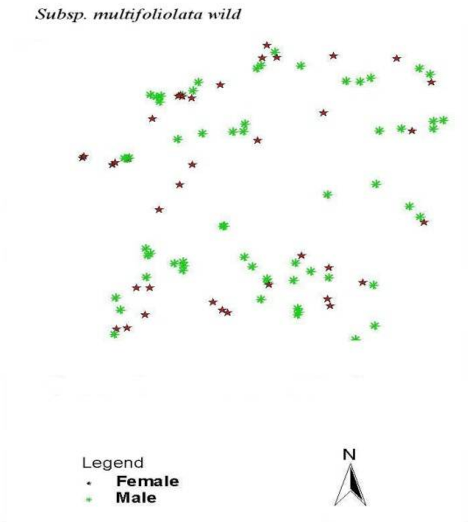
(Plot size = 4.91 Hectares)



(Plot size = 6.83 Hectares)



(Plot size = 58.79 Hectares)



(Plot size = 11.70 Hectares)

Plate 1: Scatter maps showing the assessed male and female trees of the three subspecies of *Sclerocarya birrea*, 100 trees for each population (*note that the plots are of variable sizes*)

Table 4: Distribution pattern of *Sclerocarya* trees by subspecies and on farm and wild populations

Site	Trees/m^2 [d]	Expected NND (m) [r_e]	Observed NND (m) [r_o]	Ratio [R]
caffra farm	0.000151	40.67	32.37 ± 2.45	0.80
caffra wild	0.001702	12.12	11.71 ± 0.77	0.97
birrea farm	0.002038	11.08	12.38 ± 0.90	1.12
birrea wild	0.001464	13.07	13.60 ± 1.09	1.04
multifoliolata farm	0.000170	38.34	35.23 ± 3.26	0.92
multifoliolata wild	0.000855	17.10	14.11 ± 1.17	0.82

**NND = nearest neighbour distance*

Table 5: Number of plants by sex, environmental setting and the ratio of males to 10 females for the three subspecies of *Sclerocaryabirrea*

Subspecies	Sex	On farm and wild population combined		On farm and wild populations separated			
				On farm		*wild*	
		N	*M:10 F*	*N*	*M:10 F*	*N*	*M:10 F*
S. caffra	F	83	14	41	14	42	14
	M	117		59		58	
S. birrea	F	66	20	39	16	27	27
	M	134		61		73	
S. multifoliolata	F	84	14	45	12	39	16
	M	116		55		61	

N = number of plants; M: 10F = ratio of number of male plants to ten female plants

With the exception of *S. birrea* subspecies *multifoliolata*, branching height for on farm trees was lower regardless of tree sex. It appears that farmers do not prune lower branches in order to maintain better shade under which they rest during farming activities. However, farms in Malinzanga site which is close to Ruaha National Park, *S. birrea* subspecies *multifoliolata* trees are susceptible to crop raiders such as monkeys and elephants and therefore do not consider these trees as important shade trees on their farms (Woiso 2011). As such, farmers in Malinzanga tend to prune or even remove the *S. birrea* subspecies *multifoliolata* trees to avoid conflicts with wildlife especially monkeys (Woiso 2011). Monkeys can use these trees as sources of food (fruits), cover or corridor while elephants are attracted by fruits which can be associated with crop forage and damage. However, farmers in Kiegeya and Holili study sites reported *S. birrea* subspecies *birrea* and *caffra* to be important shade trees (Woiso 2011). Pruning of on farm trees as is done in Malinzanga is also reported to improve yield of associated crops (Bayala *et al.* 2002) although the impacts on yield are specific to particular species and locality (Teklehaimanot 2008).

The higher branching height in the wild tree populations may be due to competition for light (Osada *et al.* 2004). The species light requirements may also be the reason why crown size was the only parameter with significant (0.412, $p<0.001$) correlation with altitude.

