

Empirical evidence of the impact of commercial charcoal production on Woodland in the Forest-Savannah transition zone, Ghana



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ARTICLE INFO

Article history:

Received 20 October 2015

Revised 17 March 2016

Accepted 29 March 2016

Available online xxxx

Keywords:

Basal area

Charcoal production

Harvested trees

CO₂ emission

Remnant trees

ABSTRACT

The impacts of charcoal production on woodland were assessed in the Forest-Savannah Transition Zone of Ghana to facilitate policy formulation for a win-win situation for both sustainable woodland management and charcoal production. Twenty-three harvested sites in two charcoal producing communities were assessed in terms of the extent of harvested sites, changes in biomass carbon stock and tree basal area. The boundary of each site earmarked for charcoal production was mapped with a hand-held Global Positioning System, and the diameters at breast height (d_{bh}) and the heights of trees of $d_{bh} \geq 5$ cm were measured, prior to harvest. The extent of harvested sites was compared with the Intergovernmental Panel on Climate Change criterion of “devegetation” using Wilcoxon test, while the biomass carbon and basal area of the harvested trees were compared with those of the remnant trees using Mann Whitney t-test. The median of the extent of harvested sites ($M = 0.23$ ha, $P = 1.00$) was significantly higher than 0.05 ha, the Intergovernmental Panel on Climate Change minimum criterion for “devegetation”, while the difference between median basal area of harvested and remnant trees was significantly greater than zero ($G_h - G_r = 2.6$ m² ha⁻¹; $P = 0.001$) at 95% significant level. The Mann Whitney test also provided sufficient evidence ($n = 23$; $M_{hc} - M_{rc} = 12.07$ t ha⁻¹; $P < 0.001$) against the null hypothesis that the difference between the medians of the aboveground biomass carbon in the harvested and remnant is zero at 95% significant level. On the basis of the IPCC definition of “devegetation” and the changes in basal area, it suggests that intensive charcoal production has the potential of degrading woodlands. Nonetheless, it is worth highlighting that, none of the harvested sites had zero basal area or biomass carbon after harvest, which is a significant revelation for sustainable woodland management for charcoal production. The study further revealed that the extent of harvested site is not an appropriate measure of the impact of charcoal production on woodland since it does not account for the number and sizes of the trees harvested. Therefore, the impact of charcoal production on woodland may not be as alarming as it is generally perceived when the extent of harvested site is used as a measure. The impact of charcoal production is often over-generalized and that, “devegetation” of harvested sites is an issue of post-harvest woodland management and not the impact of charcoal production *per se*. Therefore, the evidence of the impact of charcoal production on woodlands shown in this study should be basis for sustainable woodlands management and not basis for halting charcoal production in the study area.

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Introduction

Background

Charcoal production has been an important human activity since prehistoric times (Deforce et al., 2013; Raab et al., 2014; Zerboni et al., 2013) and charcoal is noted as the first synthetic material produced by man (Antal and Grønli, 2003). Since prehistoric times, charcoal

production has supported the income and energy needs of both the poor and the rich because it is relatively cheap, reliable in terms of supply, convenient to use and the perceived taste imparted to food (Kifukwe, 2013; Sander et al., 2013; Zulu and Richardson, 2013). Charcoal production has therefore become a means of alleviating rural and urban poverty in charcoal producing countries.

In 2011, global charcoal production generated US\$ 21,055 m (FAO, 2014) and contributed significantly to the Gross Domestic Product (GDP) of countries such as Brazil, Zambia and Rwanda (Belward et al., 2011; Puustjärvi et al., 2005; Zulu and Richardson, 2013). It contributed 2.2% to Zambia's GDP in 2004 (Puustjärvi et al., 2005) and also 3.4% to Rwanda's GDP in 2009 (Drigo et al., 2013). The significance of charcoal

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production to the economies of charcoal producing countries cannot be ignored (Kifukwe, 2013) and concerted efforts must be made to sustain it.

