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Full Length Research Paper

Heavy metal soil contamination in cocoa plantations in South West Region, Cameroon

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The status of heavy metal contamination of surface soils in two cocoa plantations of approximately 30 years in Cameroon was evaluated. The bioavailable fractions of Fe, Cu, Zn, Cd and Cr were used to assess the extent of heavy metal contamination using a selection of contamination indices. In addition, other physicochemical properties including organic matter, particle size, CEC and pH were assessed. One of the farms was dominated by sand (64.56 - 73.46% sand) in contrast to the other (2.56 to 37.51%) and the latter had a higher clay content. The order of abundance of heavy metals, as expressed by the mean values, is as follows: Fe > Cu > Zn > Cr > Cd in soils from the two areas. Contamination factors of Cu-, Zn- and Cd are considerable for clay-dominated soil. The potential ecological risk of the metals in both soils was low with the exception of Cd in the clayey soil. Results for hazard assessment showed Cu levels were within the low ISQC sediment criteria in the clay-dominated soil; possibly linked to the long-term application of Cu-fungicide.

Key words: Heavy metal, contamination indices, cocoa plantation, Cameroon.

INTRODUCTION

In Cameroon, like in many other developing countries, agricultural practices rely heavily on agrochemicals to prevent and/or control the crops threatening diseases (Emoghene and Futughe, 2016). Cameroon was the fifth highest cocoa producer in the world in 2013/2014 (Ngalame, 2014). Cameroon's cocoa outputs increased from 211,000 metric tons in 2013/2014 to 232,000 metric tons in 2014/2015, although some projections indicated that cocoa production would decrease to 230,000 metric tons in 2015/2016 (Statistical Portal, 2016). Cocoa production is however, threatened by a range of pests and diseases. In Cameroon, among the most common and highly destructive cocoa pests are mirids (Bisseleua et al., 2011; Babin et al., 2010), which could be responsible for between 30 to 70% of cocoa yield losses (Anikwe et al., 2009). The emergence of climate change as a global environmental problem conspicuously undermines cocoa productivity with persistent droughts coupled with outbreak of pests and diseases (Oyekale, 2017). Farmers commonly rely heavily on the use of

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pesticides in the management and prevention of cocoa pests and diseases. Copper-based fungicide is the most important component of pest and disease control programs in cocoa production systems (Olujide and Adeogun, 2006; Adabe and Ngo-Samnick, 2014).

Long term use of Cu fungicides is detrimental to soil microorganisms (Merrington et al., 2002) and are responsible for reducing respiration and microbial carbon: total carbon ratio (Gaw et al., 2003). Aikpokpodion et al. (2010) attributed copper contamination of soils in some cocoa plantations in Nigeria to the use of copper-based fungicides in treating black pod disease. Toselli et al. (2009) explained the accumulation of copper in soil as a result of repeated application of fungicides to control fungal diseases of pear and grapes in Italy. A study conducted in India also revealed that high levels of Bordeaux mixture application resulted in significant accumulation of copper in topsoil and subsoil (Savithri et al., 2003). Chaignon et al. (2001) reported that plants take in copper (Cu) as well as other metals, more intensely from contaminated soils which are poor in iron (Fe) and zinc (Zn). The concentration of cadmium, lead, copper and arsenic in cocoa beans is of the interest as these metals or trace elements (in high concentrations) are generally considered toxic to human beings. Previous research has investigated the content of cadmium (Cd), copper (Cu), lead (Pb), and arsenic (As) in cocoa beans from various countries as well as in some chocolate products (Aikpokpodion et al., 2010, 2013). Soil copper contamination can be as a result of long-term application of fungicides. The contamination of such soils with other heavy metals such as Cd, Cu, Pb, and As on which cocoa is grown is another means through which these metals can get into cocoa beans. Such contamination however could result from the nature of the parent material from which the soils are formed and the presence of other sources of contamination. Vītola and Ciproviča (2016) investigated the potential risk and safety of heavy metal contamination up the value chain from cocoa beans.

Total metal content in soil neither represents bioavailability nor toxicity of that metal. Metal availability to plants can be assessed using selective extraction and chemical speciation. The readily soluble fraction of heavy metals is generally considered to be phytoavailable. The estimation of heavy metal phytoavailability in soils is becoming more important as a risk assessment because, total metal concentrations may not be the best predictors of metal phytoavailability. Single extraction is the most widely used method for evaluating phytoavailability of heavy metals in soils.

There is limited information on the extent of soil contamination in cocoa plantations in Cameroon, despite the importance of cocoa cultivation in Cameroon. Previous studies by Manga et al. (2014) attributed the lack of such information to the absence of effective policies to manage land contamination and soil pollution risks arising from anthropogenic sources in the country. The present study evaluates the status of heavy metal contamination in the surface soils of approximately 30 years old cocoa plantations. The bioavailable fractions of Fe, Cu, Zn, Cd and Cr are used to assess the extent of heavy metal contamination by a selection of contamination indices (Contamination Factor, Degree of Contamination, Ecological Risk Index and Pollution Load Index).

MATERIALS AND METHODS

Study area

The study was carried out in Ekombe-Mbalangi, which is located in Meme Division, South West Region, Cameroon (Figure 1). The area falls within the equatorial climatic zone and has two main seasons; the rainy season which lasts for about 8-9 months (from March - October) and a dry season that runs from November - February. Annual rainfall varies between 2,500-3,250 mm, with a mean monthly temperature of about 25°C. The relief is undulating, with altitudes ranging from 155-848 m above sea level. The area is well drained by several streams (Kindongi, Mbalangi, Ota-Lobe, Basinge and Anyangari) that empty into the Mungo River. The primary vegetation comprises fragmented patches of forests and the continuous expanse of the Southern Bakundu Forest Reserve (the reserve itself being under threat from human activities). The geology is dominated by the Mungo River Formation (MRF) of Upper Cretaceous age (Turonian – Cenomanian) and ascribed to the Douala Sedimentary Basin. The MRF consists of limestones, shales, marls, sandstones, siltstones, claystones and mudstones. The study area is located to the West of the Mungo River, where significant limestone and isolated basaltic rocks are exposed, while in the north (around Ediki) isolated shaley units are exposed. Limestone and recent alluvium occur closer to the banks of the Mungo River (Diko and Ekosse, 2013). Typically, ferralitic soils are found in the lowly-lying areas, while some of the highland areas have modified orthic soils. Sandy soils are also found in some parts of the region. There is the presence of rich volcanic soils, which have favored the cultivation of a lot of food crops (cassava, maize and yam). Cocoa cultivation dominates the cash crops activities of the area.

Two farms, referred to henceforth as Farm A and B, were included in the study. Farm A covered a surface area of approximately 7 ha and has been under continuous production for 30 years. Farm B, with a surface area of about 6.5 ha, has also been under production for over 30 years. In both farms, agricultural chemicals like insecticides and pesticides are used in an attempt to check the ravaging effects of pest and diseases on the yield of cocoa. Sanitary harvesting is practiced here, where infected pods are harvested, placed in a pit and burned, in order to reduce the spread of the pathogens to uninfected pods. Lastly, intercropping is also carried out in the cocoa fields to sustain the farmers with income during non-peak cocoa periods.

METHODOLOGY

Soil samples were collected from Farms A and B and the samples shall hereafter be referred to as soils A and B respectively. Six composite samples were collected from each farm, giving a total of 12 soil samples;

Farm A = (A1, A2, A3, A4, A5 and A6) and
Farm B = (B1, B2, B3, B4, B5 and B6).

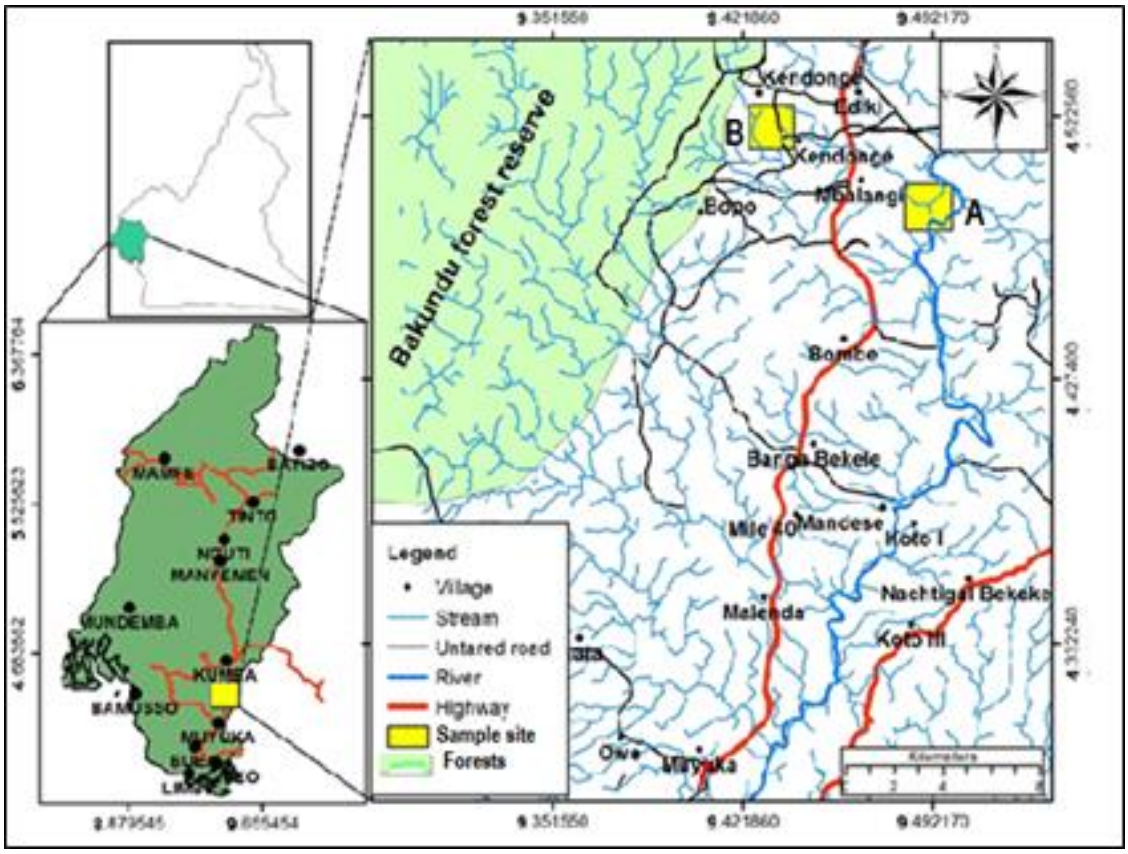

Figure 1. Map showing the location of the study sites.

Samples were collected using a soil auger at depths of 0-15 cm. The sample collection was at this depth because the build-up of Cu is more in the surface soil, between 0-15 cm (Savithri et al., 2003). A control sample was collected from a primary forest in the Southern Bakundu Forest Reserve, part of which is in Ekombe-Mbalangi for Farm B, while another control for Farm A was retrieved in primary forested land closer to the banks of the Mungo River. The soil samples were air-dried for 3 weeks and taken to the Geology Laboratory of the University of Buea where they were crushed with a ceramic mortar and pestle and sieved through the 2 mm sieve. The less than 2 mm fraction was collected and homogenized for subsequent analyses. Part of the samples was analyzed for routine soil physic-chemical parameters in the Institute of Agricultural Research for Development (IRAD) Ekona, while the other part was parceled and shipped to a laboratory in Ontario, Canada for heavy metal analysis. Particle size composition was determined using the modified Bouyoucos hydrometer (Estefan et al., 2013). Organic carbon content was obtained using Walkley and Black method (Walkey and Black, 1934); available phosphorous was determined according to Bray and Kurtz method (Bray and Kurtz, 1945) and total nitrogen was extracted by modified Macro Kjeldahl method (Pauwels, 1992). Soil pH was measured in 1:2.5 soil: water suspension as well as in soil: $CaCl_2$ suspension using a glass electrode pH (Black, 1965). The soils were leached with 1M neutral ammonium acetate to obtain leachates for the determination of exchangeable bases and soil cation exchange capacity (USDA-NRCS, 1996). Another portion (1 g) of the soil was extracted with 10 ml of 0.1 N hydrochloric acid and the extracts were used to analyse for Cu, Pb, Zn, Cd and Fe using atomic absorption spectroscopy, AAS (Baker and Amacher, 1982).

Geoaccumulation index

The Geoaccumulation Index (Igeo) is used in determining metal pollution in soils (Singh, 2001). It is expressed as (Equation 1):

$$I_{geo} = log_2\left(\frac{C_n}{1.5\ x\ B_n}\right) \quad (1)$$

Cn = measured metal concentration at sampling point; ***Bn*** = background concentration value for element; **1.5** = the background matrix correction factor due to lithogenic effects.

The Geoaccumulation Index scale consists of seven grades (0 – 6) ranging from unpolluted to very highly polluted. These seven descriptive classes are as follows:

<0=practically uncontaminated; 0-1=uncontaminated to slightly contaminated; 1-2=moderately contaminated; 2-3=moderately to highly contaminated; 3-4=highly contaminated; 4-5=highly to very highly contaminated and >5=very highly/strongly contaminated.

Contamination factor (CF)

Adopted from Hakanson (1980), this refers to the quantification of the degree of contamination as a single metal index (CF) (Equation 2) and as overall degree of contamination (C_{deg}) (Equation 3). The measurement reflects the relative quantification of the respective

Table 1. Contamination factors and degree of contamination categories and terminologies.

CF classes	CF and Cdeg terminologies	Cdeg classes
CF < 1	Low CF indicating low contamination/low Cdeg	Cdeg < 8
1 ≤ CF < 3	Moderate CF/Cdeg	8 ≤ Cdeg < 16
3 ≤ CF < 6	Considerable CF/Cdeg	16 ≤ Cdeg < 32
CF ≥ 6	Very high CF/Cdeg	Cdeg ≥ 32

Ecological risk factor (Er).

metal to a measured background value:

$$\boldsymbol{CF} = {}^{\boldsymbol{C_m}}/_{\boldsymbol{B_m}} \quad (2)$$

$$C_{deg} = \sum \left(\frac{C_m}{B_m}\right)\text{i} \quad (3)$$

Where:
I = The respective metals (Cu, Pb, Zn, Cd),
Cm = The measured concentration in soil while
Bm = The background (adjacent forest) concentration value of metal (m) within the area of study.

The assessment of soil contamination was carried out using the contamination factor and the degree of contamination, which is based on four classification categories (Hakanson, 1980), as shown in Table 1.

Ecological risk factor (Er)

Er is quantitatively calculated to express the potential ecological risk of a given contaminant as suggested by Håkanson (1980) is given in Equation 4:

$$Er = Ti.Cf \quad (4)$$

Ti is the toxic response factor (Hakanson) assigned as follows, Cu (5), Zn (1), Cd (30) and Cr (2)

The following terminologies are used to describe the ecological risk factor:

Er I < 40, low potential ecological risk;
40≤ *Er*< 80, moderate potential ecological risk;
80≤ *Er*< 160, considerable potential ecological risk;
160≤ *Er*< 320, high potential ecological risk; and
Er ≥ 320, very high ecological risk.

The potential ecological risk index (RI) was in the same manner as degree of contamination defined as the sum of the risk factors (Equation 5):

$$\text{RI} = \sum \text{Er} \quad (5)$$

Where: *Er* = The single index of ecological risk factors.

Hakanson (1980) and Yang et al. (2009) suggested that RI represents heavy metals toxicity and the environmental response to all five risk factors (Pb, Cd, Cu, Zn, and Cr) as total Cr in playground soils. In this study, only 4 of the 5 metals have been used and Cr concentration is the bioavailable concentration instead of total Cr. The following terminologies are used for the potential ecological risk index as given by (Hakanson, 1980):

RI < 150, low ecological risk; *150 ≤ RI < 300*, moderate ecological risk; and *RI > 600*, very high ecological risk.

RESULTS AND DISCUSSION

Soil characteristics

The soils in this study vary widely in their properties (Table 2 and Figure 2). Mean soil pH values are 5.28 and 6.2 in Farm A and B soils respectively; classifying these soils as low to moderate acid, which may enhance heavy metal distribution and availability to the plants. Average CEC values are low (11.75) to moderate (21.26) for soils A and B respectively. Sandy soils dominate Farm A soils (64.56 - 73.46% sand). These soils are located close to the banks of the Mungo River where the geology is composed of recent alluvium (Diko and Ekosse, 2013). In fluvial and alluvial soils, the redistribution of heavy metals within fractions occurs relatively quickly; it is not retained in the exchangeable fraction, which considerably decreases the risk of its mobility and inclusion into the food chain. Soils B on the other hand can be classified as retentive. They have compositions varying from 2.56 to 37.51% sand and therefore have higher clay contents. The most likely source of this characteristic is the parent material composition. Diko and Ekosse (2013) identified the presence of shaley material in these soils. Clayey soils are known for their high-water retention capacity, metal adsorption capacity, and nutrient storage. The clay content can be attributed to the soil mineralogy (especially the secondary clay minerals). Exchangeable cations (particularly Ca^{2+} and Mg^{2+}) and CEC values are higher in soils B. The CEC range, for both soils, qualify them favorable for agricultural use considering that none displays a low capacity for nutrient storage (CEC < 10 cmol kg^{-1}).

The mean available phosphorous in both soils is > 10, which is suitable for crop production (FAO, 1976). The concentrations of heavy metals are presented in Table 3. The order of abundance of heavy metals, as expressed by the mean values, is as follows: Fe > Cu > Zn > Cr > Cd in soils from the two areas. The average concentrations are higher than the background levels in both soils; indicating possible contamination in these

Table 2. Physico-chemical properties of the soils used in the study.

Soil	OC	Tot. N	Av P	$pH_{(H2O)}$	$pH_{(CaCl)}$	Na+	K+	Mg^{2+}	Ca^{2+}	Al+H	CEC
	%									cmol/kg	
Farm A											
A1	2.17	0.1	9	5.63	4.35	0.03	0.14	0.31	1.39	0.25	15.05
A2	2.58	0.12	8	5.22	3.75	0.04	0.07	1.34	0.69	0.87	16.27
A3	1.85	0.1	9	6.34	5.17	0.04	0.14	0.67	1.39	0.12	9.75
A4	1.36	0.94	48	4.18	3.46	0.03	0.12	0.83	2.08	1.75	9.8
A5	1.8	0.1	13	5.9	4.72	0.06	0.12	1.38	0.69	0.17	9.76
A6	1.13	0.76	35	4.4	3.74	0.06	0.12	0.48	2.09	1.81	9.86
Mean	1.82	0.35	20.33	5.28	4.2	0.04	0.12	0.84	1.39	0.83	11.75
Farm B											
B1	3.28	0.22	13	5.63	4.53	0.08	0.47	3.45	3.76	0.18	25.07
B2	3.61	0.37	21	5.78	4.81	0.07	0.6	7.58	4.69	0.07	25.66
B3	2.05	0.07	49	6.42	5.12	0.06	0.2	6.36	2.89	0.11	16.82
B4	3.87	0.31	8	6.38	5.49	0.18	1.21	9.17	9.32	0.17	25.22
B5	2.73	0.16	6	6.52	5.29	0.07	0.18	4.76	3.7	0.04	16.54
B6	2.71	0.28	13	6.7	5.86	0.08	0.34	6.23	2.29	0.43	18.25
Mean	3.04	0.24	18.33	6.24	5.18	0.09	0.5	6.26	4.44	0.17	21.26

Organic matter=OC %*1.72.