On the other hand, frequent bush fires tend to kill and hence remove lower branches in wild populations. Removal of lower branches could reduce crown depth allowing lighter to penetrate to the underground, eventually promoting growth of herbaceous vegetation. The herbaceous layer provides suitable fuel load, creating an environment prone to fires each season (Mapaure and Campbell 2002; Ribeiro *et al.* 2008) which sustains killing of the lower branches of the trees year after year.

The abundance of *S. birrea* subspecies *birrea* and *caffra* was higher (up to twice) than that of *S. birrea* subspecies *multifoliolata*. *S. birrea* subspecies *birrea* was the most abundant and unlike *S. birrea* subspecies *caffra* and *multifoliolata*, its on farm population was more abundant than the wild population. The differences in abundance between the subspecies may relate to variability in agroecology and human influences but normally, a combination of factors interplay to shape abundance and distribution of plants (Kikula 1986; Zolho 2005). Observations made during the field work showed that unlike the other sites, at the Kiegeya site, the growth of *S. birrea* subspecies *birrea* was affected by wild fires (Plate 2) which occurred every season. But in Malinzanga, farmers tend to remove *S. birrea* subspecies *multifoliolata* on their farms for crop protection against wildlife and that the tree is also used for timber while in Holili, the growth of *S. birrea* subspecies *birrea* has been affected by brick carving which has led to severe land degradation on the farmlands (Plate 3). The wildlife conflicts, fire incidents and brick carving may be reasons for the status of population density in the respective villages.

Plate 2: Burnt forest at Kiegeya where subspecies *caffra* was studied

It has been reported that moderate levels of fire have been found to be a useful management tool in woodland vegetation in Africa for it breaks seed dormancy (Banda *et al.* 2006) and promotes tree growth and species diversity (Chidumayo 1998; Frost 1996), which could be the same case in Kiegeya. Elsewhere, it is reported that where there is soil erosion, there are also less trees in agroforestry systems (Bofa 1999), as was the case in Holili. The intentional removal of trees in Malinzanga to avoid conflicts with wildlife directly reduces tree populations on farms.

Plate 3: Stone-blocks mining in Holili, Tanzania

Compared to subspecies which are found in other countries, the abundance of the Tanzanian populations is high. The abundance of *S. birrea* subspecies *birrea* was exceptionally high (20.4 stems ha^{-1}), much more than its own wild populations and any of *S. birrea* subspecies *birrea* recorded elsewhere across the species range for trees on farmlands with >10cm Dbh. Hall *et al.* (2002) reviewed past inventory data including that by Lewis (1987), Scholes and Walker (1993), Marchal (1980) and Coetzee *et al.* (1979) and found that stand density, for both wild and on farm trees hardly exceeds 5 stems ha^{-1} and this includes trees with < 10 cm diameter. A stand density of 1.5 stems ha^{-1} for *S. birrea* subspecies *caffra* (including individuals of <1 cm diameter) was found by Nghitoolwa *et al.* (2003) during sex distribution survey on an on farm population in two neighbouring villages in Namibia. Lewis (1987), Shackleton (1996, 1997), Bandeira *et al*. (1999) and Lombard *et al.* (2000) found different population densities ranging from 7.5 to 37.5 stems ha^{-1}for *S. birrea* subspecies *caffra* from different areas in South Africa, Mozambique and Zambia. Their surveys included saplings or trees with Dbh of <10 cm. The abundance of *S. birrea* subspecies *birrea* trees with Dbh of >13 cm in Benin was found to be 4.2 and 13.4 stems/hafor on farm and wild populations respectively (Gouwakinnou *et al.* 2009). Therefore, Tanzania is not only harbouring the highest genetic diversity for *S. birrea* subspecies *birrea* (Kadu *et al.* 2006), but for the first time this study reports that it has among the densest populations across the species range, both on farm and in the wild.