The global production of charcoal in 2009 was estimated at 47 million metric tonnes, of which Africa accounted for about 63% (Steierer, 2011). While the global production increased by 9% from 2004 to 2009, that of Africa increased by almost 30% for the same period, with an estimated annual production of 29 million tonnes (Belward et al., 2011; Steierer, 2011). Africa therefore plays a lead role in global charcoal production and this is further supported by the fact that six African countries, including Ghana, are among the top ten global charcoal producing countries (Kifukwe, 2013). Increasing trend in charcoal production in the continent is unlikely to change (Chidumayo and Gumbo, 2013) since the main consumer of charcoal in Africa, the urban population, is on the increase.

Despite the importance of charcoal in socio-economic development, its production in Africa is being criticized for its contribution to woodland degradation. Charcoal production in the continent has therefore generated debate as to whether its economic benefits are worth the degradation of woodlands and forests that is associated with it (Chima et al., 2013; Zulu and Richardson, 2013). However, lack of empirical data on the impact of charcoal production on woodland in terms of extent of harvested woodlands or amount of biomass harvested is a hindrance to decisive argument upon which policy makers could draw conclusions for effective policy formulation (Kambewa et al., 2007). Consequently, debate about charcoal production is based on perceptions and over-generalizations rather than on concrete data in support of the argument (Kambewa et al., 2007). This has contributed to contradictions and misinterpretation of the actual impacts of charcoal production on woodlands and forests (Mwampamba et al., 2013). Accordingly, there are diverse opinions on the way forward for the charcoal industry in Africa – outright ban, shift in urban energy supply, legalize charcoal production, formalize charcoal trade, modernize charcoal production methods and business-as-usual (Kambewa et al., 2007; Neufeldt et al., 2015; World Bank, 2009). The lack of decisive policy to manage charcoal production is a major hindrance to the sustainability of both woodlands and charcoal production itself.

There is the need to provide basis that will facilitate informed debate on perceived impact of charcoal production on woodland in the Forest-Savannah Transition Zone of Ghana, a major charcoal producing area in the country. The aims of this study are: (i) to compare the extent of harvested sites with IPCC standard of woodland degradation (ii) to compare the biomass carbon in the harvested trees with that of the remnant trees (iii) compare the basal area of harvested trees with that of the remnant trees (remaining trees after harvest) and (iv) to ascertain whether charcoal production results in woodland degradation based on the IPCC definition of “devegetation”.

Assessment of impact of charcoal production on woodland

Assessment of woodland degradation is complicated by different ways of characterizing woodland degradation and absence of thresholds for indicators of degradation (Bolognesi et al., 2015; Dons et al., 2015; Hosier, 1993; Kouami et al., 2009; Rembold et al., 2013). Also, duration for which an anthropogenic activity must occur to cause degradation makes it difficult to distinguish between isolated human activities that cause momentary woodland degradation from those that persistently cause woodland degradation (Miettinen et al., 2014; Thompson et al., 2013). However, Thompson et al. (2013) suggested that 3 to 5 years duration is a sufficient time interval for change to occur for most indicators of degradation.

The need for accurate quantitative data on the impacts of anthropogenic activities on non-forest vegetation for policy development, has led the Intergovernmental Panel on Climate Change (IPCC) to define “devegetation” based on its classification of vegetation as either forest or “other vegetation types” (tree areas covered with vegetation other

than forest). The national (Ghana) definition of forest adopted from the IPCC (2003) definition of forest for REDD+ activities is Reducing Emission from Deforestation and forest Degradation coupled with forest conservation, sustainable forest management and enhancement of forest carbon stock (REDD+) “a piece of land with a minimum area of 1.0 hectare, with a minimum tree canopy cover of 15%, or with existing tree species having the potential of attaining more than 15% canopy cover, with trees that have the potential or have reached a minimum height of 5.0 m at maturity in situ” (Forestry Commission of Ghana, 2013). Per the national definition of forest, the vegetation (woodland) in the study area does not qualify as forests since it does not meet the 15% tree canopy cover for the minimum area required and is therefore classified as “other vegetation types” based on the IPCC classification of vegetation. Therefore the impact of charcoal production on woodlands in the study area was assessed based on the definition of “devegetation” of other vegetation types.