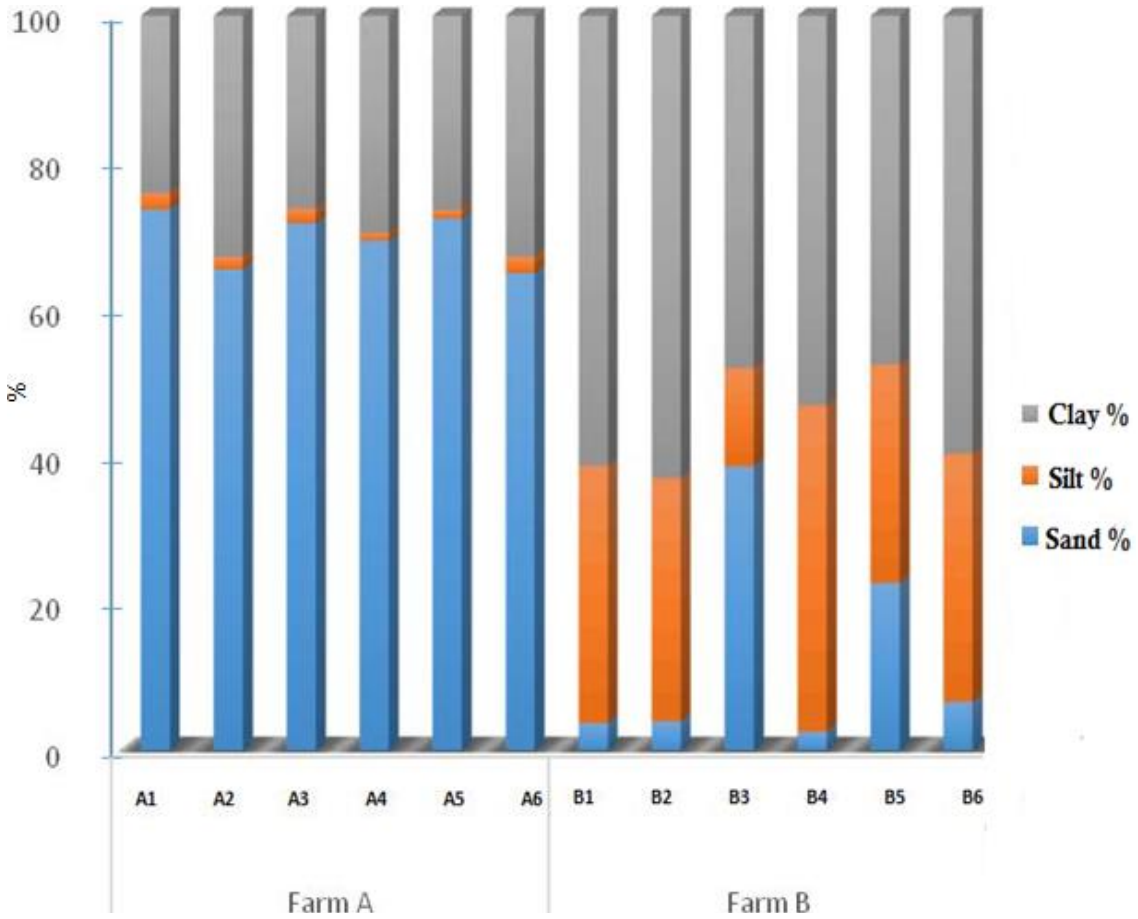

Figure 2. Soil particle size distribution soils from A and B.

Table 3. Concentration of heavy metals (cmol/kg) in the study area.

Sample	Sample	Cu	Zn	Fe (%)	Cd	Cr
Farm A	A1	23.77	4.0	0.18	0.03	1.2
	A2	9.55	3.9	0.15	0.03	1.1
	A3	13.59	3.5	0.15	0.02	1.2
	A4	14.14	2.2	0.15	0.01	1.2
	A5	24.48	3.6	0.13	0.03	1.0
	A6	11.72	1.2	0.13	<0.01	1.0
Control		4.40	1.9	0.02	0.02	0.1
Farm B	B1	20.39	20.7	0.10	0.23	0.9
	B2	11.58	23.3	0.04	0.24	0.7
	B3	24.88	10.8	0.14	0.21	1.6
	B4	38.92	32.1	0.04	0.83	0.7
	B5	24.92	11.7	0.09	0.26	1.3
	B6	20.39	15.0	0.06	0.28	0.9
Control		4.72	2.9	0.05	0.05	0.08

Table 4. Comparison of heavy metal concentration (cmol/kg) between study and control sites.

Element	Mean	t-stat	p-value	Confidence level (95%)	
				Lower	Upper
Soils A					
Cu	16.21	4.78	0.002	9.55	22.87
Zn	3.07	2.55	0.025	1.89	4.25
Fe (%)	0.148	17.13	6.2E-06	0.13	0.17
Cd	0.024	1	**0.19***	0.014	0.034
Cr	1.17	25.3	8.9E07	1.02	1.22
Soils B					
Cu	23.51	5.13	0.0018	14.09	32.93
Zn	18.93	4.84	0.0024	10.41	27.45
Fe (%)	0.08	1.77	**0.068***	0.039	0.12
Cd	0.34	2.97	0.016	0.09	0.59
Cr	1.02	6.37	0.0007	0.64	1.4

Significant at p<0.05; *Insignificant.

soils. The results of a two-sample t-test (Table 4) show that there are significant (P < 0.05) differences between the means of the soils and the control values, with the exception of Cd in Farm A and Fe in Farm B. This suggests that Cu, Zn and Cr inputs to the soils may be attributable to anthropogenic activities, specifically agriculture. Cadmium, Cd and Fe, in Farm A and B respectively, may be linked to anthropogenic activities. Besides Fe, average concentration heavy metals in soils B are higher than those in soils A. These variations may be attributed to; the differences in parent rock composition, the rates of metal solubility in soils (predominantly controlled by pH), amount of metals (Cations Exchange Capacity), organic carbon content, and oxidation state of the system (Ghosh and Singh, 2005).

Pollution indices

Results of the Geoaccumulation Index, I_{geo}, (Table 5) show the mean for Cu in Farm A as 1.3 and in Farm B as 1.73. This classifies soils from both farms as moderately contaminated. These values are similar to those earlier reported in a study of cocoa farms in Cross River State, Nigeria (Aikpokpodion et al., 2010). While anthropogenic

Table 5. Determined indices of pollution for the studied soils (CF, Er, and Igeo).

Heavy metal	Farm A			Farm B		
	Cf	Er	Igeo	Cf	Er	Igeo
Cu	3.40	19.10	1.30	5.00	25.00	1.73
Zn	1.60	1.61	0.11	6.53	7.14	2.12
Cd	1.20	36.00	-0.32	6.80	204.00	2.18
Cr	11.20	22.30	2.90	12.70	25.40	3.09
Cdeg		17.4			31.0	
RI		79			261	

activities (particularly the use of Cu-based fungicides) may account for these observations in both cases, these effects may also be mediated by the differences in lithology, especially since exchangeable Cu is bound to OM in soil (Teusch et al., 1999). Farm B, with a slightly higher OM content should therefore have a higher potential for Cu adsorption. This capacity may be enhanced (compared to Farm A) by the higher pH of Farm B, given that previous research has also reported increases in bound Cu in soil, reducing its mobility in the process (Teusch et al., 1999).

The mean values of Igeo of Zn and Cd in Farm A are 0.11 and -0.32 respectively. These qualify them as practically uncontaminated and negligible (that is, no contribution for Cd). In Farm B the Igeo values for Zn and Cd are 2.12 and 2.18 respectively, qualifying them as moderately to highly contaminated. At pH>5.2, Zn is probably bound to Fe-, Mn-, Al-rich oxides and OM. The stability of these phases is known to affect the depletion/enrichment of Zn in soils (Manga et al., 2014). The range of Igeo for Cr is very similar, with means of 2.9 and 3.1 for Farms A and B respectively. This value classifies the soils as being highly contaminated with Cr. Considering the absence of any dominant source of anthropogenic pollution, lithologic composition may be a likely factor contributing to Cr content in both cases.

Contamination Factor (CF) values are widely used to make inferences on natural versus anthropogenic origins of contamination. It has been suggested that metals having CF values between 0.5 and 1.5 are entirely derived from crust materials or natural processes; whereas CF values greater than 1.5 are more likely to be anthropogenic (Akoto et al., 2008). The calculated values of CF are shown in Table 4. The values obtained vary from 1.2 - 11.2 and 5.0 - 12.7 for soils A and B respectively, with Cr having the highest value in both cases. According to Hakanson (1980), Cd contamination is low while those for Cu and Zn are moderate in soil A. On the other hand, Cu-, Zn- and Cd-contaminations are considerable for soil B, implying that these metals are derived from anthropogenic sources. In view of the fact that the study site is far from urban activities, the most likely source is therefore agricultural inputs. The degrees (C_{deg}) of contamination rank both soils as considerably contaminated; however, the contribution in soil A is mostly attributable to Cr levels while in that of soil B to the other metals (that is, Zn and Cd which are also contaminants).

Potential ecological risk indices of Cu, Zn, Cd and Cr are also shown in Table 4. As for the single-factor pollution, the average values range from 61.1 to 261.0, implying that the potential ecological risk of the metals in both soils are of low ecological risk, with the exception of Cd in soil B which is 204.0. This is rated as a high potential ecological risk. The comprehensive potential ecological risk is higher in soil B with a value of 261.0 attributable mostly to Cd. The input of Cd into the soils of the study area is of great concern because of its high toxic response factor. Agricultural inputs, particularly fungicides, inorganic fertilizers and phosphate fertilizers have variable levels of Cd, Cr, and Zn, depending on their sources. Cadmium enrichment also occurs due to the application of sewage sludge, manure and limes (Yanqun et al., 2005). Cadmium increases are most noticeable in certain crops, particularly in leafy vegetables (lettuce, spinach etc.), which may be consumed by animals or human being (Singh and Kumar, 2006). In addition, cocoa has been reported to accumulate excessive levels of Cd in its beans (Mounicou et al., 2003). Cadmium is highly toxic to human beings and as such, a lot of caution needs to be taken if intercropping is to be practiced in soils B with the use of agrochemicals.

Hazard assessment

Table 5 compares the average bio-available concentrations of heavy metals in the study area with soil quality guidelines, to assess the degree of contamination and potential adverse biological effects. The New York Sediment Criteria and Provincial Sediment Quality Guidelines for metals are divided into low effect range (ISQG-Low) and high effect range (ISQG-High). ISQG-Low level indicates the sediment contaminants would not have adverse effects on aquatic organisms in sediment. ISQG-H level indicates that the sediment contaminant certainly has adverse effects on organisms that live in the

Table 6. Comparison of heavy metals in this study with sediment quality guidelines in µg/g.

Quality guideline	Cu	Zn	Cd	Cr
New York Sediment criteria[a]				
Lowest effects range	16	120	0.6	26
Severe effects range	110	270	9.0	110
Sediment quality criteria[b]				
Lowest effects range (ISQG-Low)	16	120	0.6	26
Severe effects range (ISQG-High)	110	220	10	110
Soils A (This study)	16.2	3.1	0.024	1.17
Soils B (This study)	23.5	18.9	0.340	1.02

[a] New York State Department of Environmental Conservation Division of Fish, Wildlife and Marine Resources, (1993); [b]Wisconsin Department of Natural Resources (2003).

sediment. The level of sediment contamination that is between ISOG-L and ISQG-H also shows that the contaminants probably have adverse effects (Nweke and Ukpai, 2016) (Table 6).

Based on these criteria, the soils under investigation are below the lowest effects and ISQC-L levels for Zn and Cr, indicating that these metal levels are not contaminating. The exception, however is the average value for soils B for Cu, which is quite close (including +SD) to the low effects level. Previous studies have reported the accumulation of Cu in soils treated with Cu-fungicide (Akinnifesi et al., 2006; Aikpokpodion et al., 2013). These studies point out that accumulation of copper in cocoa plantation could be a consequence of continuous, long term use of copper-based fungicides.

Conclusions

The study has revealed the present status of heavy metal contamination of soils under cocoa cultivation in Meme Division, Cameroon. The pollution indices identify the soils, particularly those in Farm B as moderately polluted; implying that continuous application can lead to major contamination problems. The indices, CF and Igeo are high in both soils, with the possibility that Cr content is not influenced by anthropogenic factors, but rather could be rather associated with parent rock composition and atmospheric deposition. The values for these indices point to moderate contamination of levels of Cd, Cu and Zn in soils B, possibly influenced by anthropogenic sources. Among the elements, Cu levels are within the low ISQC sediment criteria in soil B. Its concentration is associated with the long-term application of Cu-fungicide. Cd levels in soils B, are of high ecological risk following the Er index.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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The role of rural women in natural resources management and utilization: A case of Delanta District, South Wollo Zone, Ethiopia

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Natural resources provide any material from the natural environment that can be used by people for support and sustenance of life on earth with its ecological value and manifold resources. The purpose of this study was to explore the role of rural women in natural resources management and utilization in Ethiopia by taking Delanta as the case. The research design was descriptive survey using stratified random sampling technique along the agro-ecology. Both quantitative and qualitative data collected. The target population was 300 sample households from the total of 2992 households in six Kebeles. The data were analyzed using both descriptive (percentage, mean score, cumulative frequency) and inferential (Chi-Square tests) statistical techniques. The results have shown that women are good natural resources managers and the primary gatherers of fuel-wood (76%), fetching water (71%), agriculture participation (83%) and fodder to meet immediate household needs. However, women are culturally denied the right to register and control land resources. Women have also limited access of technology, skill training, education, extension services and information. The depletion of natural resources directly impact on women with increasing workload and drudgery, and the overall livelihood of people who depend on natural resources. Henceforth, women's role in natural resources exploitation and management cannot be undermined. To reinforce and build up women's participation in resources management and sustainable uses, all concerned bodies should take appropriate measures to empower women in decision making, skill training, education, extension services and information.

Key words: Agriculture, environment, natural resources, resources management, resources utilization.

INTRODUCTION

Natural Resource Management (NRM) means the management of resources such as land, water, forest, plants and animals, with a particular focus on how management affects the quality of life for both present and future generations. Without access to resources, there cannot be enough incentive for sustainable NRM

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and consequently rural development is curtailed (Babu and Nautiyal, 2015). The concept of NRM is basically attached with rural development, because the allotment of resources is essential in generating sustainable livelihoods. There needs to be equality in the allocation of resources and support mechanisms, which encourage people to use their resources sustainably (Nyamekye and Oppong-Mensah, 2016).

Natural resources have been crucial for the existence of life on earth which is vital both for lives and livelihoods in the community. They depend directly on natural resources for their livelihoods and ecological benefits. Thus, women are at center of the environment and development nexus. They perform many of the agricultural tasks worldwide, representing 43% of the agricultural labor force in developing countries and over half of all agricultural laborers in sub-Saharan Africa (SOFA Team and Doss, 2011). Women also responsible for small livestock production comprise around two-thirds of livestock keepers' worldwide (Genzebe et al., 2016). They are the primary caretakers of poultry and dairy animals, engaging in the sale of eggs and the production of cheese or other dairy products (SOFA Team and Doss, 2011).

Women are frequently responsible for firewood collection and fetching water, generate substantial income for the family budget from sale of handicrafts, a variety of grown and wild foods, firewood and other products, and care for their children and homesteads. To accomplish their tasks, women are, formally or informally, resource managers (Chen and Ravillion, 2008). Moreover, women play a key role in food production, some 80% of all food produced in Africa is grown at least in part by women (IKNWP, 2013). As an example, women in sub-Saharan Africa are major contributors to the agricultural economy, but face various constraints that limit them from achieving optimal production and agricultural development (Kaaria and Osorio, 2014). Most rural women derive basic resources such as fuelwood, forage, fodder, leaves litter, and non-timber forest products with economic, social, cultural or religious significance from forest ecosystems for their households' livelihoods. Their indigenous knowledge, strategies and roles in conserving and using various plant and animal species found in different ecosystems are very crucial to sustain the environment, their households' livelihoods, and those of their communities (Khadka and Verma, 2012).

However, research has shown that in many contexts, women often have less ownership and access to resources than men, making them more vulnerable to negative changes in the environment to productive resources and opportunities such as land, labour, education, extension, financial services and technology (Mehra and Rojas, 2008). The reduced access to land due to insecurity or damages to local resources, destruction or looting of agricultural infrastructure and equipment, lack of availability of extension services and inputs, and reduced access or loss of markets can all render food production insufficient to meet the daily needs of families and children, which remain the responsibility of women in many cases, and lead to loss of critical income (FAO, 2014). As per Chayal et al. (2013), women are less educated than men, less access to information; extension systems tend to be male-biased. In addition, women have low decision making power than men when it comes to issues of household income allocation, livestock and cash crop production and marketing, and water management, and this is often rooted in cultural and social norms (Akeredolu et al., 2007).

A sustainable practice for management of natural resources to meet the need of life for both the present and future generations is of crucial concern to all societies (Belay, 2016; Agarwal, 2010). The impacts of degraded ecosystem services are being disproportionately borne by the poor, are a principal factor contributing to poverty, and are a barrier to achieving the Millennium Development Goals set by the United Nations (FAO, 2010). The natural resources coverage especially forest, portable water and protection of soil degradations are still very low in Ethiopia. As a result, the distance traveled and time taken to gather fuelwood and to fetch water has negative consequence for health and for economic productivity of women (Belay, 2016). The main burden to feed families and negative impact tends to fall on women, who are traditionally responsible for maintaining the household water supply and on their children. However, the program has problems in its implementation and it is not achieving what it had intended in terms of 'improving women's social status and traditional role structure in water management.

Women in Ethiopia have not shared the fruits of development equally with their male counterpart. Rights such as, access to land, credit and other productive resources are difficult for women to attain (Ogato, 2011; Bremner et al., 2010). They also experience multiple forms of other deprivations such as longer working days, women specific ill health, low levels of education relative to men, and lack of adequate representation in leadership and decision making positions (Agarwal, 2010; Ogato, 2013). Women's role in NRM issue remains collecting, storing and using for various purposes rather than to participate in decision making. This study tries to find out the role of women in NRM practices and performances in Ethiopia Delanta district taking as a case study. Moreover, it presents good practices and lessons for future participatory gender equality and women's empowerment policy formulation, implementation and evaluation in Ethiopia generally in the study area in particular. As it result may help to create a general over view about the status of women society, especially in relation to NRM and women in Delanta district.