Wild populations of *S. birrea* subspecies *caffra* and *multifoliolata* were denser than the corresponding on farm population, which is expected. But for *S. birrea* subspecies *birrea,* on farm population was denser that the wild population. Therefore, while it is obvious that farmers tend to retain just a few trees and weed out tree seedlings to give way for agricultural crops (Bofa 1999; Fischer *et al.* 2010; Bayala *et al.* 2010), results of this study suggest that it is not always necessarily so. Farmers in Kiegeya retained most of *S. birrea* subspecies *birrea* on their farms alongside their cultivated crops and abundance of the tree was high on farms than in the wild. The results for *S. birrea* subspecies *caffra* and *multifoliolata*, but not *S. birrea* subspecies *birrea* are similar to the ones reported by Gouwakinnou *et al.* (2009) from Benin who found 10 times more abundance of the subspecies in the wild population. Results of this study which showed high abundance of *S. birrea* subspecies *birrea* on farm may be used as a good indicator that domestication of the species as an agroforestry component is feasible. Farmers in this site do not use inorganic fertilizers implying that they might be retaining the trees on their farms because they improve crop yield. However, further assessments on tree-crop interaction are important to obtain empirical evidence on the influence of the tree on yield of intercrops as well as types of intercrops and optimum spacing.

At all levels, there were more male than female trees. This is contrary to what has been reported for *S. birrea* subspecies *birrea* and *caffra* in other countries where there are more female than male trees (DFID 2003; Nghitoolwa *et al.* 2003; Gouwakinnou *et al.* 2009). To suggest that the sex ratio disparity is a result of human selection pressure may not be accurate because *firstly*, for Tanzania, regeneration of the trees both on farm and in the wild is 100% natural. No farmer is reported to have planted the tree in any of the three study sites. *Secondly*, the high ratio of male to female trees is observed for both on farm and wild populations. Therefore, the observed higher number of male to female trees may be due to physiological and environmental reasons, although the information in this study is not adequate enough to draw a conclusion on. Some studies have suggested that for the resulting seed embryo to be female, more pollen would have been needed to fertilize the respective ovaries (Stehlik *et al.* 2006; 2007; 2008). The higher the concentration of pollen deposited onto a female flower, the more likely that the resulting offspring will be a female. Therefore, for expected offspring to be females, the maternal parent needs a couple of male plants around it and in close proximity to intensify pollen volume deposited on ovaries. If this mechanism applies to *S. birrea* subspecies *birrea*, the observed higher number of male to that of female trees favours not only availability of pollen supply for improved fruiting but also more female offsprings to be produced in the next few generations.

Spatial distribution pattern

All the populations were observed to be randomly distributed with $\boldsymbol{R}$ values close to 1.0, meaning that the observed distribution ($\boldsymbol{r_o}$) was close to the expected distribution ($\boldsymbol{r_e}$) as $\boldsymbol{R}$ is the ratio between the two ($\boldsymbol{R = r_o/r_e}$). Given that the areas were different in size hence differences in density, the randomness is due to the values between pair trees making up a significant proportion of the total population (Cottam and Curtis 1956). This is possible because most of the values can be duplicates due to paired neighbours being neighbour to each other and making a significant proportion of the total population. This implies that even if some of the populations occupied a much bigger area compared to the others, the trees were close to each other and therefore the empty spaces within the plots had no effect on the nearest neighbour distance (Okia 2010). Since both wild and on farm populations showed random distribution, it indicates that human activities have limited influence on the species distribution.

CONCLUSIONS AND RECOMMENDATION

This study concludes that there was a significant variation in stand parameters of *S. birrea* trees between its subspecies, on farm and wild populations and sex. Genetics, habitat conditions and forest fires could have contributed to the variations. For the first time, this study reports sex dimorphism for *S. birrea* subspecies *birrea*. Male trees are bigger than females probably because of reproductive roles of the latter which consume reasonable proportion of the food resources. The density of the populations showed some variation from what was expected. There were cases of on farm populations being more abundant than the wild populations and also there being more male trees than female trees. These are interesting findings but it is recommended that detailed and wider coverage (more sites) studies be undertaken in Tanzania.