IPCC (2003) defined “devegetation” (degradation) of “other vegetation types” with four different options with emphasis on “removal of”, “change in”, “reduction in” and “conversion of” vegetation. In this study, the definition that emphasizes on removal of vegetation has been chosen based on the nature of the anthropogenic activity under consideration, namely charcoal production, which involves the removal of trees. The definitions that emphasize on change and reduction in vegetation do not capture the “tree removal” effect of charcoal production. For instance, burning and girdling of trees in woodlands can change or reduce the vegetation without necessarily removing the trees. The conversion of vegetation is also too general and difficult to operationalize in the field because it lacks thresholds for the indicators of “devegetation” which makes it difficult to operationalize it in the field. Moreover the best definition proposed by the IPCC based on the above four optional definitions of devegetation, has not been adopted by Ghana. On this basis of the aforementioned explanations, “devegetation” in this study as adopted from IPCC (2003) is defined as “a long term direct human-induced activity that decreases carbon stocks in vegetation through the removal of vegetation that covers a minimum area of 0.05 ha at a time”. Per this definition, charcoal production is a long term human activity since it pre-dates 1980 (based on Brown and Amanor, 2006; Nketiah, 2008) and is still being practised, and capable of decreasing biomass carbon stock of woodlands through the removal of trees. In this study, “devegetation” and “woodland degradation” are used interchangeably.

However, Berhane et al. (2015); de Waroux and Lambin (2012); El-Juhany (2009) and Houghton (2005) have explained that in the case of selective harvesting, woodland degradation most often does not show much decrease in area of woodland but rather a gradual reduction in biomass, and changes in species number and composition. The explanation of Berhane et al. (2015); El-Juhany (2009) and Houghton (2005) suggests the need for a complement to the extent of harvested sites in assessing woodland degradation due to selective harvesting of trees. Basal area of trees is a common measure of quantity woody biomass and has been used as a proxy for anthropogenic influence on woodlands through selective removal of trees (Fastie, 2010; Hosier, 1993; Kouami et al., 2009). It accounts for the number and size of tree harvested (Salvador, 2000) as well as the extent of the harvested sites. Basal area per site is the sum of stem cross-sectional area at breast height of 1.3 m of all trees within the site, expressed as metre square per unit area (West, 2004).

The minimum area threshold in the IPCC definition of “devegetation” of other vegetation types makes it a good starting point in terms of quantitative assessment of “devegetation” compared to the alternative definitions suggested by Houghton (2005) and El-Juhany (2009). These alternative definitions do not have any thresholds for the indicators of “devegetation”. With the current need to assess baseline data for land use-based CO₂ emission and sequestration potentials for the implementation of REDD+ activities (Chidumayo and Gumbo, 2013), many countries, including Ghana, will rely only on the area indicator of the

definition of “devegetation” in assessing the impact of anthropogenic activities on non-forest vegetation such as woodlands. However, the area indicator does not account for the amount of biomass harvested or biomass carbon lost and may not reveal the actual impacts on woodlands. A comprehensive approach for assessing the impact of charcoal production on woodland is necessary in the Monitoring, Reporting and Verification (MRV) systems for REDD+ activities to effectively account for the quantity of aboveground biomass (AGB) harvested for charcoal production (Chidumayo and Gumbo, 2013 and Dons et al., 2015). A combination of extent of harvest and basal area of harvested trees could be an appropriate way to assess woodland degradation due to selective harvesting of trees for effective accounting of biomass harvested.

Material and methods

Description of study area

The study was carried out between January and October 2014 in the Kintampo Municipality of Ghana, which lies between latitudes $7^{\circ} 45'N$ and $8^{\circ} 50'N$ and longitudes $1^{\circ} 0'W$ and $2^{\circ} 15'W$ (Fig. 1), and covers an estimated area of 5108 km². It is located at the centre-most part of Ghana and serves as a transit point between the northern and southern parts of the country. The study focused on two communities in the municipality, namely Asantekwa and Kunsu. The vegetation forms part of the Forest-Savannah Transition Zone of the country (Codjoe and

Bilsborrow, 2011), although it is more savannah than forest. This is because it is losing most of its original forest cover due to anthropogenic activities (Afikorah-Danquah, 1997; Codjoe and Bilsborrow, 2011). The Forest-Savannah Transition Zone exhibits the wooded savannah type of vegetation and is well noted for charcoal production in Ghana.