Statement of the problem

Over half of the world's poor live in rural areas and depend heavily on natural resources for survival. Assets critical to rural women and men not only for securing food and a livelihood for their household but also for the conservation and sustainable use and management of natural resources (Agarwal, 2010). The key to sustainable environment and NRM is to integrate marginalized rural people into the formal economy. The current trends in population growth and ecosystem health suggest a challenging future for the world's poorest. More than 1.4 billion people live in extreme poverty, their daily income is less than one dollar (Chen and Ravillion, 2008), and many of them depend on degraded ecosystems. The majority of such people are rural women, who have virtually no access to farm-based resources. This lack of resources access also increases women's vulnerability and their livelihood strategies to be dependent on the natural resource base. As natural resources decline, women must dedicate increasing amounts of time to obtaining resources for both sustenance and livelihood needs (New Course, 2010; UN-Women, 2014).

Women and men play different roles in the utilization and management of natural resources including agricultural production. These differences can be specific to cultures, but women tend to have more responsibility for subsistence crops, they collect fuel wood, and contribute more of the labor. Coupled with their domestic responsibilities they have greater demands on their time, and factors that affect labor are likely to have a greater impact on women (New Course, 2010). This gender differences can create 70% of the world's poor women (Solar, 2010) who have less access to financial resources, land resources, education, health and other basic rights like decision making processes than men which also affect NRM in a number of ways. Access to extension advice is also harder for women than men. In many developing countries most extensionists are men, so tend to focus on the tasks and interests of men, and women may be socially inhibited from interacting with male extensionists. Although the situation may have improved in the last two decades, in Africa less than 3% of agricultural advisers and extension workers were female (APF, 2007), and less than 2% of all extension contacts are with women farmers (Blackden, 2006).

The major difference between men and women in NRM including agriculture is their ownership and access to resources. Despite a strong reliance on land and natural resources for survival and livelihood, women own less than 2% of the world's titled land (Coleman, 2008). The lack of land ownership can affect access to other resources, such as credit, water and grazing rights, limiting livelihood options for women and increases vulnerability (Nyamekye and Oppong-Mensah, 2016). More than one fifth of humanity lives in poverty while nearly two-thirds of humanity subsists on less than three dollars per day. All together, the world is hurtling away from environmental sustainability (UN-Women Watch, 2009).

The last two to three decades, the role of women in natural resource management was often overlooked, perhaps because the onlookers were viewing communities through the lense of their own developed country experience and perspective (Fish et al., 2010). With few exceptions, women are at the forefront of the environment and development nexus. In most communities, women have a pivotal role in economic development and in challenging poverty. They are farmers, workers and entrepreneurs, but almost everywhere they face more severe constraints than men in accessing productive resources, markets and services (SOFA Team and Doss, 2011). Their role was seen as that of 'housewife', and in that context the concern of environmentalists was with limiting environmental degradation through population control.

Ethiopia for the last couple of decades has faced serious ecological imbalances due to large scale deforestation and soil erosion caused by improper farming practices, destructive forest exploitation, wildfire and uncontrolled grazing practices (Belay, 2016). This has resulted in a declining agricultural production, water depletion, disturbed hydrological conditions, poverty and food insecurity. One of the keys to successful poverty alleviation is enabling rural poor people to have access to natural resources and to enjoy the new technologies to use resources sustainably (IFAD, 2011). So as to facilitate women's participation in sustainable development process of Ethiopia and the other developing countries, there is a great need to promote changes in policies, laws, structures and attitudes in development programs.

The existing low level of consciousness about the roles of women play in the development of Ethiopia; the deep-rooted cultural beliefs and traditional practices that prevent women from playing their full roles in the development process of the country; lack of appropriate technology to reduce the workload of women; shortage of properly qualified female development agents to understand, motivate and empower rural women by eliminating the major constraints hindering their progress (UN-Women, 2014) motivating to conduct this research on rural women involvements in resources utilization management and their major constraints access to productive resources: the case of six rural communities in Delanta district.

Women have additional roles as mothers along with other productive community work. This takes up much of their time. They can devote that much less time for investment in their human capital and capacity building. Hence, involvement of women in additional conservation work without labor availability and means of production will only increase work load, burden and drudgery for

women. In the Delanta context, sustainable development would depend primarily on a wise use of the existing resources (land, water and forests); reduced exploitation of novel resources and adapting better agricultural practices over time. Proper natural resource management can release more time for women to use on income generation activities, child care and personal development. Hence, this study tries to assess the role of women in NRM in Delanta, a rural community in south Wollo zone Amhara Region, Ethiopia.

Objectives of the study

The general objective of this study was to assess the overall roles and contributions of women in natural resources management and comprehend their constraints to empower women. In line with the general objective, the study explored the following specific objectives:

(1) to assess the overall contribution of rural women in managing natural resources;
(2) to investigate people's awareness and appreciation of natural resources, environmental issues and their effects on resources degradation; and
(3) to establish factors that affect women's involvement in NRM and utilization in the study area.

Research questions

To achieve these objectives, the paper outlined the following research questions:

(1) What are the major roles of rural women in natural resource management and utilization?
(2) How much attention does the community give to environmental issues such as natural resources deprivation and its effect on their livelihood?
(3) What are the major drawbacks that faced women's involvement in resource utilization and management?

MATERIALS AND METHODS

Description of the study area

Delanta is located in South Wollo Zone the Amhara Regional State of Ethiopia which lies between 11° 29' 29.82" to 11° 41' 25.53" N and 39° 02' 19.19" to 39° 14' 05.04" E with an altitude ranging from 1500 to 3819 m above sea level at the bottom of the valleys (Gosh Meda) and the top of the mountain (Mekelet), respectively. Delanta is bordered on the south by the Beshilo River which separated it from the Debub Wollo Zone, on the west by the Dawunt, on the northwest by Wadla, on the northeast by Guba Lafto and on the east by Ambasel. The major town is Wegeltena. It is situated at about 499 km north of Addis Ababa and 98 km northwest of Dessie town in South Wollo Zone (Figure 1).

The major landforms of the District comprise extensive plateaus, chains of hills with mountainous ridge, river-valleys and very deep gorges at the boundary. It is oval in shape with dendritic drainage pattern, steep ridges, and numerous convex hills at the plain area and gorges at the boundary. The area is characterized by the trap series of tertiary periods, similar to much of the central Ethiopian highlands. It is covered by Oligocene rhyolite and very thick ignimbrite units encompassing predominantly of alkaline basalt with numerous inter-bedded flow of trachyte. The granite, gneisses and basalt rock types exist in the area the forming part of the basement complex and most of the soils are basaltic parent material. According to Nahusenay et al. (2014) the soils are predominantly Vertisols, and other types are Cambisols and Leptosols which are greatly influenced by topography with high surface runoff during the main rainy season.

According to WAOR (2013) report, the total area of the district is 98002 ha stretching from lowland to highland, much of it being in the mid-altitude ranges dominated by plateaus. Average land holding size is 1 ha per household (0.75 ha for crop production and 0.25 ha for grazing). The land uses are both private and communal land holdings which can be identified through land use patterns. The largest proportion of the land is currently unutilized which accounts about 45%. Cultivated and grazing lands are the major land use types in the study area.

According to traditional agro-ecological classification of Ethiopia, the area falls in all the categories that basically correlate with elevation. These are *Kolla (lowland)*, *Woina* D*ega (midland)*, *Dega (highland)* and Wurch (very highland). The climate of the area is characterized by dry seasons (from October to February cold-dry and from March to June hot-dry) and wet season (from mid-June to September). The fifteen years mean annual rainfall of the study area is about 812 mm of which 75 to 80% is received in summer (*Kiremt)* and 25 to 20% in the spring (*Belg*) seasons. The mean annual minimum and maximum temperatures of the same period are 6.8 and 19.6°C, respectively. Peoples living on upper elevation, their farming activities primarily depend on *Belg* rains, while those on middle and lower elevation rely on both the *Kiremt* and *Belg* rains. However, there is small, erratic and unreliable rainfall and the area is prone to sporadic droughts.

As per reported by the Central Statistical Agency (CSA, 2008), Delanta has a total population of 132,770 (26554 Households), of whom 66243 (49.89%) are men and the remaining 66528 (50.11%) being women; 8535 (6.43%) are urban and 124236 (93.57%) being rural inhabitants. The district is densely populated area with average family size of five persons per family. The majority of the inhabitants practiced Ethiopian Orthodox Christianity with 90.78% reporting that as their religion, while 9.21% of the population said they were Muslim. The district is divided into 35 Kebeles-the least administrative structure, that is, local districts which are stretched into different agro-ecological zones. The community of the district (Woreda) did not produce sufficient food for year-round consumption even in the normal climate conditions. This is due to severe land degradation, land scarcity, and erratic rainfall (WAOR, 2013).

Design of research, data sources and sampling techniques

The research design was descriptive and survey method using stratified random sampling technique along the agro-ecology. The data collection approaches were both quantitative and qualitative methods. The study was conducted in six Kebeles from the total of 35 Kebeles and 300 household (HH) from the total of 26554 HHs in the district through a structured questionnaires and focus group discussions.

Data types and sources

The research was considered both as the primary and secondary

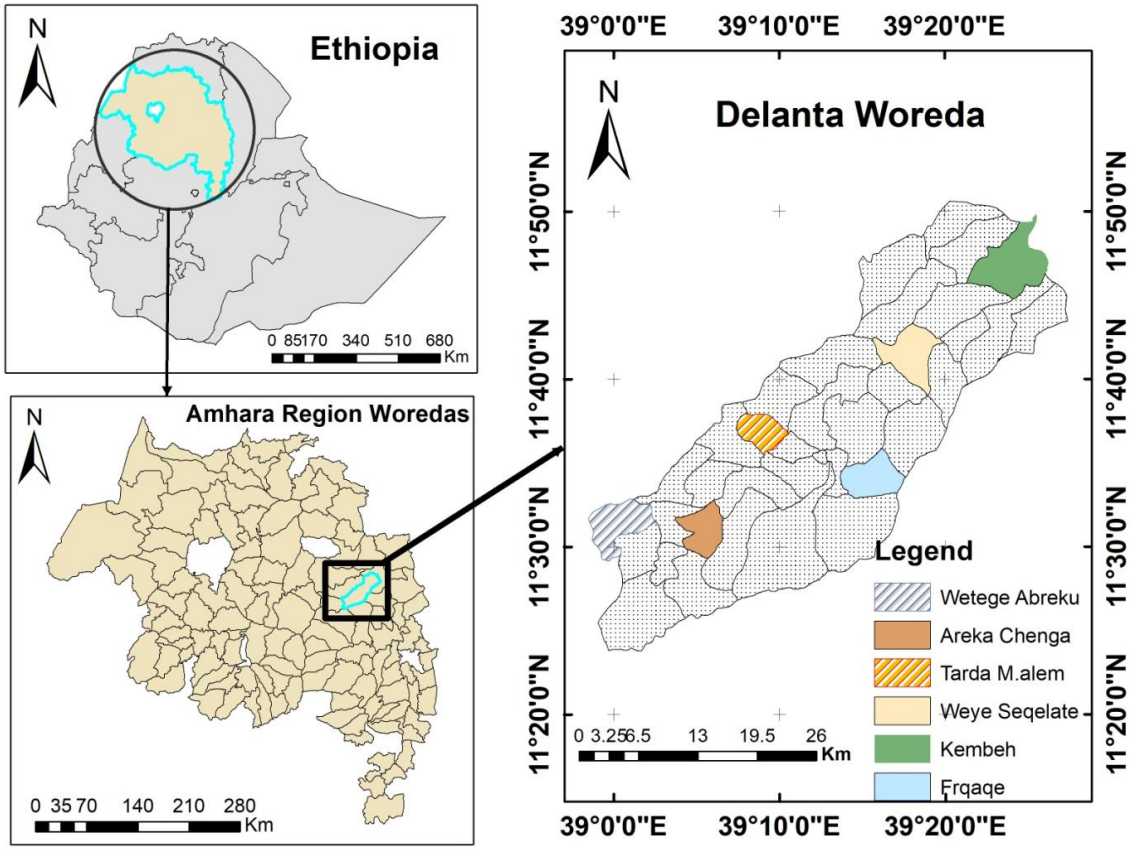

Figure 1. Location map of the study area.

data sources. The primary data were conducted in household surveys which were administered through field observations, questionnaires, formal interviews and focus group discussion with rural women, men, women affair office and other concerned authorities. For this purpose, questionnaires were developed and provided to all key respondents. Most of the items were close-ended and some open-ended questions were also included due to accomplish qualitative information on the attitudes, beliefs and practices of the people. The secondary data were reviewed from published and unpublished documents of governmental and non-governmental organizations to supplement and strengthen the primary data. Historical, cultural, socio-economic backgrounds of the area were also obtained by using secondary data.

To check the appropriateness of the items in the instrument and to make necessary correction on the feedbacks obtained from the respondents, pilot test was administered by randomly taking five men and fifteen women from the non sampled Kebeles. Based on the pre-test results, some improvements were made in preparing the final questionnaires. Finally, 300 copies of the questionnaires were distributed to the key respondents and all of them were filled in and gathered

Sampling techniques

According to the Central Statistical Agency (2009) report, Delanta has a total population of 132770 people of whom 66528 (50.11%) are women and 124236 (93.57%) rural inhabitants. Therefore, the target populations were rural women and to know the attitudes of men towards women's employment, 25% of men were considered from the total sampled population. The sample size was 300 rural households from the total of 2992 HHs in six Kebeles of which 75% of women and 25% men. One of the motives of the survey was to investigate variation in the patterns of agricultural works and coping mechanisms based on agro-ecological variations. To this end, six Kebeles were randomly selected in the earlier stated variations and to make the study manageable, on average 50 household was taken from each rural Kebeles using simple stratified random sampling techniques by altitude, sex and agro-ecological zones (Table 1).

Methods of data analysis

The primary data were analyzed and presented by using both descriptive and inferential statistical techniques. The descriptive techniques include percentage, cumulative frequency, while the inferential statistical techniques used Chi-Square tests. The Chi-Square test was employed to see the association or homogeneity between the agro-ecological zones with reference to responses regarding agricultural works and coping strategies used by peasants during famine (scarcity of food) and its impacts.

RESULTS AND DISCUSSION

The term resource is a broad concept to define and refer

Table 1. Site location of the study peasant associations.

Site name	NRP	Total HHS	Agro-ecological zone
Ferqaqe	48	483	Kolla (Lowland < 2100 m)
Kembeh dega	47	474	Dega (Highland > 2700 m)
Weyesequleho	49	489	Dega (Highland > 2700 m)
Tardate medihanialem	53	532	Woina Dega (Midland b/n 2100 and 2700 m)
Arka-Chinga	52	519	Woina Dega (Midland b/n 2100 and 2700 m)
Wetege-Aberkut	50	495	Kolla (Lowland < 2100 m)
Total	299	2992	-

Source: Based on Field Survey.

to various aspects, but the interest of this study concentrates on farmland, water, forest, agricultural output, household income, women's access to resources and their challenges. It is accepted that the decision-making process is the reflection of the resources control management. The issue of NRM has always been dominated by men, though women in the area generally depend heavily on natural resources for their survival (Mondal, 2013). The degree to which women are involved in the control of the earth's life is just beginning to dawn on most of us. The result showed the key role of women as conservationists and sustainers of the environment. They are highly involved in afforestation, water harvesting and soil conservation programs in the district. However, their roles remain informal and unrecognized. One thing should be clear at the outset: women who are closer to water, forest fuel, fodder and other natural resources than men. The role of women in natural resources management has been investigated under the following broad sub-heads, such as land resource, water resource, forest resource and women's accessible to the resources control.

Women and land resource

Land is one of the most vital natural resources for people and it partly determines the volume of output and the status of a farmer in the social setting of the society. It is a store house for minerals and forest resources of various kinds. This kind of natural capital is mostly controlled by men, while women have limited power to control the resource and have also limited or no access to external inputs such as extension, fertilizer and credits. In the study area, males have the right to register and control land resources, while women are culturally denied such a right except when they are divorce or become widows. In the survey, a further attempt was made to understand the feeling of women regarding the existing land registration practice. None of the respondents have expressed dismay towards the tradition of registering land in the name of their husbands. As the results showed that about 81% of the sampled respondents' said that women and men do not have equal accessible for the land resources (Table 2).

This is due to the inheritance laws, customary laws and cultural norms which are more favorable to men than women in the study area. The Chi-Square test showed that there were significant differences among the three agro-ecological zones with regards to the subjects in question *Woina Dega* (86%) having a higher proportion than *Kolla* (78%) and *Dega* (68%). The question comes why are their differences? As information obtained from sampled respondents and WAOR (2013), these are traditional and cultural influences. This indicates the environment, institution, socioeconomic, cultural norms and demographic factors have prejudiced women's resources accessibility.

The other characteristic of farmland has something to do with the spatial extent fragmentation of plots. It is a common form of landholding arrangement in Ethiopia in general and the study area in particular. Dispersed plots involve distance between homesteads and farmsteads, which demand additional time and labor. In case of possession of distant plots, household members need to travel and transport implements and farm outputs, the time and labor demand of which progressively increases with distance. The round trip to distant plots is quite considerable. The impact is much more serious on women than men due to their double role both in homesteads and farmsteads.

As shown in Table 3, in terms of local measurement, that is, *timad* (approximately 0.25 ha) of the total population about 57% have less than 1 ha of land. The results indicated that 16.5% of the households have below one and one *timad*. The majority of peoples (40.5%) owned 2 to 3 *timads and 3*2.5% of the respondents categorized in 4 to 5 *timads.* The others (10.5%) have above five *timads*. In terms of agro-ecology, peasants in Woina Dega have less farm plots than in Dega and Kolla areas. This has something to do with high population pressure.

Women and water resource

Women gather water and manage it for household use,

Table 2. Degree of accessibility for land resources.

Activity			*Dega*		*Woina Dega*		*Kolla*		Total	
			NRP	%	NRP	%	NRP	%	NRP	%
Do men and women have equally access for land resources?	Yes	Atc.	32	32	14	14	16	22	62	19
		Exp.	24		16		20			
	No	Atc.	68	68	86	86	84	78	238	81
		Exp.	76		84		80			
	Total		100	100	100	100	100	100	300	100

χ^2 = 8.5; C.V = 5.99; p = 0.05; df = 2.
Source: Based on Field Survey.

Table 3. Distribution of respondents by agro-ecology and category of plot size.

Size of plots	Dega		Woina Dega		Kolla		Total	
	NRP	%	NRP	%	NRP	%	NRP	%
Below 1 timad*	10	10	11	11	4	4	25	9
One timad	8	8	7	7	8	8	23	7.5
2-3 timads	30	30	45	45	42	42	117	40.5
4-5 timads	48	48	31	31	20	20	99	32.5
Above 5 timads	4	4	6	6	26	26	36	10.5
Total	100	100	100	100	100	100	300	100

1 timad* is approximately 0.25 ha; NRP: Number of respondents.
Source: Based on Field Survey.

ensuring adequate supply, storing and keeping it clean while stored in the house. They also play key community management roles in domestic water supply at the community level including maintenance of traditional sources. Over centuries, women have acquired extensive knowledge about water quality, health and sanitation. As shown in Table 4, respondents have stated that the main water sources in the district are springs, ponds, rivers and wells (ground water). The tasks of fetching water are exclusively left to women who engaged that about 70.5% of the sampled households. However, children are parts of the community who participate in fetching water [19.5%], especially girls are the ones that carry the greater burden. The participation of men in fetching and carrying water is very low with only 7.5% of them. This implies that any development effort to provide water should be made to alleviate the problems women face due to lack of potable water.