ACKNOWLEDGEMENTS
The Leverhulme trust from the UK is highly acknowledged for funding this study. The invaluable support and cooperation received from farmers and village leaders in the respective study sites is highly appreciated.

REFERENCES

Akinnifesi, F,. Kwesiga, F., Mhango, J., Mkonda, A., Chilanga, T. and Swai, R., 2004.Domesticating priority miombo indigenous fruit trees as a promising livelihood option for small-holder farmers in southern Africa. Journal of Acta Horticulture.632, pp. 15-30.

Akinnifesi, F., Kwesiga, F., Mhango, J., Chilanga, T., Mkonda, A., Kadu, C., Kadzere, I., Mithöfer, D., Saka, J., Sileshi, G., Ramadhani, T. and Dhliwayo, P., 2006.Towards the development of miombo fruit trees as commercial tree crops in southern Africa. Journal of Forests, Trees Livelihoods, 16, pp. 103-121.

Banda, T., Schwartz, M. and Caro, T. 2006.Woody vegetation structure and composition along a protection gradient in a miombo ecosystem of western Tanzania. Forest Ecology and Management, 230, pp. 179-185.

Bandeira, S.O., Albano, G. and Barbosa, F.M. 1999. Diversity and uses of plant species in Goba, Lebombo Mountains, Mozambique, with emphasis on trees and shrubs. *In:* Timberlake, J. and Kativu, S. (Ed.). African plants: biodiversity, taxonomy and uses. pp. 429-439. Royal Botanic Gardens, Kew. 591 pp

Bayala, J., Teklehaimanot, Z. and Ouedraogo, S.J. 2002. Millet production under pruned tree crowns in a parkland system in Burkina Faso. *Agroforestry Systems,* 54, pp. 203–214.

Boffa, J.M. 1999. Agroforestry parklands in sub-Saharan Africa.FAO Conservation Guide 34.Food and Agriculture Organization of the United Nations, Rome, Italy.

Chidumayo, E. 1998. A re-assessment of effects of fire on miombo regeneration in the Zambian Copperbelt. Journal of Tropical Ecology 4 (4), pp. 361-372.

Chirwa, P.W. and Akinnifesi, F.K. 2008. Ecology and biology of *Uapacakirkiana*, *Strychnoscocculoides* and *Sclerocarya birrea* in Southern Africa: *In,* Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., Matakala, P. and Kwesiga, F.R. (Eds.). Indigenous fruit trees in the tropics: domestication, utilization and commercialization. Wallingford: CAB International. pp. 322-340.

Clark, P.J. and Evans, F.C. 1954. Distance to nearest neighbour as a measure of spatial relationships in populations. Ecology 35, pp. 445-453.

Coetzee, B.J., Englebrecht, A.H., Joubert, S.C.J. and Retief, P.F. 1979. Elephant impact on *Sclerocarya caffra* trees in *Acacia nigrescens* tropical plains thornveld of the Kruger National Park. Koedoe**,** 22, pp. 39-60.

Correia, O. and Diaz-Barradas, M.C., 2000. Ecophysiological differences between male and female plants of *Pistacialentiscus* L. Journal of Plant Ecology, 149, pp. 131–142.

Cottam, G. and Curtis, J.T. 1956. The use of distance measures in phyto-sociological sampling. Journal of Ecology37, pp. 451-460.

DFID 2003. Winners and losers in forest product commercialisation. Final report (Marula–*Sclerocaryabirrea).* Centre for Ecology and Hydrology (CEH). Wallingford, Oxfordshire, UK.

Fischer, J., Zerger, A., Gibbons, P., Stott, J. and Law, B. 2010. Tree decline and the future of Australian farmland biodiversity. Proceedings of the National Academy of Sciences, USA. 145: 19597-19602

Frost, P. 1996. The *Ecology* of Miombo Woodlands. In: B.M. Campbell (Ed.). The Miombo in Transition: Woodlands and Welfare in Africa. Centre for International Forestry Research, Bogor, Indonesia.