The Kintampo Municipality comprises two traditional authorities: the Mo Traditional Council (of the Mo people) with its headquarters at Old Longoro town (Fig. 1) and the Nkoranza Traditional council (of the Bono people) with its headquarters in Nkoranza town (about 60 km south of Kintampo but in a different political district). The traditional authority is an important local institution in respect of land rights and this is recognized by the laws of the government of Ghana (Afikorah-Danquah, 1997). Each of these traditional authorities thus influences how land and its accompanying resources are utilized, since they are the overall custodian of the land and are responsible for allocating usufruct rights to families and individuals (Afikorah-Danquah, 1997).

The ethnic composition of the municipal is heterogeneous with the Mos and Bonos being the indigenous custodians of the land. The Municipality is a net receiver of immigrants, mainly settler farmers and charcoal producers from the northern part of Ghana and nomadic herdsmen from Burkina Faso, Mali and Niger (Kintampo Municipal Assembly, 2012). These migrants compete for land for various uses and conflicts of land use are frequent problems, either between herdsmen and farmers, herdsmen and charcoal producers or charcoal producers and

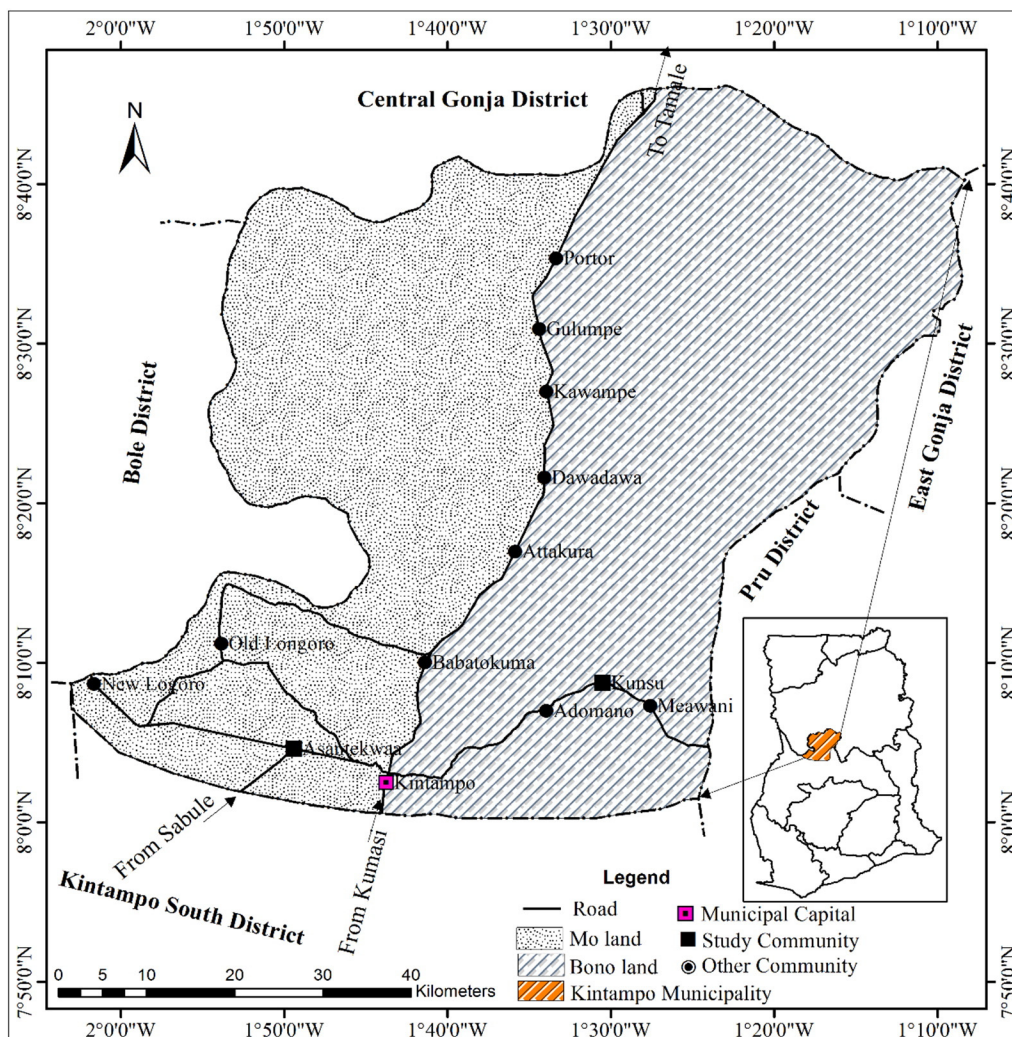


Fig. 1. Kintampo Municipality of Ghana.