Women are good water managers in the study area. However, many people suffer from water stress on a seasonal and annual basis, due to lack of accessibility and availability of portable water. As the results showed, over half of the villagers in the study area do not attain potable water. Still they have used unsafe water from springs, rivers and ponds. The researcher observed during the field work women still carry water on their back even when they are pregnant and lactating. The situation is particularly worse in *Kolla* agro-ecological zone of which 72% have no access to potable water (Table 5). As was also reported by UN-Women (2014), the proportion of rural women were affected by water scarcity, for example, is estimated at 55% in Africa, 32% in Asia, and 45% in Latin America, with the median time for collecting water in the dry season at 1.6 h per day. If water resources are scarce, it affects both men and women negatively with less productivity. At the same time, it affects women and children more with more workload and drudgery and poorer nutrition as compared to men and boys.

Women in biomass energy consumption and management

Over centuries, women have gathered and managed biomass energy for household consumption. Most domestic energy in rural Ethiopia comes directly from biomass sources which include fuel-wood, charcoal, agricultural residue, animal dung and bushes. The burden of fuel-wood crisis is borne by women's because they have the responsibility for meeting household energy needs through fuel collection, preparation and

Table 4. Gender specific tasks in fetching water

AEZ	Women		Men		Both		Children		Total	
	NRP	%	NRP	%	NRP	%	NRP	%	NRP	%
Dega	66	66	8	8	4	4	22	22	100	25
Woina Dega	71	71	8	8	3	3	18	18	100	50
Kolla	74	74	6	6	0	0	20	20	100	25
Total	211	70.3	22	7.3	7	2.3	60	20.0	300	100

AEZ: Agro-ecological zone; NRP: number of respondents.
Source: Based on Field Survey.

Table 5. Access to potable water in the study area.

AEZ	No. of HHs with access		No. of HHs without access		Total
	NRP	%	NRP	%	NRP
Dega	36	36	64	64	100
Woina Dega	67	67	33	33	100
Kolla	28	28	72	72	100
Total	131	49.5	169	50.5	300

AEZ: Agro-ecological zone; HHs: households.
Source: Based on Field Survey.

use. Fuel-wood preparation, cooking and care of the fire are almost exclusively tasks for women and young girls. Tables 6 and 7 show this fact.

As Table 6 depicts, the majority of the respondents (94%) are used for animal dung. The remaining sources of energy were wood (71%), gas/kerosene (82%) and crop residue (44%). Due to lack of resources and awareness of the people, less mount of charcoal was used in energy consumption. In terms of agro-ecological zones, wood and bushes were highly used in Kolla area than the others. Gas/Kerosene used as electricity during night and not for cooking activities.

Women work long hours in both domestic and economic activities (11 to 14 h per day) have been documented in nearly every country. Compared to men, women in rural areas of developing countries spend long hours working in survival activities such as firewood collection (75%), water hauling (90%), food processing (76%), cooking (100%) and 75% of small animal caring (Table 7) as was also reported by UN-Women (2014), of the total burden of work, women carry on average 53% in developing countries and 51% in industrial countries.

Women and livelihood agriculture

The rural women assist to prepare farm, and then plows, harvests, weeds and transplants, while they do milking and act as a shepherd. Also, they weave carpet, try to make tools and handicrafts, bake bread, cook, do housekeeping duties, fetch water from water sources that are far away, collect firewood, care for children, spin wool and make curd, buttermilk, yogurt, butter and oil. In addition to all these, they are mothers and family supervisors too. The research was tested, women's participation in crop production activities, by using Chi-Square tests to see whether there was any significant difference among the three agro-ecological zones or not. As the results showed that there was a significant difference among the three agro-ecological zones. In case of *Kolla,* 94% of the sampled women respondents have participated regularly in crop production. The participation of women *in Woina Dega* and Dega were 82% and 74%, respectively (Table 8). However, their activities are not considered as economical and they are simply removed from agriculture and rural development programs. In consent with this study World Bank (2002) and Mihiret and Tadesse (2014), in spite of that, rural women in developing countries provide 70% of agricultural labor, 60–80% labor for household food production, 100% labor for processing the basic food stuffs, 80% for food storage and transport from farm to village, 90% for water and fuel wood collection for households and 30% for supervising rural families. This, therefore, suggests that their role in natural resource exploitation and management cannot be undermined.

The questions come why are there differences of women's activities in agro-ecological zones? The reasons for the involvements of women differ in agro-ecological zones, and the types of crops have sown in the area. Some type of crops, namely *teff*, maize, sorghum, some

Table 6. Source of energy consumption.

Energy sources	*Dega*		*Woina Dega*		*Kolla*		Total	
	NRP	%	NRP	%	NRP	%	NRP	%
Animal dung	100	100	100	100	76	76	276	92.0
Wood	56	56	68	68	90	90	214	71.3
Crop residue	24	24	42	42	68	8	134	44.7
Charcoal	10	10	10	10	14	14	34	11.3
Bush/Shrub	16	16	12	12	46	46	74	24.7
Gas/Kerosene	84	84	89	89	64	64	237	79.0

NRP: Number of respondents.
Source: Based on Field Survey.

Table 7. Time allocation to survival activities among women and men (hour per day).

Activity	Dega			Woina dega			Kolla			Total		
	NRP	%	HPD	NRP	%	HPD	NRP	%	HPD	NRP	%	HPD
Firewood collection												
Women	70	70	2.92	82	82	3.42	64	64	2.67	216	75	3.1
Men	30	30	1.25	18	18	0.75	36	36	1.5	84	26	1.06
Water hauling												
Women	92	92	3.83	92	92	3.83	82	84	3.5	266	90	3.75
Men	8	8	0.33	8	8	0.33	16	16	0.67	32	10	0.42
Food processing												
Women	74	74	3.08	82	82	3.42	66	66	2.75	222	76	3.17
Men	26	26	1.08	18	18	0.75	34	34	1.42	78	24	1
Cooking time												
Women	100	100	4.17	100	100	4.17	100	100	4.17	300	100	4.17
Men	0	0	0	0	0	0	0	0	0	0	0	0
Small animal care												
Women	70	70	2.92	82	83	3.46	64	64	2.67	216	75	3.1
Men	30	30	1.25	18	17	0.71	36	36	1.5	84	26	1.06
Mean total work time												
Women	82	82	3.38	88	88	3.66	76	76	3.15	246	83	3.46
Men	18	18	0.78	12	12	0.51	24	24	1.02	54	17	0.71

NRP: Number of respondents; HPD: hours per day.
Source: Based on Field Survey.

pulses have never be sown in *Dega* areas but are commonly found in *Kolla* and *Woina Dega* areas. These types of crops require intensive labor forces, particularly the weeding season. The other reasons might be farm size and household income level. As per the focus group discussants said that the farm size and household income level that determines the degree of women's involvement in crop production. If the farm size is larger, it needs more household labor forces including women. In some cases, the households with high-income level tend to use hired labor, not demand for females labor. The participation of women in agriculture everyday jobs is high in all agro-ecological zones. The only difference is the extent of participation. Women in *Kolla* area are more involved than in *Woina Dega* and *Dega* areas [FGD information during the field work].

Table 8. Women's participation in crop production activities.

Types of activity		*Dega*		*Woina Dega*		*Kolla*		Total	
		NRP	%	NRP	%	NRP	%	NRP	%
Participated	Act	74	74	82	82	94	94	250	83
	Exp	83	-	83	-	83	-	249	-
Not participated	Act	26	26	18	18	6	6	50	17
	Exp	17	-	17	-	17	-	51	-
Total		100	100	100	100	100	100	300	100

χ^2 = 7.23; C.V = 5.99; α = 0.05; df = 2; NRP: Number of respondents.
Source: Based on Field Survey.

Women and resources accessibility

In the study area to see land registration as an example, men have the right to register and control land resources, while women are culturally denied such a right except when they divorce or become widows. In the survey, a further attempt was made to understand the sentiment (attitude) of women regarding the existing land registration practice. None of the respondents have expressed dismay towards the tradition of registering land in the name of their husbands. The other aspect of resource control system is who holds the income derived from various sources. Different sources of income were identified and the respondents were asked to express who hold the money derived from this sources and who ought to hold.

The major income sources are decided and controlled by the husbands, while the minor income sources by wives in all agro-ecological zones. The management of crop production (86%) and large animals including cattle, sheep, goat, and equines (91%) were dominantly performed by the husbands, while the small animals like poultry (84%), dairy products (82%), and 88% of handicrafts (cotton and wool spinning, grass basketry, pottery) and 95% of local liquor (*areky/katicala, tella)* were carried out by women. In case of fuel-wood collection activities, it can be categorized in two ways. If the amount of fuel-wood/construction materials are large in size and quantity, for instance the eucalyptus tree, the resources are mostly managed by men (19%), while less amount and dry woods packed on human beings or animals, and animal manure preparation for fuel activity is carried out by women (81%) (Table 9).

As was also similar results stated by World Bank (2007), traditionally in all of Ethiopian indigenous cultures, public space is considered to be a male domain. Women have had little to say in public matters. They have virtually no decision-making powers with respect to resource distribution at the communal level. At the domestic level, however, women enjoy some limited decision-making power. When talking about the land resource in Ethiopia on a traditional or modern scale, one thinks of the man on the front line. Women are in marginal positions with regards to access, decision and control of resources.

Challenges related to infrastructure and service provisions

Some of the main challenges that face the people of Delanta suffered from food shortage and famines, that is, food quantity and quality (84%) due to the backwardness of agricultural practice, erratic rainfall, small landholdings, recurrent drought, frost and the inappropriate use of resources, lack of transportation (85%), water resource quantity and quality (82%), the shortage of health service facility in the area (74%) and shortage of fuel wood (55%) due to deforestation and related provisions (Table 10). Women are the backbones of socioeconomic circumstances in rural Ethiopia in general and the study area in particular. However, the existence of different taboos and recurrent famines made their lives much more complicated.

When to look at women respondents alone, food quality and quantity (63%), water (62%), health problem (56%), lack of transportation (64%) and fuel-wood (41%) were more susceptible to women in the area (Table 11). As stated earlier, insecure land tenure systems reduces rural women's incentive to improve natural resource management and conservation practices as women have limited access to new technological innovations in agricultural extension programs, skill training and supportive programs, including credit and loan services, installation and maintenance of water or biogas plants are designed mainly to men rather than to women.

CONCLUSIONS AND RECOMMENDATION

Sustainable development in Delanta district depends primarily on a balanced approach that includes biodiversity conservation, sustainable management of existing land and forests, reduced exploitation of new

Table 9. Family asset control in the sampled households

Types of income sources		*Dega*		*Woina Dega*		*Kolla*		Total	
		H	W	H	W	H	W	H	W
Crop productions	NRP	74	26	89	11	94	6	257	43
	%	74	26	89	11	94	6	85.7	14.3
Large animals	NRP	94	6	82	18	98	2	274	26
	%	94	6	82	18	98	2	91.3	8.7
Small animals	NRP	22	78	17	83	10	90	49	251
	%	22	78	17	83	10	90	16.3	83.7
Dairy products	NRP	14	86	10	90	30	70	54	246
	%	14	86	10	90	30	70	18.0	82.0
Handicrafts	NRP	8	92	9	91	20	80	37	263
	%	8	92	9	91	20	80	12.3	87.7
Local beer	NRP	5	95	7	93	4	96	16	284
	%	5	95	7	93	4	96	5.3	94.7
Fuel wood	NRP	4	96	8	92	46	54	68	242
	%	4	96	8	92	46	54	19.3	80.7

H: Husband; W: wife; NRP: number of respondents.
Source: Based on Field Survey.

Table 10. Accessibility of the basic infrastructure and resources.

Activity	*Dega*		*Woina Dega*		*Kolla*		Total		Rank
	NRP	%	NRP	%	NRP	%	NRP	%	
Food (quantity and quality)	94	94	87	87	70	70	251	83.7	2
Lack of health service	68	68	62	62	92	92	222	74.0	4
Fuel-wood shortage	70	70	51	51	44	44	165	55.0	5
Lack of education service	20	20	28	28	28	28	76	25.3	7
Lack of transportation	86	86	89	89	80	80	255	85.0	1
Lack of agricultural inputs	46	46	47	47	38	38	131	43.7	6
Water (quantity and quality)	90	90	73	73	84	84	247	82.3	3

NRP: Number of respondents.
Source: Based on Field Survey.

forest resources, adapting efficient agricultural systems and building proper marketing linkages. Expansion of agricultural area into accessible primary forest should also be checked through adaption of better farming practices. The disparities of gender in terms of work opportunity, income, education and decision-making were observed in Delanta district. Women are excluded from economic opportunities, social network services, and decision making. Such exclusions are related with cultural taboos, backward technologies and partisan religions. In the study area, women do not plough with oxen and men do not cook their food. These are taboos laid against women and men. The agricultural extension training programs hardly have women participants. This further marginalizes women.

Environmental depletion and resource degradation magnify women's workload and drudgery. These are the results of women walk long distances to collect firewood and to fetch water. Women's recognize the natural resources, not only for crop production but also for fuel

Table 11. Women respondents alone based on the agro-ecology zones.

Activity	*Dega*		*Woina Dega*		*Kolla*		Total	
	NRP	%	NRM	%	NRP	%	NRP	%
Food (quantity and quality)	71	70.5	65	65.3	53	52.5	188	62.8
Lack of health service	51	51.0	47	46.5	69	69.0	167	55.5
Fuel-wood shortage	53	52.5	38	38.3	33	33.0	124	41.3
Lack of education service	15	15.0	21	21.0	21	21.0	57	19.0
Lack of transportation	65	64.5	67	66.8	60	60.0	191	63.8
Lack of agricultural inputs	35	34.5	35	35.3	29	28.5	98	32.8
Water (quantity and quality)	68	67.5	55	54.8	63	63.0	185	61.8

NRP: Number of respondents.
Source: Based on Field Survey.

and water, and incorporating these concerns into plans and policies for environmental management would release more time for women for income generation, child care and personal development. Women are much closer to water, forest or fuel-wood, fodder and land resources than other members of the community make them indispensable for managing natural resources. Generally speaking, they are conservationists and sustainers of the natural environment in the study area. Therefore, recognition and empowerment of women in these and many other roles could accelerate the conservation and proper use of natural resources.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Wildlife harvesting and bushmeat trade in Rivers State, Nigeria: The resilience of the African civet, *Civettictis civetta* (Carnivora: Viverridae) and records of rare species

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The first step in making exploitation of wildlife more sustainable is to determine the sustainability of current levels of harvest, which has two components: determining the offtake from an area and appraising the effect that this offtake has on species. The exploitation of wildlife from the catchment area of a major bushmeat market at Omagwa, in the eastern Niger Delta was initiated in 2005. Analyses of 2019 results are presented. The vegetation in the catchment area is not uniform lowland rainforest. Data on numbers of different species brought to the market were collected daily; after counting, the unsold carcasses were dismembered smoked and sold. Weekly numbers were pooled and monthly totals obtained. The sums of the 2-monthly totals collected in the rainy season of 2005, 2009, 2014 and 2019 were analyzed. Standard keys were used for identification. In 2005, *Thryonomys swinderianus* was dominant. The dominance of *T. swinderianus* was repeated in 2009. In 2014, there was no dominant species, although *T. swinderianus* constituted approximately 30%; the addition of the numbers of *Tragelaphus spekei, Cercopithecus mona, Xerus erythopus and Atherurus africanus* increased the figure to about 90%. In 2019, Civecttictis civetta rose to 43.12%, a 7-fold increase over the 2014 figure while that of *T. swinderianus* was 32%. Two rare species *Panthera pardus* and *G. alleni*, which had not been collected, were recorded. *Civecttitis civetta* conservation is recommended. It may serve as a flagship or ambassador species for the conservation of the large carnivore *Panthera pardus* and the primate Galago alleni.

Key words: Carnivores, conservation, *Civettictis civetta*, resilience, ambassador species, Niger Delta.

INTRODUCTION

Bushmeat is an African term for the meat of wildlife. These animals are captured by indigenous people for income and subsistence (Colishaw et al., 2004). In Sub-Saharan Africa, the proportion of wild animal meat in total

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Table 1. Numbers of Carcasses at Omagwa over 2 months in the rainy season (2005-2019)

S/N	Species name		Year of study			
	Common	Scientific	2005	2009	2014	2019
1	African Civet Cat	*Civettictis civetta*	89 (3.98%)	226(3.37%)	457 (6.88%)	2040 (43.12%)
2	Brush-tailed Porcupine	*Artherurus africanus*	320 (14.31%)	557(8.30%)	608 (9.15%)	280 (5.91%)
3	Bush Baby	*Galago alleni*				10 (0.21%)[#]
4	Emin's Giant Rat	*Cricetomys emini*				396 (8.37%)
5	Forest Genet	*Genetta poensis/G. cristata*	68 (3.04%)	179(2.67%)	54 (0.81%)	14 (0.29%)
6	Geoffrey's Ground Squirrel	*Xerus erythopus*	49 (2.19%)	99(1.48%)	983 (14.80%)	9 (0.19%)
7	Greater Cane Rat	*Thryonomus swinderianus*	1356 (60.67%)	4160 (61.98%)	1975 (29.74%)	1523 (32%)
8	Guinea Fowl	*Numida meleagris galeata*	69 (3.09%)	294(4.38%)	170 (2.56%)	116 (2.15%)
9	Leopard	*Panthera pardus*				7 (0.14%)
10	Maxwell's Duiker	*Cephalophus maxwelli*	123 (5.50%)	737(10.98%)	187 (2.81%)	206 (4.35%)
11	Mona Monkey	*Cercopithecus mona*	49 (2.19%)	136(2.02%)	1246 (18.76%)	21 (0.44%)
12	Red River Hog	*Potamochoerus porcus*	47 (2.10%)	92(1.37%)	210 (3.16%)	34 (0.71%)
13	Rufus Mouse-eared Bat	*Myotis alleni*				24 (0.50%)
14	Sitatunga	*Tragelaphus spekei*	65 (2.91%)	231(3.44%)	750 (11.29%)	51 (1.07)
Total			**2235**	**6711**	**6640**	**4731**

Sources: Okiwelu et al. (2008, 2010); Nzeako et al. (2016); Noutcha et al. (2017), [#]percent of annual total of all species.

protein supplies is exceptionally high. The determining factor influencing wild animal consumption appears to be the adequacy of supply. African civet *Civettictis civetta* is a small carnivore found in countries across equatorial and eastern Africa. It is sought after because it is the source of civetone, an important fixative in perfume manufacture (Rails, 1971), which is extracted from "civet", a waxy substance produced by the perineal glands of both sexes for scent marking (Eisenberg and Kleiman, 1972; Mateos et al., 2015). Only one species of the genus *Civettictis* has been recorded in Nigeria. The distribution extends throughout the rainforest and savannah zones of the country. They are nocturnal, terrestrial and secretive carnivores. *C. civetta* also consumes maize (Mateos et al., 2015). They are well camouflaged by their distinctive pelage which blends with the light and dark patches in dense vegetation (Happold, 1987).