Gouwakinnou, G.N., Kindomihou, V., Assogbadjo, A.E. and Sinsin, B. 2009. Population structure and abundance of *Sclerocarya birrea* (A. Rich) Hochst subspecies *birrea* in two contrasting land-use systems in Benin. International Journal of Biodiversity Conservation6, pp. 194–201.

Guangxiu, L., Wei, Z., Tuo, C., Xuelin, C., Yongshan, L. and Lizhe, A. 2009. Gender-specific carbon discrimination and stomatal density in the dioecious tree of Hippophaterhamnoides. South African Journal of Botany, 75(2), pp. 268-275.

Hall, J.B., O' Brien, E.M. and Sinclair, F.L., 2002. *Sclerocaryabirrea*: *A monograph.* School of Agricultural and Forest Sciences No. 19, University of Wales, Bangor 157 pp.

Hillman, Z., Mizrahi, Y. and Beit-Yannai, E., 2008.Evaluation of valuable nutrients in selected genotypes of marula (*Sclerocaryabirrea* ssp. *caffra*). *Scientia Horticulturae*, 117(4), pp. 321-328.

Kadu, C.A.C., Imbuga, M., Jamnadass, R. and Dawson, I.K. 2006. Genetic management of indigenous fruit trees in southern Africa: A case study of *Sclerocarya birrea* based on nuclear and chloroplast variation. South African Journal of Botany, 72(3), pp. 421-427.

Karin, G. and Nontokozo, N. 2006. Participatory Planting and Management of Indigenous Trees: Lessons from Chivi District, Zimbabwe. Agriculture and Human Values 23, pp. 231 – 243.

Khonje, C., Ngulube, M.R. And Chanyega, T., 1999.Distribution and population structures of *Sclerocarya birrea* (A.Rich.) Hochst. Malawi. Forest Research Institute Malawi, Zomba, 22 pp.

Kikula, I.S. 1986. The Influence of Fire on the Composition of Miombo Woodland of SW Tanzania. Oikos, 46(3), pp. pp. 317-324.

Kleiman, R., Ashley, D.A. and Brown, J.H. 2008. Comparison of two seed oils used in cosmetics, moringa and marula. Journal of Industrial Crops and Products, 28(3), pp. 361-364.

Kokwaro, J.O. and Gillett, J.B. 1980. Notes on the Anacardiaceae of Eastern Africa. Kew Bulletin, 34(4), pp. 745-760.

Krhoda, G. O. 1998. Conflicts in resource utilization resulting from highland-lowland interactions: a study of Taita Hills, Kenya. In: F. F. Ojany (ed.).African mountains and highlands. Planning for sustainable use of mountain resources .The United Nations University, Tokyo, Japan. Pp. 25-39

Leakey, R. and Tomich, T. 1999.Domestication of tropical trees; from biology to economics and policy. In: Buck, L.E., Lassoie, J. and Fernandes, E.C.M. (eds) Agroforestry in Sustainable Agriculture Systems. CRC Press/Lewis Publishers, New York.

Leakey, R., Shackleton, S. and Plessis, P.D. 2005b. Domestication potential of Marula (*Sclerocarya birrea* subsp*caffra*) in South Africa and Namibia: 1. Phenotypic variation in fruit traits. Journal of Agroforestry Systems, 64(1), pp. 25-35.

Leakey, R., Tchoundjeu, Z., Schreckenberg, K., Shackleton, S. and Shackleton, C. 2005a. Agroforestry tree products (AFTPs): targeting poverty reduction and enhanced livelihoods. International Journal for Agricultural Sustainability 3, 123.

Lessard, C., Reed, D. and Monkevich, N. 1994. Comparing n-tree distance sampling with point and plot sampling in northern Michigan forest types. Journal of applied forestry 11, pp. 12–16.

Lewis, D.M. 1987. Fruiting patterns, seed germination, and distribution of *Sclerocarya caffra* in an elephant-inhabited woodland. Biotropica, 19, pp. 50-56.

Ludwig, J. A. and Reynolds, J. F. 1988. Statistical ecology. USA: John Wiley & Sons.