In 2005, the African civet number over a 2-month period was 89 and constituted 3.98% of all mammals recorded at the Omagwa bushmeat market. In 2009, there was a 2.5-fold increase to 226 which constituted 3.37% of all mammals collected. In 2014, there was, a 2-fold increase to 457, over the 2009 total of African civet and it constituted 6.88% of all mammals collected (Table 1), (Okiwelu et al., 2008; 2010; Nzeako et al., 2016; Noutcha et al., 2017). This study was undertaken to assess changes in populations of fauna in the catchment area of the bushmeat market in 2019, 5 years later.

MATERIALS AND METHODS

The Omagwa bushmeat market, the largest in the eastern Niger Delta, Nigeria receives carcasses from as far afield as a radius of approximately 80 km. The vegetation of the catchment area is not uniform lowland rainforest. It consists of deforested plantation-savannah, flood forest, secondary rainforest, Marsh deltaic forest, Mangrove and barrier islands (Luiselli et al., 2015). The detailed keys of Happold (1987) and Kingdom (1979) were used for the identification of wildlife. Data on numbers of different species brought to the market were collected daily; after counting, the unsold carcasses were dismembered, smoked and sold. Weekly numbers were pooled and monthly totals obtained. The sums of the 2-monthly totals collected in the rainy season of 2005, 2009, 2014 and 2019 are presented in Table 1 (Okiwelu et al., 2008; 2010; Nzeako et al., 2016; Noutcha et al., 2017).

RESULTS

In 2005, there was a dominant species, *Thryonomys swinderianus*, constituting 60.67%; when the number of *Artherurus africanus* was added, this percent rose to 75% of the total carcasses. In 2009, that same species, *T. swinderiaus,* constituted more than 60% of carcasses and when the numbers of *A. africanus* and *Cephalophus maxwelli* were added the total rose to more than 80%. In 2014, five species (*T. swinderianus*, *Cercopithecus mona, Xerus erythopus, Tragelaphus spekei, Artherurus africanus*) constituted about 90% of carcasses. In 2019, *Civettictis civetta* carcasses rose to 43.12%, a 7-fold increase over the 2014 figures; when the percent of *T. swinderianus* was added, both species constituted 75.12% of all carcasses. The numbers of *C. civetta* carcasses in 2005 were 89 (3.98%), 226 (3.37%) in 2009, 457 (6.88%) in 2014 and 2040 (43.12%) in 2019. Two rare species, a large carnivore (*Panthera pardus*) and an ape (Galagos), *Galago alleni* were also collected in 2019.

DISCUSSION

Over the 15-year period, there were approximately 2-fold increases in the numbers of *C. civetta* in 2005, 2009 and 2014. In 2019, the increase was about 7-fold over the 2014 figure, constituting more than 43.12% of total carcasses collected in the late rainy season. The numbers would probably have been higher, if the collections were made in the dry season, the reproductive season (Happold, 1987). The resilience might also be partly dependent on the ability of *C. civetta* to occupy varied vegetation zones. In the eastern Niger Delta, it was recorded in extensively deforested plantation-savanna mosaic, flood forest, marsh deltaic forest, mangrove forest, barrier islands (Luiselli et al., 2015). The significant increase in the number of *C. civetta* might also not be unconnected with the sudden discovery by entrepreneurs of the economic importance of *C. civetta.* The dominance of a wildlife community by a few generalists had been described by Petrozzi (2015) as a process of biotic homogenization. The outcome is often a reduction and simplification of community richness (La Sorte, 2006; Devictor et al., 2008).

This was the first record of *P. pardus* carcasses at the Omagwa bushmeat market, the dominant market in the eastern Niger Delta, over a 15-year period. Carcasses were received from locations approximately 80Km far afield in the rainforest-savanna ecotone. Leopard skins, skulls, bones and reliable hunters' accounts had indicated the presence of the species in the Niger Delta (Angelici et al., 1998; Ikemeh, 2007a, b). The Africa civet *C. civetta* may serve as ambassador species (Macdonald et al., 2017) for the conservation of larger carnivores that include leopards. The elusive nature of *G. alleni* may be related to their behavior. They are nocturnal, live in rainforest undergrowth of saplings, shrubs, creepers and occasionally in leaf litter. The earliest record of *G. alleni* from the area was at Elele, 15 km north of Omagwa (Jewell and Oates, 1969). Since identification was exclusively morphological, the forest genet could have been *Genetta cristata* because of speciation of genets in West Africa (Gaubert, 2013).

Conclusion

Conservation of *C. civetta* is recommended. It may serve as flagship or ambassador species for the conservation of the large carnivore, *P. pardus* and the primate, *G. alleni.*

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Quantifying poached wildlife mammal species in Center-western region of Côte d'Ivoire

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Poaching or illegal hunting of wildlife for bushmeat is common in Côte d'Ivoire and particularly in center-western regions where it is actually a major income source contrary to traditional livelihood need. In order to assess the threat and impact of illegal bushmeat off take on sustainable biodiversity and conservation of wildlife resources to fill the information gap we examined the quality and quantity of extracted wildlife fauna for bushmeat in these regions from September 2018 to April 2019. Forty-seven bushmeat data collection sites were considered. Data collection was designed to collect information on the species poached, quantity, sex of poached animals, age estimate as well as poaching methods. A total of 352 wildlife mammals corresponding to 8 orders and 18 species was collected from bushmeat traders and markets. The order of rodents comes largely in the lead with more than half of the specimens encountered that is, 67.05% and the grass cutter species, *Thryonomys swinderianusis* the most poached and the only one found in all the sites investigated. A significant sex-specific pressure ($p<0.009$) was noted. Despite 77.78% of the species collected are classified minor concern, it is undeniable that the conservation status of wildlife biodiversity will always be threatened by illegal hunting. It is therefore up to the state authorities to officially cover hunting with clear control measures for the sustainable management of wildlife biodiversity.

Key words: Bushmeat, illegal hunting, poaching, biodiversity, wildlife, harvest, conservation.

INTRODUCTION

Bushmeat, defined as meat and organs derived from wildlife species has always been a source of food for humans living in rural areas in many parts of the world (Milner-Gulland and Bennett, 2003). Todays, consumption of bushmeat, besides being an important source of protein for rural households, has implications for food security and income generation for millions of people in tropical areas (Nasi et al., 2008). Bushmeat is increasingly

becoming a preferred meat compared to domestic meat for urban populations in many African countries (Codjia and Assogbadjo, 2004; Williamson and Bakker, 2017).

However, current population growth, increased access of hunters to row forests due to expansion of roads, marketing of bushmeat in large urban cities, taste preference and illegal hunting procedure have resulted in hunting and related bushmeat trade activities which negatively impact wildlife worldwide, with serious implications for biodiversity conservation (Chaves et al., 2019; Gonçalves et al., 2019).

In most areas where hunting has been studied, vertebrates represent almost all of the meat of wild animals consumed and traded. By category, mammals are the most common (Pimm et al., 2014). Around the 1990s, it was estimated that more than 5 million tons of wild mammals' meat were consumed each year, including 4.9 million tons in tropical Africa areas (Fa and Peres, 2001). More recent estimates suggest that almost six million tons of wild mammal meat are consumed each year in the neo-tropical and tropical Africa regions (Nasi et al., 2011), with up to 301 species of terrestrial mammals currently threatened with extinction (Ripple et al, 2016).

In Côte d'Ivoire, during decades, biodiversity has been subject to various pressures such as extensive slash-and-burn agriculture, agro-industrial plantations, uncontrolled exploitation of forest products and unauthorized hunting (Goné Bi et al., 2013) although around independence first years, a series of laws aimed at creating national parks, natural reserves and protected forests for biodiversity purpose has been adopted (Monza, 1996). Currently, many households, in both rural and urban areas depend on wildlife resources for their livelihoods and as a source of income with serious impact on biodiversity (Fa and Brown, 2009; Gonédélé et al., 2017). Despite the growing offtake bushmeat leading to biodiversity threatened in Côte d'Ivoire, scientific literature to quantify the importance of the concern are scarce leading to lack of information. The objective of this work is to examine the diversity and quantity of species hunted in Center-western Côte d'Ivoire to raise awareness to policymakers for conservation strategies.

METHODOLOGY

Study area and sampling sites

Bonon, Daloa, Gonaté, Issia, Sinfra, Vavoua and Zoukougbeu are Ivorian cities located in the Central-western part of the country, visited to collect specimen and information on the bushmeat poaching and trade. This area straddles savannah and forest vegetation, surround the Marahoué National Park and numerous protected forests, with the most important being the Haut-Sassandra protected forest. The climate is shared between a warm and humid equatorial on one hand and a subtropical on other hand. The main activity is agriculture with numerous coffee and cocoa plantations.

Forty-seven sample collection sites were visited, including nine in Bonon, nine in Daloa, four in Gonaté, five in Issia, seven in Sinfra, eight in Vavoua and five in Zoukougbeu (Figure 1) according to the availability of traders.

Data collection

Collection of bushmeat samples was conducted over 8 months' period (September 2018- April 2019) in cities mentioned above in 47 collection sites. The bushmeat sample collectors were introduced to traders to develop mutual confidence. Each site was surveyed two time per day (from 6:30 a.m. to 10:00 a.m. and from 4:00 p.m. to 6:30 p.m.) looking for availability of bushmeat based on testimonials bushmeat traders during a pre-survey phase. These two visits time correspond to the usual delivery times for hunters or suppliers. Unexpected visits are sometimes carried out in addition to regular visits time.

When a bushmeat is found, morphological identification of the species is made based on the field guide of Jonathan Kingdon (Kingdon, 1997). In some cases, we relied on local knowledge for identification. Interviews to traders were conducted either in French or local languages to get information about hunting tools, local knowledge on species, most preferred species etc.

Data analysis

Qualitative and quantitative parameters of illegal hunting species and links between the hunting grounds and the samples were assessed with the following calculations:

(i) The Relative Abundance Index (RAI) with the formula: RAI (%) = ni / N × 100
with RAI the relative abundance, ni the number of individuals of the species considered and N the total number of individuals of all species combined;
(ii) Shannon - Weaver (H') specific diversity index applied to the species killed with the formula:

$$H' = -\sum [(ni / N) \log2 (ni / N)]$$

where H' represented the specific diversity, ∑ the sum of the results obtained for each of the species represented, ni the size of the species i, N the total number of individuals observed with respect to all the species together;
(iii) Simpson Index (S) was calculate with the formula:

$$\lambda = \sum_{i=1}^{R} p_i^2,$$

and measure the degree of concentration when individuals are classified into subtypes or the probability that two entities taken at random from the dataset of interest represent the same subtype. R the richness is the total number of types in the dataset and pi the

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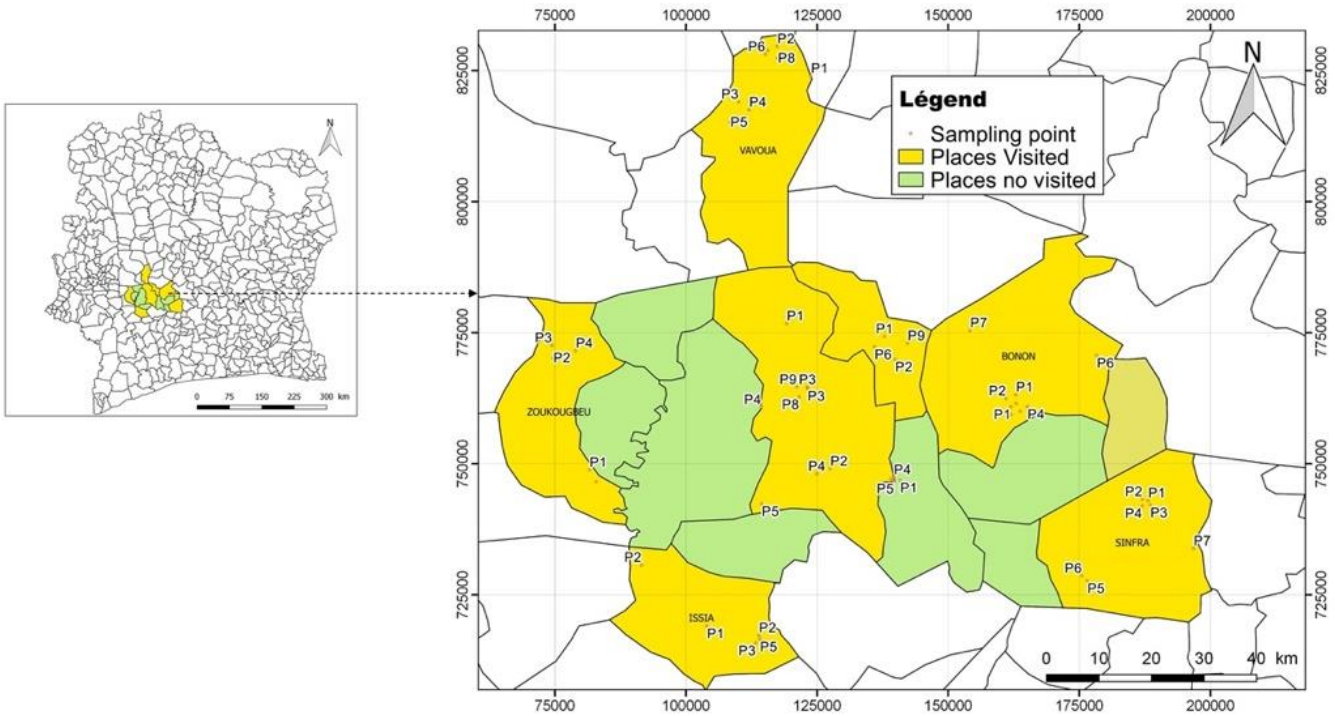

Figure 1. Bushmeat sales outlets in seven cities in the Center-West of Côte d'Ivoire.

arithmetic mean weighted of the proportional abundances of the types of interest.

(iv) Fairness index (J) was used to estimate the distribution of species within the surveys by evaluating the proportion of dominant and dominated species and calculated from the value of H' and the specific richness S with the formula:

$$J = H' / H_{max} = H'/ \log_2 (S).$$

(v) Poaching pressure on wildlife species was the analysis regarding sex of the species slaughtered, the age group and physiological state of the females using generalized linear mixed effect models (Bolker et al., 2009) with the lme4 package (Bates et al., 2015).

The conservation status was analyzed using local information and that provided by IUCN website (www.iucnredlist.org)(IUCN, 2020).

RESULTS

Diversity and abundance of wildlife poached and trade

A total of 352 wildlife mammals corresponding to 8 orders and 18 species was collected from bushmeat traders and markets of the seven cities visited. The site from Vavoua area provided a greater number of bushmeat (69) corresponding to 13 out of 18 species observed. The order of rodents comes largely in the lead with more than half of the specimens encountered that is, (67.05%). The primate order was represented by one species, *Cercopithecus petaurista,* only found in Daloa and Issia (Table 1 and Figure 2). At the specific level, the grass cutter species *Thryonomys swinderianus* is the most poached species (141 out of the 352 specimens collected) and the only one found on all the sites investigated. It presents a substantially equal abundance in all the regions visited and is followed by the species *Cricetomys gambianus*, both belonging to the rodent order (Table 1 and Figure 3). Two species *Funisciurus* sp and *Dendrohyrax dorsalis sylvestris* were observed only once each at Vavoua and Gonaté respectively.

The overall Shannon H index observed on all the sites visited is equal to 2.03 with more or less significant differences between the sites. The Gonaté site has the highest H index, while the Daloa site has the lowest H index, reflecting a great disparity in the abundance of species on this site. Regarding the spatial distribution of species, the Global Fairness Index of 0.70 reflects the lack of fairness between the different poached species and their numbers. However, with a fairness index of 0.84, close to 1, Gonaté's site tends towards a fairness between species and number of animals killed (Table 2).

Wildlife slaughter pressure and conservation status

The pressure on wildlife was measured taking into account the age of the animals slaughtered, the gestational status, the poaching method and the sex. Our investigations showed that there is a significant difference ($p < 0.001$) between adults and juveniles poached; adults

Table 1. Order, species and number of wildlife hunted in study site in survey period.

Order	Animal species	Visited localities							Total
		BONON	DALOA	GONATE	ISSIA	SINFRA	VAVOUA	ZOUKOUGBEU	
Rodentia	*Cricetomys gambianus*	9	-	13	-	13	13	2	50
	Funisciurus sp.	-	-	-	-		1	-	1
	Thryonomys swinderianus	22	26	11	33	22	13	14	141
	Xerus erythropus	5	-	7	-	6	16	2	36
	Atherurus africanus	1	1	1	1	-	3	1	8
	Philantomba maxwellii	5	-	1	2	-	1	-	9
	Cephalophus dorsalis	-	-	-	-	-	3	-	3
	Phacochoerus aethiopicus africanus	-	1	-	-	-	1	-	2
Artiodactyla	*Tragelaphus scriptus*	2	3	3	8	-	9	6	31
	Civettictis civetta	3	1	2	-	4	1	1	12
	Genetta pardina	1	-	4	-	-	3	-	8
	Atilax paludinosus	-	-	-	2	-	-	-	2
Carnivora	*Galerella sanguinea*	-	-	1	-	1	3	-	5
Primates	*Cercopithecus petaurista*	-	4	-	2	-	-	-	8
Pholidota	*Manis tricuspis*	-	-	1	2	-	-	-	3
Lagomorpha	*Lepus microtis*	-	-	6	-	6	2	-	23
Hyracoidea	*Dendrohyrax dorsalis sylvestris*	-	-	1	-	-	-	-	1
Chiroptera	*Eidolon helvum*	-	6	-	3	-	-	-	9
Total		59	42	51	53	52	69	26	352

being the most hunted. However, there is a selective pressure according to sex ($p < 0.009$) with male the most poached animals (Table 3). The most common method used by illegal hunters is the rifle ($p=0.001$) from afar followed by the snares although the later has low cost (Table 4). There are significantly more non-pregnant females killed ($p<0.001$), although the 13.86% of pregnant females killed is not negligible at all (Figure 4).

This pressure can also be examined by assessing the poached species included in the IUCN red list (Table 5). It appears that 77, 78% of the species collected are classified Least concern (LC) and only 5.55% endangered (EN) and 16.67% classified as almost threatened. At the local level, according to the protection criteria in Côte d'Ivoire, 83.83% of the species are considered to be abundant whereas the Western tree hyrax considered LC by IUCN is found in the category of rare species (Table 5).

DISCUSSION

Illegal hunting or poaching can have direct effects on wildlife populations and indirect effects on the functioning, structure and composition of the ecosystems of which they are part (Nasi et al., 2010). Evidence of the effects of depletion exists in some African regions where more than half of the forest mammals are considered to be hunted unsustainably (Fa and Peres 2001; Fa et al., 2002).

In this region of Center-West of Côte d'Ivoire which is the subject of our study, the period from September to April corresponds to the period where poaching is most practiced unlike the period from May to August, period of heavy rains, devoted to agricultural activities. The period of our investigation therefore provides a real view of the diversity and abundance of bushmeat harvesting. It appears that the wild fauna commonly poached and sold in restaurants in west-central Côte d'Ivoire is largely made up of small mammal

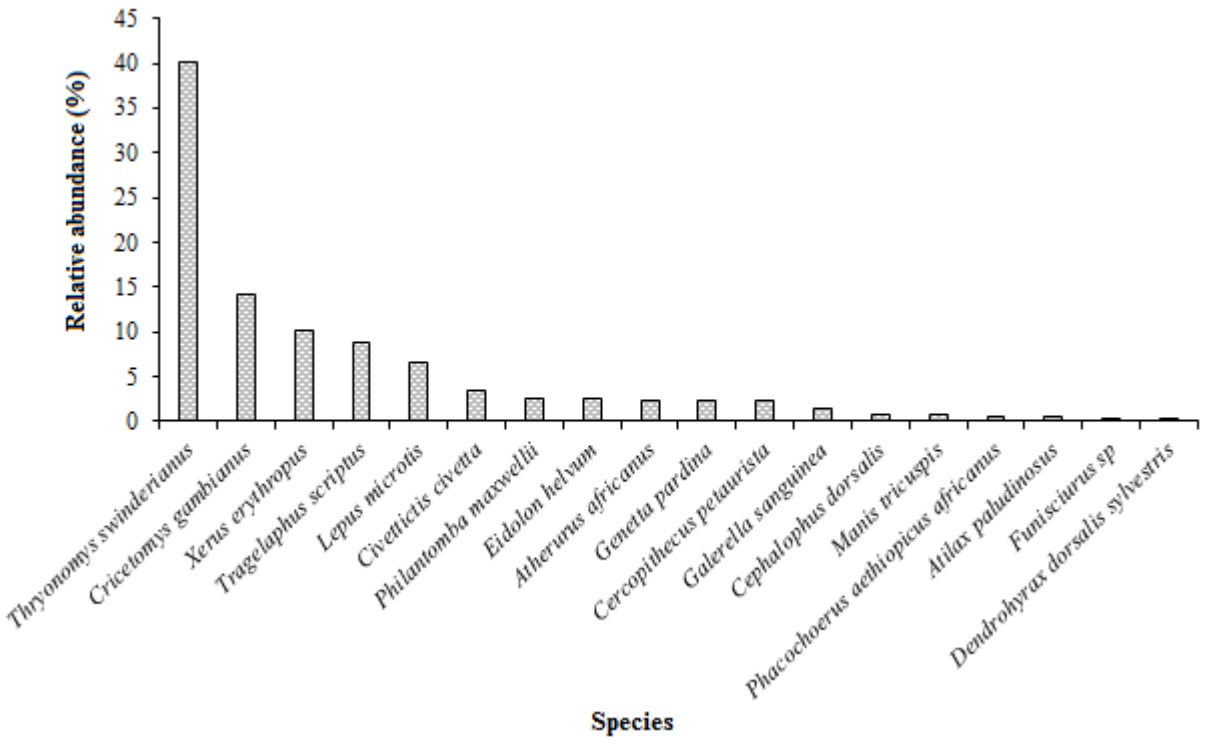

Figure 2. Comparative abundance of bushmeat species in whole area surveyed.

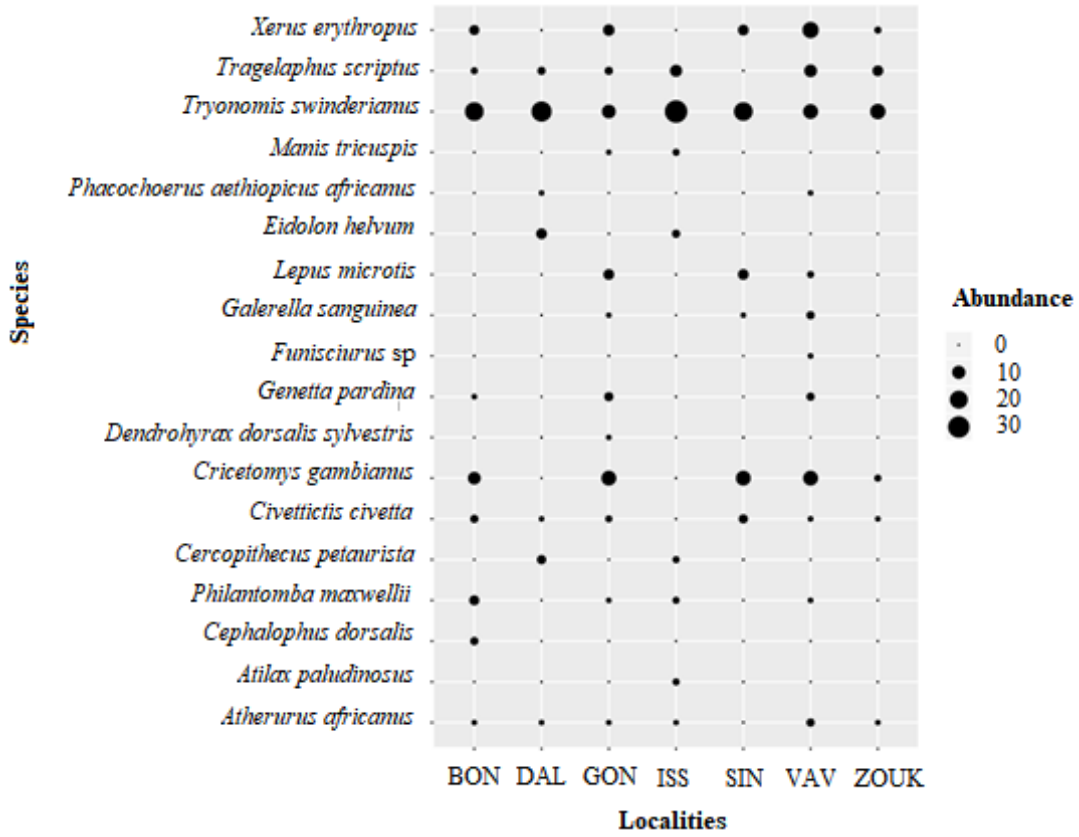

Figure 3. Abundance of bushmeat species traded according to visited localities.

Table 2. Index of diversity of bushmeat in the localities surveyed and throughout the study area.

Index	Localities surveyed							
	BON	**DAL**	**GON**	**ISS**	***SIN***	***VAV***	***ZOUK***	***Global***
Shannon-Weaver (H')	1.74	1.25	2.08	1.31	1.48	2.04	1.32	2.03
Simpson (SI)	0.75	0.58	0.84	0.58	0.73	0.84	0.64	0.78
Equitability (J)	0.79	0.64	0.84	0.63	0.83	0.82	0.74	0.70
Species richness (S)	9	7	12	8	6	13	6	18

BON: Bonon, DAL: Daloa, GON: Gonate, ISS: Issia, SIN: Sinfra, VAV: Vavoua, ZOUK: Zoukougbeu.

Table 3. Sex- and age-specific impact of poaching mortality in regions surveyed.

Parameter	Age categories				*Sex of animals*			
	Adults	**Juveniles**	***t***	***P***	**Females**	**Males**	***t***	***p***
Total	339	13			123	229		
Meanabundance (± sd)	48.4 ±12.8	1.8 ± 0.6	9.5	< 0.001	17.57 ±	32.71± 10.8	3.10	0.009

Table 4. Prevalence of methods used to hunt wildlife for bushmeat in center-western region in Côte d'Ivoire.

	Poaching methods				
	Dogs	**Rifles**	**Snares**	**Others**	**P**
Number of poached wildlife	23	277	34	18	
(%)	6.53	78.7	9.66	5.11	0.001

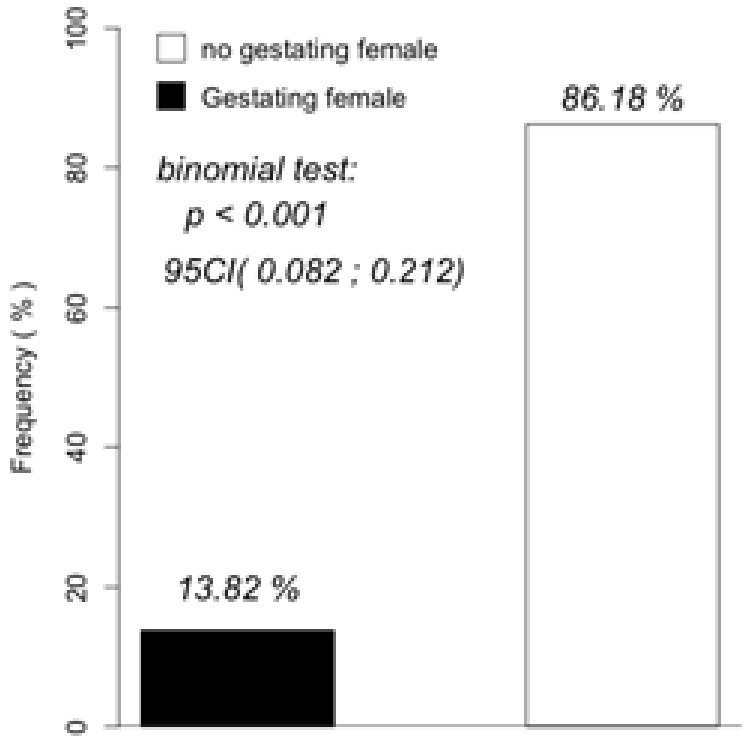

Figure 4. Gestational status of poached females.

Table 5. Wildlife conservation status in Côte d'Ivoire and international level.

Order	Animal species	Common name of species	Conservation status	
			UICN 2020	Local
Rodentia	*Cricetomys gambianus*	Gambian rat	LC	XXX
	Funisciurus sp	Squirrel	LC	XXX
	Thryonomys swinderianus	Marsh cane rat	LC	XXX
	Xerus erythropus	Striped ground squirrel	LC	XXX
Artiodactyla	*Atherurus africanus*	African Brush-tailed porcupine	LC	XX
	Philantomba maxwellii	Maxwell's duiker	LC	XXX
	Cephalophus dorsalis	Bay duiker	NT	X
	Phacochoerus aethiopicus africanus	Common warthog	LC	XXX
	Tragelaphus scriptus	Bushbuck	LC	XXX
Carnivora	*Civettictis civetta*	African civet	LC	XXX
	Genetta pardina	Pardine genet	LC	XXX
	Atilax paludinosus	Marsh mangoose	LC	XX
	Galerella sanguinea	Slender mangoose	LC	XXX
Primates	*Cercopithecus petaurista*	Spot nosed monkey	NT	XX
Pholidota	*Manis tricuspis*	White-bellied pangolin	EN	X
Lagomorpha	*Lepus microtis*	African savanna hare	LC	XXX
Hyracoidea	*Dendrohyrax dorsalis sylvestris*	Western tree hyrax	LC	X
Chiroptera	*Eidolon helvum*	African straw-coloured fruit-bat	NT	XXX

LC : Least concern ; NT: Near threatened; EN: Endangered; XXX : Abundant species; XX : Scarce species; X : Rare species.

species mainly from the rodent order (67.05%) and to a lesser extent, from the order of Lagomorpha (6.23%) as already observed in other regions of Côte d'Ivoire (Gonedelé et al., 2017).

Given the important role of mammals as key indicators for measuring anthropogenic impacts on biota (Ceballos and Ehrlich, 2002), and the maintenance and functionality of ecosystems through seed and fruit dispersal, pollination, nutrient recycling, and plant succession (Davidson et al., 2012; Ripple et al., 2015), the large poaching of small species that we observed testifies the strong threats to which the wild fauna of this part of the country is subject. In fact, a large part of the forest area in this region of west-central Côte d'Ivoire has been destroyed in favor of cash crops (coffee, cocoa, hevea) or fallow (Sangne et al., 2015; Kouakou et al., 2015) immediately removing large mammals. The current landscape of this region of the country is ideal for the survival of small species where hunting activities are practiced (Gonedelé Bi et al., 2017; Chabi-Boni et al, 2019). The high specific diversity of small mammals observed is in agreement with the studies of Ahmadi et al which affirm that the small species are slaughtered in fields and fallows close to rural habitats while the large species are slaughtered in reserves and protected areas in tropical countries, far from the places where hunters live (Ahmadi et al., 2018).

The mostly poached species is the grass cutter *T. swinderianus*, which alone represents almost half (40.06%) of the wild animals killed and observed in our sampling sites. It is the most abundant in all the sites visited, except in Vavoua where the species *Xerus erythropus* was the most encountered. This confirms the results of our pre-surveys which revealed that the grass cutter was the most popular and observed species in the bushmeat sector in the Haut-Sassandra region. These results are in agreement with studies on the trophic preferences of bushmeat in Ghana, where grass cutter was undoubtedly the most popular and consumed meat with 73% of all poached species (Kuukyi et al., 2014). This strong distribution of the grass cutter in all the sites investigated could be explained by the fact that hunting takes place for the most part in the dry season when water points are scarce and only rivers and their banks attract the animals which come there to drink. Aware of this situation, the hunters in the region made fallows and gallery forests, their preferred hunting area. Fortunately, local conservation data show that grass cutter remains abundant in Côte d'Ivoire and does not suffer from extinction. In addition, research is well advanced for the domestication of grass cutter species in West Africa (Falade et al., 2010; Ibitoye et al., 2019). When wildlife harvesting is not controlled, as it is the case here, when it is poached, the consequences for animal populations and biodiversity are disastrous. Indeed, the results of this study show that juvenile populations and pregnant females do not benefit from preferential treatment from hunters. They are slaughtered in the same way as adults

and non-pregnant even if the proportions remain statistically insignificant. This has already been observed by other researchers working on the conservation of wildlife biodiversity and the inventory of wildlife and wildlife resources in Côte d'Ivoire (Dufour et al., 2015). Animals slaughtered without distinction of sex, age or physiological state exacerbated by a noticeable over-exploitation preventing populations from rebuilding causes the extinction of species. In addition to demographic concern on small populations, age and sex-biased poaching prevalence may contrast sustainable ecosystem complexity (Corlatti et al., 2019). Our results also show that the rifle is the most used hunting tool in the center-west of the country. These results are contrary to those obtained near the Dassioko reserve in other part of Côte d'Ivoire where the use of snares was the dominant hunting method (Gonedelé et al., 2017). These results could be explained by the fact that the socio-political crisis that went through the country for ten years was most felt in the west and the center-west of the country. This led to the proliferation of shotguns and demonstrates the use of more modern hunting tools. These results are consistent with the conclusion of General state of the forest workshop on wildlife and water resources in Côte d'Ivoire (Dufour et al., 2015). Although the majority of the species encountered are considered to be of Least Concern according to IUCN and the national and local status, the species *Cephalophus dorsalis* and the pangolin are part of threatened categories because the laws on hunting are not respected.

Conclusion

Eighteen species of mammal were identified in seven localities in the central west of the Côte d'Ivoire. These species belong to eight taxonomic orders. The rodent order is the most widely represented, with the majority of species being the grass cutter *T. swinderianus*. The main cause of the scarcity of wildlife in Côte d'Ivoire is illegal hunting for commercial purposes, because despite the ban of hunting since 1974, poaching still takes place, beyond the limits of protected areas with various methods, the rifle being the most observed for this study. All these means and methods do not promote sustainable management of wildlife biodiversity. It is undeniable that the conservation status of wildlife biodiversity will always be threatened by illegal hunting. It is therefore up to the state authorities and policy-makers to officially cover hunting with clear control measures for the sustainable management of wildlife biodiversity and promote farming of preferred bushmeat. It is only on this basis that hunters will leave illegality to comply with the established rules.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Analysis of growth rings to determine age and mean radial growth of selected *Baikiaea-Guibourtia-Pterocarpus* species from regrowth stands after pole/ firewood harvesting and abandoned crop fields, north-western Zimbabwe

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Anthropogenic disturbances (cultivation, harvesting of poles and firewood and protection) play a pivotal role in the recovery and growth of *Baikiaea-Guibourtia-Pterocarpus* woodland species. The aim of this study is to determine the reliability of tree growth rings in age determination and average radial growth of re-growing woodland stands. The relationship between stem diameter, number of growth rings, and age of selected stands was also investigated. The research assisted in understanding the growth patterns of the key commercial timber species (*Baikiaea plurijuga, Guibourtia coleosperma* and *Pterocarpus angolensis*) of the seasonally dry *Baikiaea-Guibourtia-Pterocarpus* woodlands around Gwaai and Tsholotsho in north-western Zimbabwe. Tree rings were physically counted on basal stem cross-sections collected from 20 trees of different age, for each species in each disturbance regime. STATISTICA statistical package version 7.0 (StaSoft inc, 1984 - 2006) was used for data analysis. The Simple Regression Model was used to test for relationships. The relationship between age and growth rings, showed a strong correlation ($p<0.0001$). Diameter and number of growth rings had a poor correlation. This showed that growth rings and not diameter can be used to determine the age of the three key timber species. Mean annual ring width was significantly different between species within the same disturbance category ($p<0.005$) within a specific stand age. Mean radial growth was highest in abandoned crop fields, compared to pole and firewood collection sites. It was therefore concluded that forest managers need to adopt disturbance regimes that prompt optimal mean radial growth of at least key species in the woodlands.

Key words: Disturbance, mean radial growth, tree rings, *Baikiaea plurijuga*, *Guibourtia coleosperma*; *Pterocarpus angolensis.*

INTRODUCTION

Information on growth rates is key in determining the sustainability of harvesting systems and the formulation of sound forest management systems (Caetano et al., 2019; Khai et al., 2020) in natural forest and woodland systems. The relationship between stem diameter and stand age of key tree species and the variation in mean

radial growth between different stand conditions should guide good silvicultural management. Several authors have reported that attempts at plantation cultivation of indigenous species have not been successful, for example *Pterocarpus angolensis* (DC) (Boaler, 1966; Van Daalen et al., 1991, Moses, 2013), *Baikiaea. plurijuga* (Harms) (Piearce, 1993) and *Guibourtia coleosperma* (Benth.) J. Leonard (Lemmens et al., 2008; Heita, 2019), making it difficult to estimate their age, mean annual increment (MAI), productivity and other growth parameters (Montoro et al., 2017). How then can forest managers determine the age and growth rates of indigenous tree species when it is difficult to raise them in plantations? However, some tropical and sub-tropical tree species can produce growth rings which correlate with age (Fahn et al., 1981; Gourlay and Barnes, 1994; Grundy, 1995; Stahle et al., 1999; Geldenhuys, 2005; Ngoma et al., 2017). Annual growth rings have been used in the past by forest managers in determining the age of Miombo woodlands in Zambia (Fanshawe, 1956; Syampungani et al., 2010) and in Zimbabwe (Grundy, 1995; Stahle et al., 1999). Grundy (1995) did a 4-year study on stems of unknown management history. Syampungani et al. (2010) showed that ring counts can be used in age determination, with a strong correlation between growth rings, known stand age, and stem diameter, for three Miombo woodland species. *B. plurijuga* was studied in Zambia by Miller (1952) about the determination of age and rotations and by Ngoma et al. (2017) in terms of dendrochronological potential. Both Miller (1952) and Ngoma et al. (2017) highlighted that *B. plurijuga* shows clear annual growth rings. Stahle et al. (1999) studied the correlation between the growth rings in *P. angolensis* and seasonal climatic data, using evidence from phenology, ring anatomy and cross-dating. However, they did not analyze the relationship between the number of growth rings, age of the study site and stem diameter.