Maghembe, J. and Seyani, J. 1992. Multipurpose trees used by small-scale farmers in Malawi: results of an ethnobotanical survey. AFRENA Report No. 42. International Centre for Research in Agroforestry, Nairobi, Kenya.

Mapaure, I.N. and Campbell, B.M. 2002. Changes in miombo woodland cover in and around Sengwa Wildlife Research Area, Zimbabwe, in relation to elephants and fire. African Journal of Ecology, 40(3), pp. 212-219.

Marchal, J.Y. 1980.Arbresetbrousses de paysagesoudano-sahélien; dynamiques des formations végétales au nord de la Haute Volta. Cahiers de l'Office de la Recherche Scientifiqueet Technique Outre-Mer, Série Science Humaine, 17, pp. 137-149

MBOMIPA, 2006. Matumizi bora ya mali hai tarafa za Pawaga na Idodi.Pawaga-Idodi proposed WMA Zone Plan

McHardy, T. 2003. Inventory of available marula resources on the Makhatini Flats Maputa land in the fruiting season of 2002. Report to UK DFID Forestry Research Programme (Project No R7795). Institute of Natural Resources, Scottsville, South Africa.

Mng'omba, S., Akinnifesi, F., Sileshi, G., Ajayi, O., Chakeredza, S. and Mwase, F. 2008. A decision support tool for propagating Miombo indigenous fruit trees of southern Africa. African Journal of Biotechnology 7 (25), pp. 4677- 4686.

Moyo, M., Ndhlala, A.R., Finnie, J.F. and van Staden, J. 2010. Phenolic composition, antioxidant and acetylcholinesterase inhibitory activities of *Sclerocaryabirrea* and Harpephyllum caffrum (Anacardiaceae) extracts. Journal of Food Chemistry, 123(1), pp. 69-76.

Muok, B.O., Matsumura, A., Ishii, T. and Odee, D.W. 2007.Genetic diversity within *Sclerocarya birrea* populations in Kenya. Journal of Arid Environments, 71(1), pp. 1-11.

Ndifossap M., Frigerio F., Casimir M., Ngueguim F., Dongo E., Kamtchouing P., Dimo T., and Maechler P. 2010. *Sclerocaryabirrea* (Anacardiaceae) stem-bark extract corrects glycaemia in diabetic rats and acts on beta-cells by enhancing glucose-stimulated insulin secretion. Journal of Endocrinology 205(1):79-86

Nghitoolwa, E., Hall, J.B. and Sinclair, F.L. 2003. Population status and gender imbalance of the marula tree, *Sclerocaryabirrea* subspecies *caffra* in northern Namibia. Journal of Agroforestry Systems, 59(3), pp. 289-294.

Okia, A.C. 2010. *Balanitesegyptiaca*: A resource for improving nutrition and income of dryland communities in Uganda. PhD Thesis, Bangor University, UK

Osada, N., Tateno, R., Hyodo, F. and Takeda, H. 2004. Changes in crown architecture with tree height in two deciduous tree species: developmental constraints or plastic response to the competition for light. Journal of Forest Ecology and Management, 188, pp. 337–347.

Ribeiro, N., Saatchi, S., Shugart, H. and Washington-Allen, R. 2008. Aboveground biomass and leaf area index (LAI) mapping for Niassa Reserve, northern Mozambique. Journal of Geophysics Research andBiogeoscience113, G02S02

Ruffo, C., Birnie, A. and Tengnas, B. 2002. Edible Plants of Tanzania. RELMA Technical Handbook Series 27. Regional Land Management Unit, Nairobi, 766 pp.

Scholes, R.J. and Walker, B.H. 1993. An African savanna: synthesis of the Nylsvley study. Cambridge University Press, Cambridge. 306pp.

Shackleton, C.M. 1996. Potential stimulation of local rural economies by harvesting secondary products: A case study of the central Transvaal lowveld, South Africa. Ambio 25, pp. 33 - 38.