There is need to understand the response of key species in terms of mean radial growth under different disturbance factors. Montoro et al. (2017) emphasized the need to consider the best treatment (disturbance) for each species according to the ecological requirements in order to maximize radial growth of the residual trees and enhance the species' economic value. Therefore, forest managers need to adopt land use practices in line with woodland disturbance regimes and recovery potential to ensure prompt, adequate regeneration, and fast growth of key species. Tree rings and growth rate data hold key information for the development of sustainable forest management schemes, as they give indications on the time required to replace harvested trees. Such data are very useful when assessing species potential and sustainable timber exploitation (Caetano et al. 2019). The question to be answered by this study is "can we use growth rings, stem diameter or both, in age determination for the key species of *Baikiaea-Guibourtia-Pterocarpus* woodlands?"

The main objective of this study is to determine how reliable is the use of growth rings or stem diameter or both, in age determination, that is, what the relationship is between the number of growth rings, stem diameter and tree age of selected sites. The following research questions guided data collection and analysis: a) Can the individual growth rings be reliably differentiated on cut stems of key tree species in the woodlands? b) Is the number of growth rings the same in larger and smaller stems in a stand of known age? c) Can growth rings be more clearly differentiated in free-growing trees than in suppressed trees? d)Is there a relationship between the number of growth rings, stem diameter and stand age of a selected site, and can such a relationship be used for reliable stand age determination? and e) How does the mean radial growth of key tree species vary in different disturbance factors?

MATERIALS AND METHODS

Description of study area

The study was conducted in the Gwaai and Tsholotsho indigenous *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe (Figure 1). Gwaai forest (19°16¹20" S and 27°56¹36" E) and Tsholotsho (19°46¹00" S and 27° 45¹ 00" E) (JAFTA and Forestry Commission, 2001) are both located in the Matabeleland North Province at an altitude ranging between 1010 and 1055 m. Kalahari sands (uniform, both physically and chemically) cover the bulk of the study area. They belong to the regosol group in the amorphic soil order (Nyamapfene, 1991, as cited by Gambiza 2001). The underlying geology is of sedimentary rocks overlying Karoo basalt and sedimentary deposits (JAFTA and Forestry Commission 2001).

The area experienced much annual fluctuation around the average monthly rainfall over a 26 year period (bars in Figure 2). The highest rainfall was recorded in 2005/2006 followed by year 2000/2001 and 1995/1996 and lowest rainfall was recorded during the drought years of 1994/1995, 2002/2003 and 1992/1993. The short and erratic wet season is usually characterised by dry spells and sporadic droughts (Nemarundwe and Mbedzi, 1999). Mean annual temperature is 21.5°C, with mean monthly temperature ranging from 15°C (June to September) to 25°C (October to December) (Nyamapfene 1991; JAFTA and Forestry Commission 2001). Ground frosts are experienced especially in the valleys in most years between May and September (JAFTA and Forestry Commission 2001).

The area is characterised by six main vegetation types (JAFTA and Forestry Commission 2001): (i) *Baikiaea-Guibourtia-Pterocarpus* (Fabaceae) woodland occurs on the Kalahari sands;' (ii) *Brachystegia* (Fabaceae) woodland occurs along the upper Bembesi river on shallower soils with more silt; (iii) *Colophospermum*

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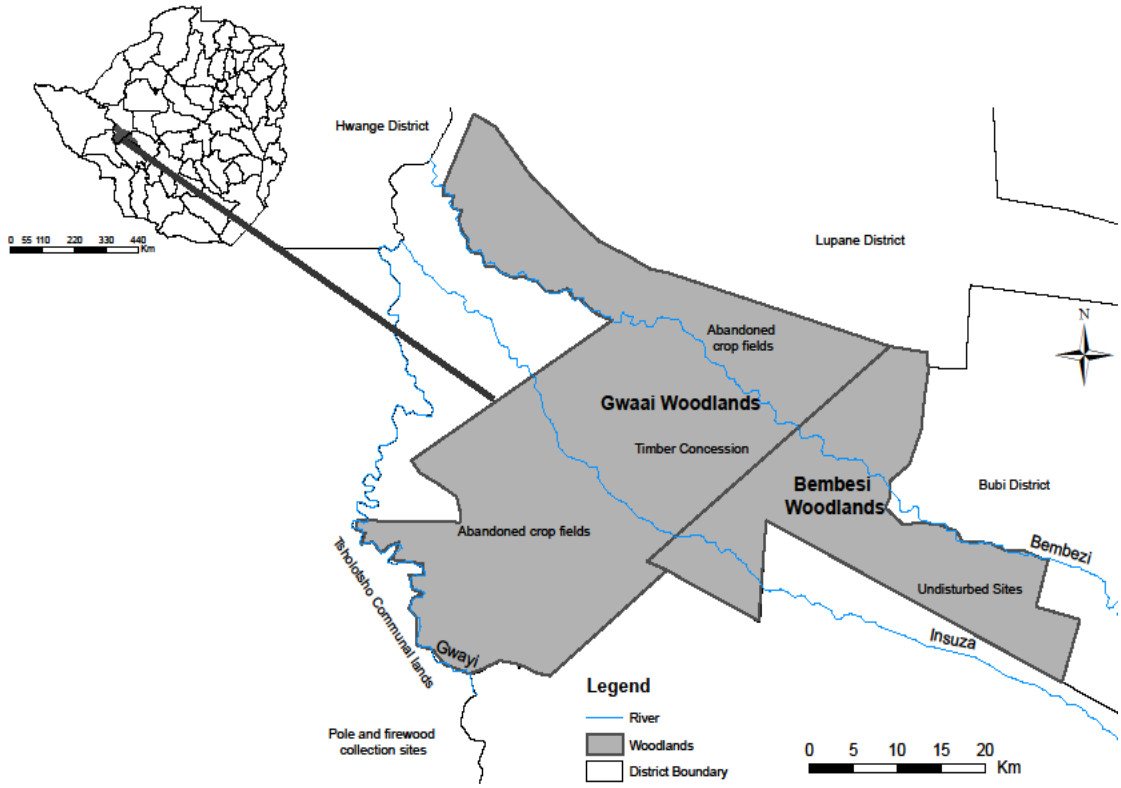

Figure 1. Location of the study area in Matabeleland North in Zimbabwe, Africa.

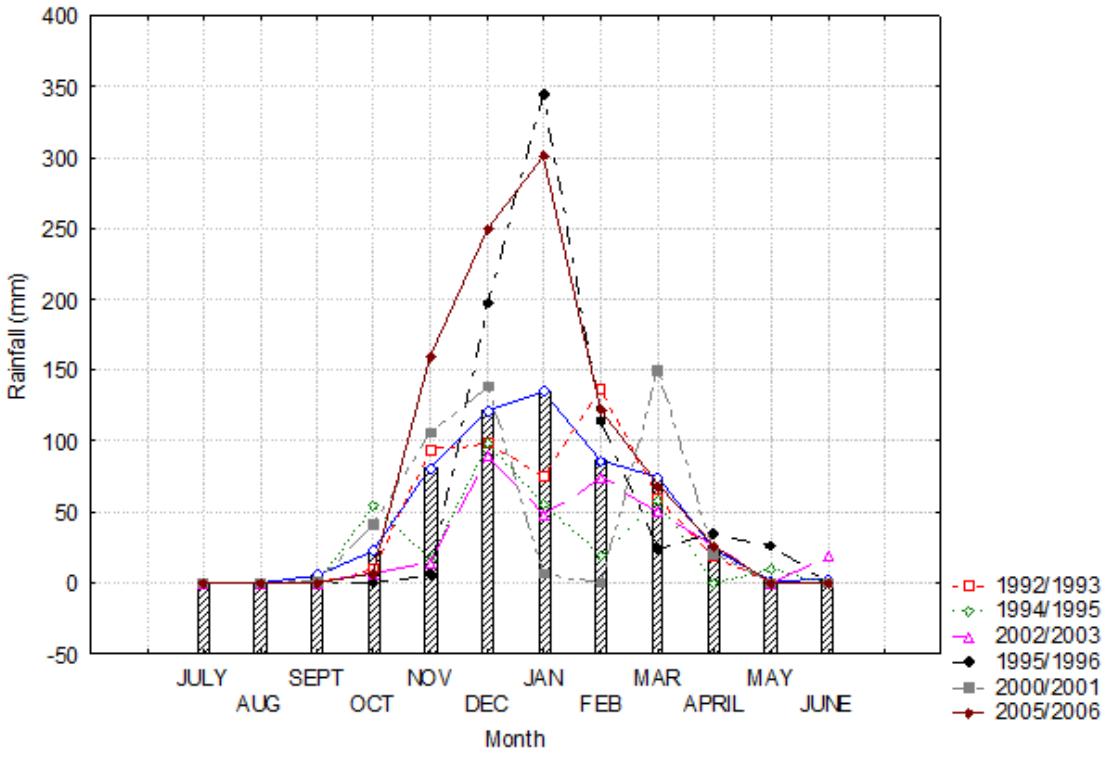

Figure 2. Mean annual rainfall from 1990 to 2015 (bars) and for years with highest (1995/1996, 2000/2001 and 2005/2006) and lowest (1992/1993, 1994/1995 and 2002/2003) rainfall (lines), over the 26 year period in Lupane District northwestern Zimbabwe, Africa.

Figure 3. Selection of stems of each tree.

mopane (Kirk ex Benth.) J Leonard woodland, dominated by either stunted or multi-stemmed *C. mopane* trees, occurs along river valleys on poorly drained and highly erodible alluvial soils; (iv) Vleis (a grassy or marshy wetland, mostly covered by water during the rainy season) are dominated by a single layer of grasses, with isolated trees occurring along vlei fringes; (v) *P. angolensis* belts growing in association with *Burkea africana* (Hook) occur as localised stands inside the *BaikiaeaGuibourtia-Pterocarpus* woodland; and (vi) *G. coleosperma* woodland dominated by *G. coleosperma* and occurs on the Kalahari sands.

Land use systems

In Tsholotsho communal areas, people harvest trees on an open-access regime for subsistence and commercial purposes (Matose 2002). Trees of different sizes are cut for various purposes (fuel wood, construction, fences, curios, etc.). Large canopy gaps are created when groups of trees are removed in the pole and firewood collection sites. Farmers grow maize, sorghum, and other crops on the agricultural fields. The agricultural fields are abandoned after many years (40 years or less) of cultivation. Fields are abandoned when they are old and are producing fewer yields (Mutsiwegota and Mudekwe, 1998). It has been noticed that trees of different species will start growing on the abandoned fields from seed or through sprouting from rootstocks.

Data collection

The data were collected in areas of known age after crop cultivation and pole and firewood collection had been terminated and in undisturbed woodland (unknown age). The following ages (8, 17, and 25 years) were selected for study in the abandoned crop fields and pole and firewood collection sites. These were based on the last date since disturbance cessation (that is, 2008, 1999 and 1992 respectively). The information on stand age was obtained from the local communities around the study areas and from Forestry Commission records. Plots were sampled in the undisturbed sites to have stems of similar height as in the development stages of the disturbed sites (Stage 1 height was <2 m; Stage 2 height was 2.1-5 m; Stage 3 height was 5.1-8 m; and Stage 4 height was >8 m). In each site of specific age or height, 20 trees per selected species (*B. plurijuga, G. coleosperma* and *P. angolensis*) were selected for sampling. The sampling approach of fixed length - variable width of Walker (1976) was adopted. The plots had a fixed length of 50 m; sampling would stop (at any width) when the required number of trees for the three species was reached, that is, 60 stems (20 stems per species) per site of specific age, giving a total of 180 stems for each disturbance factor, and an overall total of 540 stem sections. A Global Positioning System (GPS) was used to record the position of the plots in the field. A study by Chichinye et al. (2019) showed little variation in environmental factors (such as edaphic factors (soil texture, soil depth, soil nutrients), slope, aspect among others, across the studied disturbance factors hence data on edaphic factors was not collected. The following general information was recorded at each site.

(i) Study area, Study site name, Recorder name and Date
(ii) GPS coordinates: Latitude °S, Longitude °E (X and Y coordinates).
(iii) Condition of surrounding natural vegetation (the appropriate answer was selected):

(a) Height (m): 1 = <2; 2 = 2 - 5; 3 = 5 - 10; 4 = 10 - 20; 5 ≥ 20
(b) Stand cover: 1 = 0 - 30%; 2 = 30 - 50%; 3 >50%.
(c) Date when cutting or cropping was abandoned (to determine possible stand age)
(iv) Relevant information for the site that would be useful for the interpretation of the growth ring development.

The assumption was that the *Baikiaea-Guibourtia-Pterocarpus* woodland species are light-demanding. That means that a stand that developed after cultivation or harvesting of poles and firewood, would be composed of even-aged trees of different species. Smaller and larger stems would have the same number of rings and hence the same age. Trees with smaller stems would be suppressed trees. Each tree develops growth rings, with each ring consisting of a broader part of lighter wood (faster growth, possibly during the rainy period) and a narrower part of darker wood (slow to no growth, possibly during the dry period).

Single-stemmed trees with a normal, well-formed stem and with no stem defects in the lower 1 m of the stem were selected for sampling. For each selected tree, data on the following were recorded before the tree was cut and after it had been cut:

(i) Tree number (to accompany the collected stem section)
(ii) Species
(iii) Diameter at breast height (DBH, in cm) at 1.3 m above ground level
(iv) Tree height (m)
(v) Diameter (cm) for stem section (DS)
(vi) Number of visible annual growth rings for section at ground level (RS).
(vii) Bark thickness (mm) on two opposite sides of the stem section.

A horizontal smooth cut was made at the bottom of each selected stem to produce 1 cm thick discs. The stems were cut close to ground level. Site name, species code, tree number, DBH and section diameter were recorded on the backside of each disc. All discs dried under tree shade and the unmarked section was smoothened, using a belt-sanding machine. The machine used coarse sandpaper (Figure 3).

Figure 4. Measurement of ring width along each radius.

Three lines (radii) were drawn on the smoothened surface of each stem section, from the core to the inner edge of the bark of the cut section (Figure 4). Clearly visible rings were traced along each line and counted from the outside (current date) of the section. The position of every 5th ring along a line was marked around the entire section (Figure 4) to identify false and partial rings. Ring-width in mm (growth over one year) was determined by placing a ruler along each of the three radii (1, 2 and 3) with the zero point on the ruler at the inner edge of the bark (Figure 4). The average width of each ring was calculated from the ring widths from the three radii.

Data analysis

STATISTICA statistical package version 7.0 (StaSoft inc, 1984 - 2006) was used for data analysis. The Simple Regression Model was used to test for relationships between number of rings and age, and stem diameter and number of rings, for the key species. The Bonferroni test in STATISTICA was used to determine the relationship that exists in mean radial growth within species under different disturbances, and between different species under similar land use disturbances.

RESULTS

Correlation between number of growth rings and stand age since disturbance cessation

The growth ring boundaries were reasonably distinct for *P. angolensis*, as shown here for a 25-year old abandoned crop field (AF) site and a 17-year old pole and firewood collection (PFC) site (Figure 5a and d), and for *B. plurijuga,* as shown here for a 25-year old PFC site and a 17-year old AF site (Figure 5b and e). *G. coleosperma* did not show very distinct growth rings as shown here for a 17-year old PFC site and a protected area (PA) site (Figure 5c and f). Less clear rings were typical of the discs from mature woodlands (Figure 5f).

The number of growth rings showed a strong positive linear relationship with stand age in both regrowth stands of pole and firewood sites and abandoned crop fields (r^2 = 0.976; $p<0.01$; slope of curve = 0.97; n = 180) and (r^2 = 0.98; $p<0.01$; slope of curve = 0.99; n = 180 respectively) (Figure 6). Some discs from pole and firewood collection sites had 1 or 2 extra rings whilst those from abandoned crop fields had 1 or 2 fewer rings. However, the discs from mature woodland of the same diameter as those from the regrowth stands did not show any distinct growth rings (Figure 5f).

Correlation between the number of growth rings and DBH

All the species studied showed weak correlation between the number of growth rings and the DBH of a tree, in regrowth stands of both abandoned crop fields (r^2 = 0.51; $p< 0.01$; slope of curve = 1.02; n = 180) and pole and firewood collection sites (r^2 = 0.46; $p<0.01$; slope of curve = 0.63; n = 180) (Figure 7).

Mean radial growth in regrowth stands from abandoned crop fields and pole and firewood collection sites

Mean annual ring width was significantly different

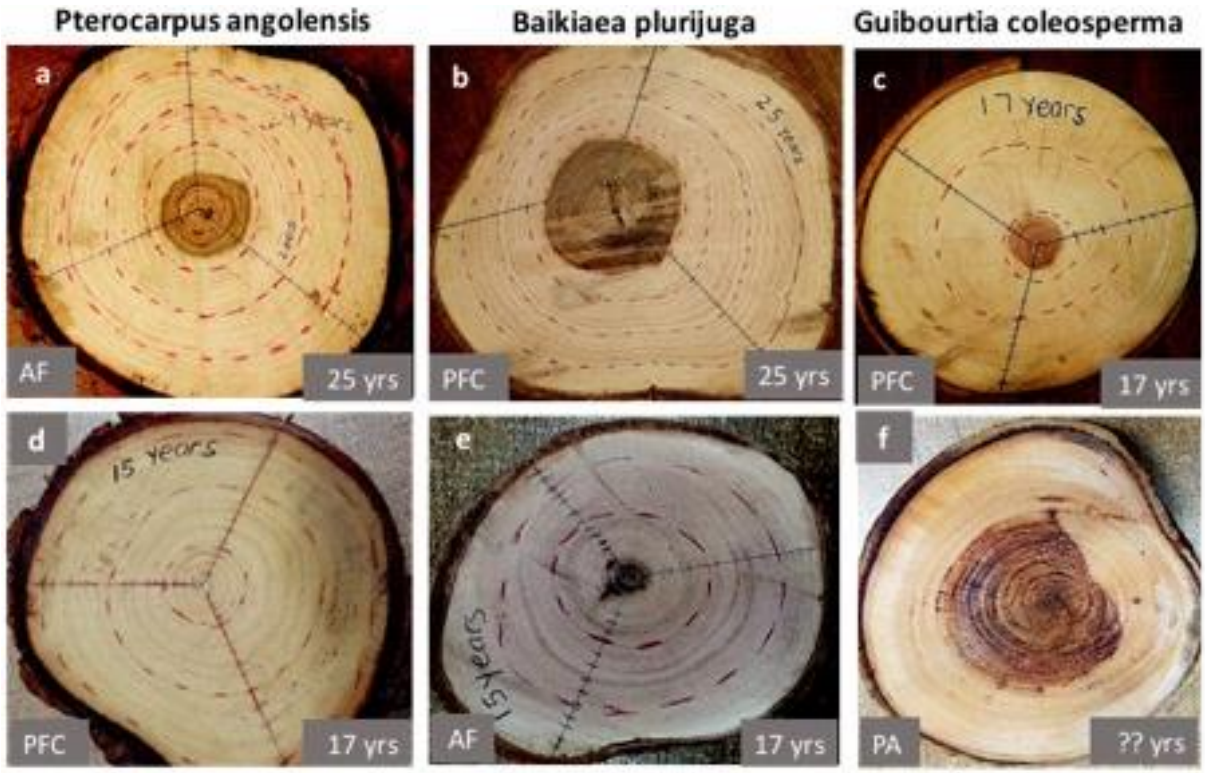

Figure 5. Six smoothed stem sections (two of each species) with three lines drawn with a sharp pencil from the center to the edge (except for section f). Along each line, every 5th growth ring from the edge was marked on the pencil line. AF - Abandoned crop fields; PFC = Pole and Firewood collection; PA = Protected area.

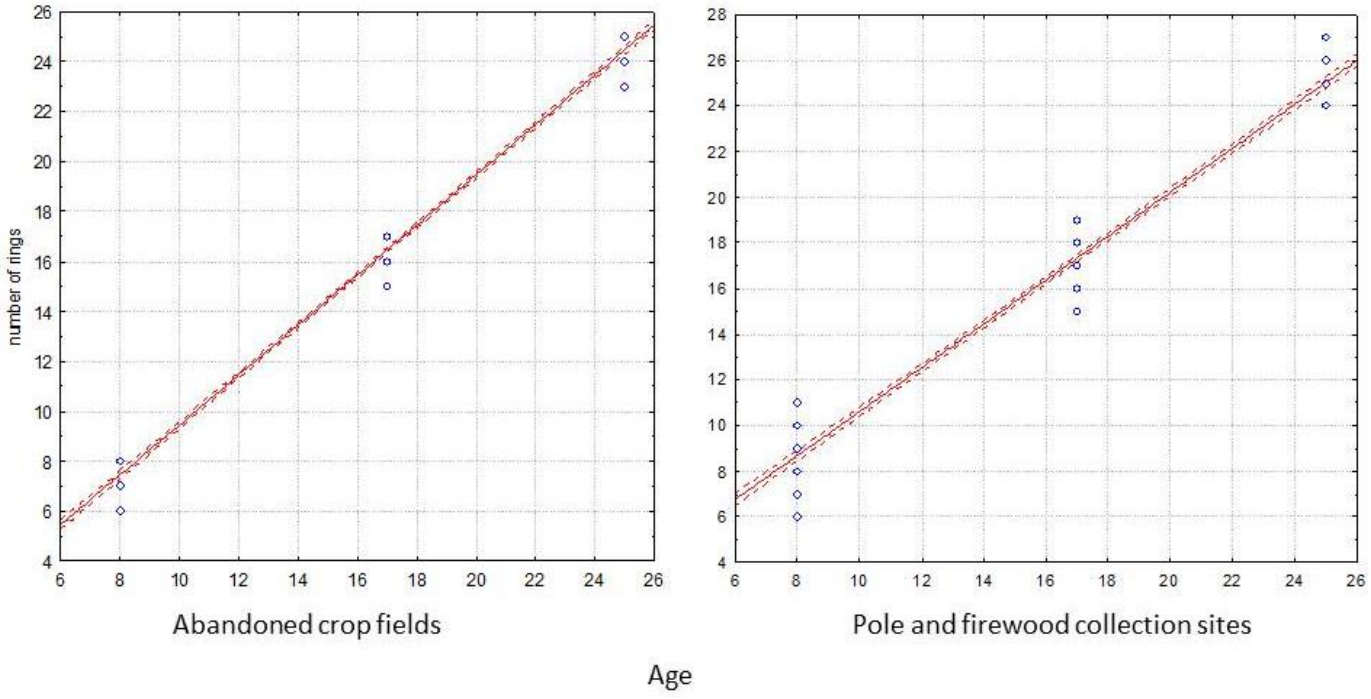

Figure 6. The positive linear relationship between stand age and the number of growth rings in regrowth stands after different years since abandoning pole and firewood collection and crop cultivation, irrespective of the species. Note that each point represents several individual trees of the 3 species studied.

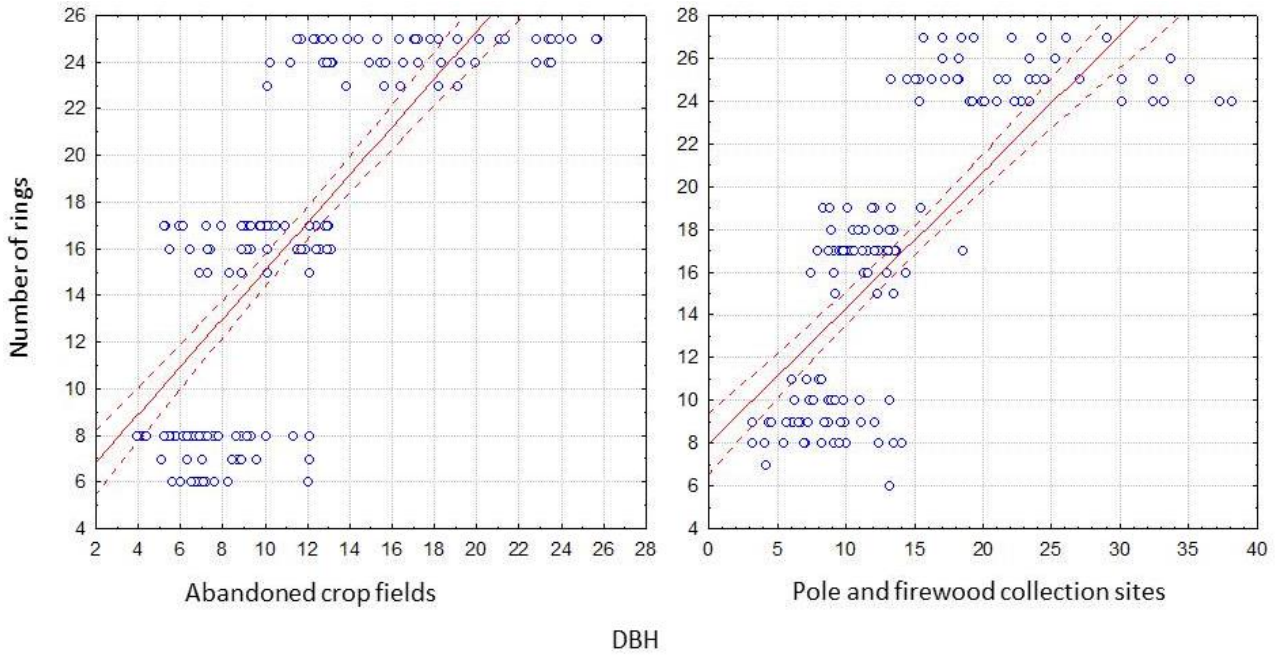

Figure 7. The relationship between DBH and number of growth rings in regrowth stands after different years after abandoning pole and firewood collection and crop cultivation.

Table 1. Mean radial growth of selected key *Baikiaea-Guibourtia-Pterocarpus* woodland species under different disturbances.

Species	Mean annual ring width, mm							
	Stand category and age							
	Pole and firewood regrowth stands age in years				Abandoned crop-field regrowth stands age in years			
	8	17	25	Mean	8	17	25	Mean
B. plurijuga	4.8± 0.3	4.4± 0.2	4.3±0.2	4.5± 0.6	5.2± 0.2	4.9±0.3	4.6±0.3	4.9±0.7
G. coleosperma	5.0± 0.2	4.7± 0.3	4.6±0.4	4.8± 0.4	5.4± 0.3	5.2±0.6	4.8±0.5	5.1±0.5
P. angolensis	5.7± 0.4	5.3± 0.3	5.0±0.2	5.3± 0.5	6.2± 0.2	5.8±0.4	5.3±0.6	5.8±0.9

($p<0.005$) between species within regrowth stands of the same disturbance category (pole and firewood collection, and abandoned crop-field) and stand age (Table 1). Mean radial growth was not assessed in the undisturbed sites because the stem discs did not show distinct rings making it difficult to measure ring width. *P. angolensis* exhibited the highest mean radial growth amongst the key species, with the mean ring width of 5.3 mm (10.6 mm radial or diameter growth per year) in pole and firewood regrowth stands and 5.8 mm (11.6 mm radial growth per year) in abandoned crop-field regrowth stands. Generally, the ring width is high in the youngest stands in all three species (Table 1). Thereafter, ring width tends to decrease as the stands get older. However, there is no significant difference in mean ring width within the same species under different disturbance factors.

Diameter growth was also assessed for the three species across the different disturbance factors. Results showed a range in diameter growth from 0.88-1.13 cm/year for *B. plurijuga*; 0.95-1.13 cm/year for *G. coleosperma* and 0.97-1.11 cm/year for *P. angolensis* (Table 2). Analysis of Variance results showed significant differences in diameter growth amongst the disturbance factors ($F_{(2,539)} = 49.2617$; $p<0.0001$) with abandoned fields having the highest diameter growth. All species showed no significant difference in diameter growth ($p>0.05$) between the abandoned crop fields and pole and firewood collection sites whilst the opposite is true for undisturbed sites ($p<0.001$). The Post-hoc Tukey test results showed that the three species had significant differences in diameter growth across the three disturbance factors (*B plurijuga* ($F_{(2,177)} = 26.45$, $p <0.0001$); *G. coleosperma* ($F_{(2,177)} = 25.85$, $p <0.0001$);

Table 2. Differences in mean diameter growth (cm/year) (mean ± standard error) for the three key species across three land use systems. Values with different superscript letters within columns and rows differ significantly (Tukey's HSD; p< 0.05).

Species	Abandoned fields	Pole and firewood collection sites	Undisturbed fields	p value
B. plurijuga	1.13 ± 0.15^{a}	1.04 ± 0.23^{b}	0.88 ± 0.19^{c}	p<0.001
G. coleosperma	1.13 ± 0.14^{a}	0.95 ± 0.14^{b}	0.99 ± 0.15^{b}	p<0.001
P. angolensis	1.11 ± 0.11^{a}	0.97 ± 0.14^{b}	0.97 ± 0.25^{b}	p<0.001
p value	p>0.05	p>0.05	p<0.001	

P. angolensis ($F_{(2,177)} = 11.47$, $p < 0.0001$). The species had high diameter growth in the abandoned crop fields. *B. plurijuga* recorded the least diameter growth in the undisturbed sites (Table 2). *G. coleosperma* and *P. angolensis* recorded the least diameter growth in pole and firewood collection sites and undisturbed sites.

DISCUSSION

Stand age-rings and DBH-rings relationships for the key species

Understanding stand dynamics of indigenous woodlands is essential for determining the sustainability of a polycyclic selective harvesting system. Limited related studies have addressed the influence of different disturbance factors on growth of residual trees over time. The few investigations of growth rate, using growth rings, have been based on coring (Stahle et al., 1999) or whole discs (Gourlay, 1995; Ngoma et al., 2017) or a combination of the two. Grundy (1995) based her study on damaging the cambium and cutting the cross section of the stems to allow for counting of growth rings. Gourlay (1995) and Grundy (1995) based their studies on observations at 1.3 to 1.4 m height from the ground. The method has a disadvantage in that some growth rings may be missed because a seedling may take time to reach the 1.3 or 1.4 m height. Coring species with dense wood may be difficult and at times the operator may miss or fail to reach the pith.

Very few studies have been investigated the influence of different disturbance factors on mean radial growth of key species in *Baikiaea-Guibourtia-Pterocarpus* woodlands of Zimbabwe. Dendrochronology of key species such as *P. angolensis* in Sikumi and Mzola gazetted forests in Matabeleland (Stahle et al., 1999) and *B. plurijuga* in Zambia (Miller 1952; Ngoma et al., 2017) have been studied. Age determination using growth rings of *G. coleosperma,* a key species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands of north western Zimbabwe (Chigwerewe, 1996), has not yet been considered.

Results from this study showed that *B. plurijuga* and *P. angolensis* showed distinct growth rings which can be used as a good estimate for stand age in both pole and firewood and abandoned crop-field regrowth stands. However, *G. coleosperma* discs did not show distinct rings hence they cannot be used as a good estimate of stand age in both pole and firewood and abandoned crop-field regrowth stands.

Results suggested that there are 1 to 2 missing growth rings in abandoned crop fields and an additional ring in pole and firewood collection sites. This shows that a tree in a 25-year old abandoned crop field will have 24 or 23 rings and a tree in pole and firewood regrowth will have 26 or 27 rings. An additional ring in pole and firewood regrowth stands may be attributed to the fact that young plants are left behind during harvesting for poles and firewood. Missing rings in abandoned crop fields may be attributed to the constant removal of seedlings or sprouts during cultivation. Delayed germination of plants, when the fields are abandoned, could explain why some plants had fewer rings. Delayed stem development may also be due to shoot die back because of frequent fires in woodlands.

The occurrence of distinct growth rings may be attributed to the strong seasonality in both temperature and precipitation experienced in the north-western parts of Zimbabwe (JAFTA and Forestry Commission 2001). The woodlands are deciduous, with trees losing leaves during the dry season and become on leaf before the onset of the rainy season. The seasonality in flowering, leaf flush and leaf fall suggest that radial growth is restricted to the summer wet season (Borchert, 1991) with distinct annual ring formation (Stahle *et al*. 1999). Strong and consistent diameter growth of free growing stems in regrowth stands contribute to the clear and wider rings (Geldenhuys 2005) because the trees are growing in the absence from intense competition (Rozas, 2001). This could explain why stems from abandoned crop-field regrowth stands showed wider rings, and that rings of stems from undisturbed sites were less clear rings because of the shading effect from larger stems of the canopy. Stems from pole and firewood collection sites also showed wider rings compared to undisturbed sites because more space and resources are released for residual plants after selective harvesting occurs (Montoro et al., 2017). *P. angolensis* and *B. plurijuga* had clear rings, thus their cambial growth develops distinctively

every year. However, growth rings for *G. coleosperma* are not very distinct, possibly resulting from poor cambial growth; the species only loses leaves for a very short period of time, or remain green throughout the year (Palgrave, 2002).

The study has revealed a weak significant relationship between DBH and the number of growth rings, in all three selected sites. This implies that the bigger and smaller stems showed the same number of rings. The smaller stems are the suppressed trees and the bigger stems are the fast-growing and vigorous stems in these even-aged stands of light-demanding species. This implies that DBH cannot be used as a reliable estimate of stand age. This contradicts the conclusions of Syampungani et al. (2010) that DBH can be used as a reliable predictor of stand age probably because they selected only bigger stems for the counting of rings; smaller stems were not considered.

Mean radial growth

The three species showed a significant difference in mean radial growth across the land use disturbances, with abandoned crop fields recording the highest ring width and diameter growth, as compared to pole and firewood collection sites. This suggests that there is more growth in the cleared areas, and that trees in open areas grow much faster than in mature stands because the younger plants grow in the absence of intense competition (Rozas, 2001). Several studies have reported high growth rates in disturbed areas than in undisturbed sites (Chapman and Chapman, 1997; Syampungani, 2008; Hawthorne et al., 2012; Gourlet et al., 2013; Khai et al., 2020). Total exposure to light and reduced competition for moisture and nutrients also contribute to increased mean radial growth (Rozas, 2001; Syampungani 2008; Khai et al., 2020). In the undisturbed stands, there is competition for space, light, moisture and nutrients between the young plants and the older trees hence mean radial growth is suppressed (Rozas, 2001). This was also observed in Mozambican Miombo woodlands (Geldenhuys, 2005). Montoro et al. (2017) recorded highest radial growth in younger stands after partial cutting while Khai et al. (2020) recorded highest diameter growth during the early post-harvesting period (5year old stands after selective harvesting) owing to the increases in open space and sunlight availability to residual trees. In their study growth rates decreased to a level of an unlogged stand at 11years post-logging in a Brazilian tropical forest and 16-years post-logging in a Ghanaian high forest. This shows that relative growth rates tend to decline with age of trees, as also mentioned by Johnson and Abrams (2009), Montoro et al. (2017) and Khai et al. (2020), since older stands are mainly composed of old and mature trees.This suggests that selective thinning of suppressed stems, for use as poles and firewood, could maintain good growth of the remaining stems.

Calvert (1986) reported a mean annual DBH increment of 1.78 mm for *B. plurijuga*, Mushove and Makoni (1993) reported 1.5 mm, and SAREC (1993) reported 1.25 to 2.04 mm for *B. plurijuga*, 1.02 to 2.37 mm for *G. coleosperma* and 1.30 to 2.72 mm for *P. angolensis*. In these studies, mean annual diameter increment was studied on permanent sample plots over several years. FAO pilot studies on forest data gathering and analysis, reported 1.75 mm DBH increment for *B. plurijuga*, 2.11 mm DBH increment for *G. coleosperma* and 2.00 mm DBH increment for *P. angolensis*. Grundy (2006) reported a mean growth of 2.7 $cm.year^{-1}$ for all trees in an area protected from fire and human disturbance. Syampungani et al. (2010) reported a mean ring width ranging between 4.4 to 5.6 mm in charcoal regrowth stands and slash and burn regrowth stands. Results from this study are almost similar to findings by Syampungani et al. (2010), maybe because of similarity in climatic conditions between the two countries. The intensity of disturbances from the different land use systems in the two studies might also be similar.

Conclusion

The identification of annual growth rings in *B. plurijuga, G. coleosperma* and *P. angolensis* for both pole and firewood collection and abandoned crop-field regrowth stands has important implications for forest ecology and management of *Baikiaea-Guibourtia-Pterocarpus* woodlands. The study concludes several important points. Individual growth rings of *P. angolensis* and *B. plurijuga,* and not of *G. coleosperma,* can be reliably differentiated on cut stems and hence can be used in determining the age of young to intermediate aged *Baikiaea-Guibourtia-Pterocarpus* woodlands. The number of growth rings is the same in larger and smaller stems in a stand of known age. Trees growing in suppressed stands did not show clear rings compared to free-growing trees. Annual growth rings, and not diameter at breast height, can be used as a good estimate of stand age in both pole and firewood and abandoned crop-field regrowth stands. The mean radial and diameter growth data has shown that trees that grow in open areas (outside undisturbed woodland) grow much faster than trees growing under the canopy of the undisturbed woodlands. Such growth-ring width information would be particularly useful when used together with the climatic data for all the calendar years involved. It would provide an understanding of the disturbance and other biological factors that the land was exposed to in order to relate the growth rings and growth parameters with drought frequencies, disturbance factors and stand development (stand density suppression). However, it can be noted from this study that many stems were cut to determine stand age. This could be avoided if forest managers would monitor closely forest activities and growth of trees in stands of known age since disturbance cessation;

hence tree age can be estimated without having to cut them. However, if stand age is not known, then smaller, suppressed two to three trees without any damage to the lower 1 m of the stem could be cut to determine stand age.

Mean radial and diameter growth information generated from the study will help in size predictions of the key *Baikiaea-Guibourtia-Pterocarpus* species in that the study has provided a means of collecting mean radial and diameter growth data in both pole and firewood sites and abandoned crop fields. The current data may be supplemented with other growth rate data for trees of known age. We therefore conclude that forest managers need to adopt silvicultural practices of selective thinning and limited clear-felling (as disturbance regimes) that would stimulate optimal growth of at least key species in the woodlands.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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