Shackleton, C.M. 1997. The prediction of woody productivity in the savanna biome, South Africa. PhD Dissertation, University of the Witwatersrand, Johannesburg, South Africa.

Shackleton, C.M., Botha, J. and Emanuel, P.L. 2003. Productivity and abundance of *Sclerocaryabirrea* subspecies *caffra* in and around rural settlements and protected areas of the Bushbuckridge lowveld, South Africa. Journal of Forests, Trees Livelihood 13, pp. 217–232.

Shackleton, S.E., Shackelton, C.M., Cunningham, A. B., Lombard, C., Sullivan, C. A. and Netshiluvhi, T. R. 2002. Knowledge on *Sclerocarya birrea* subspecies *caffra* with emphasis on its importance as a non-timber forest product in South and southern Africa: A summary. Part 1: Taxonomy, ecology and role in rural livelihoods. South African Forestry Journal 194, pp. 27–41.

Shackleton, S., Campbell, B., Lotz-Sisitka, H. and Shackleton, C. 2008.Links between the Local Trade in Natural Products, Livelihoods and Poverty Alleviation in a Semi-arid Region of South Africa. World Development, 36(3), pp. 505-526.

Sheil, D., Ducey, M.J. and Samsoedin, I., 2003.A new type of sample unit for the efficient assessment of diverse tree communities in complex forest landscapes. Journal of Topical Forest Science.15 (1), pp. 117–135.

Sparks, J. C., Masters, R. E. and Payton, M. E. 2002.Comparative evaluation of accuracy and efficiency of six forest sampling methods. Proceedings of Okla Academy of Science, 82, pp. 49-56.

Stehlik, I, and Barrett, S. 2006. Pollination intensity influences sex ratios in dioecious *Rumexnivalis*: A wind-pollinated plant. Evolution, 60, pp. 1207–1214.

Stehlik, I., Friedman, J. and Barrett, S. 2008 Environmental influence on primary sex ratio in a dioecious plant.

Proceedings of National Academy of Sciences, USA 105: 10847–10852.

Stehlik, I., Kron, P., Barrett, S. and Husband, B. 2007. Sexing pollen reveals female bias in a dioecious plant. New Phytol., 175, pp.185–194.

Teklehaimanot, Z. 2005. Indigenous fruit trees of Eastern Africa. The Leverhulme Trust Study Abroad Fellowship Report, 32 pp.

Teklehaimanot, Z. 2008. The role of indigenous fruit trees in sustainable dryland agriculture in Eastern Africa. In: Festus K. Akinnifesi, Roger R.B. Leakey, Oluyede C. Ajayi, Gudeta Sileshi, Tchoundjeu, Z., Matakala, P., and Kwesiga F.R. (Eds.): Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization., pp 204-223. CAB International Publishing.

Varga, S.and Kytöviita, M.M. 2010. Mycorrhizal benefit differs among the sexes in a *gynodioecious* species. Ecology, 91(9), pp. 2583-2593.

Welch, J. 1960. Observations on Deciduous Woodland in the Eastern Province of Tanganyika. Journal of Ecology, Vol. 48, No. 3, pp. 557-573

Wheelwright, N. 1993. Fruit size in a tropical tree species: variation, preference by birds, and heritability. Journal of Vegetation, 107, pp. 163 – 174.

White, F. 1983. The vegetation of Africa: a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. Paris. UNESCO.

Williams, W., Lance, G., Webb, L., Tracey, J. and Connell J. 1969. Studies in the numerical analysis of complex rain-forest communities: The elucidation of small-scale forest pattern, Journal of Ecology 57, pp. 635–654.

Woiso, D.A. 2011. A comparative study of the subspecies of *Sclerocarya birrea*: Their potential for domestication in Tanzania. PhD Thesis, Bangor University, UK

Zolho, R. 2005. Effect of Fire Frequency on the Regeneration of Miombo Woodland in Nhambita, Mozambique .Master's thesis. University of Edinburgh, UK.