farmers (Afikorah-Danquah, 1997). Farming, charcoal production, timber logging and cattle rearing are the major land uses and major economic activities in the rural communities of the municipality. The main land tenure arrangement is share-cropping (Afikorah-Danquah, 1997; Kasanga and Kotey, 2001) and this forms the basis for other natural resource use. The woodland tenure arrangements for charcoal production are produce and share, rental of woodland or outright purchase of selected trees species. Charcoal production is both a fulltime and part-time economic activity in these communities. Repeated harvesting is practised in the area, whereby charcoal producers revisit old-harvested sites to harvest the remnant trees when they mature, provided the land use of the harvested sites is not changed to farming or settlement.

Methodological approach

The field study involved community entry, sampling of charcoal producers, demarcation of sites to be harvested and inventory of trees within the demarcated sites.

Community entry

The community entry was done in August and September 2013, and at two levels: institutional and community. At the institutional level, the Municipal Assembly and the District Forestry office at Kintampo were contacted for their consent to conduct the study. At the community level, Assembly person (political administrative representative) was contacted to facilitate meetings with chiefs and key charcoal producers. The community entry was important to gain access and confidence of relevant institutions, communities and charcoal producers (Ochocka et al., 2010). Charcoal production in this area is, strictly speaking, illegal (Acheampong and Marfo, 2011) because producers do not obtain permits for the use of chainsaw in felling trees as required by law.

Sampling of charcoal producers

Asantekwa and Kunsu communities (Fig. 1) were selected based on their role in charcoal production, geographic location and land tenure systems in relation to charcoal production in the Kintampo Municipality. These communities are major charcoal producing communities in municipality and each community has a different tenure system, which influences access to woodland. Asantekwa is situated in the Mo traditional area while Kunsu is situated in the Nkoranza traditional area. The selection of the communities in these locations was made in order to account for spatial variability in the preferred tree species and the influence of the two traditional authorities on access to the woodlands for charcoal production.

The selection of preferred species for charcoal production was influenced by mostly three factors: (i) production site, which influences the types of species, (ii) experience of charcoal producers, which also influences the type of tree species to use, and (iii) the climatic seasons (rainy or dry season) of the year, which influence the accessibility to production sites. The first two factors are controlled by the charcoal producers since they search for and acquire the site, select the preferred species based on their knowledge and experience in charcoal production. To account for variability in experience and type of tree species and sizes, the study area was stratified into two and three strata as recommended by Lenth (2001) and Coe (1996). Asantekwa was stratified into three blocks using the Kintampo-New Longoro road and Asantekwa Sabule road while Kunsu was stratified into two blocks using the Kintampo-Kunsu-Meawani road. Fifteen charcoal producers were randomly sampled in each community in proportion to the size of each stratum. However, it was not possible to assess charcoal production sites of all the fifteen producers in both communities due to the laborious nature of the field work and the time allowed for the field work. Therefore, ten different sites were assessed in Asantekwa while thirteen were assessed in Kunsu, totaling 23 sites in all. For the purpose of this study, a charcoal production/harvested site is defined as “the area

of woodland where the trees are harvested for a single charcoal production cycle in the field i.e. from the harvesting of trees, packing the wood logs, through carbonization of the wood, to harvesting and bagging the charcoal”. This is based on the fact that the trees are harvested and the charcoal is produced on the same site. The same mode of felling the trees for charcoal production, mostly by chainsaw, is used in the study area due to the high efficiency of chainsaws compared to axes or cutlasses. Similarly, the same method of charcoal production, namely the traditional earth mound (Kiln), is practised in the study area. For each harvested site, one or more earth mound(s) are built, depending mostly on the amount of wood harvested and the nature of the soil, the size and distances among the harvested trees. If either the harvested wood is a lot and the soil within the harvested site is hard or the harvested trees are far apart and big, then more than one mound is used to make it easy to get enough soil to cover the wood and also to make it easy to pack the logs. In all the 23 harvested sites, a maximum of two mounds were used per site for the above stated reasons.

Interview

The type of charcoal production practised, years of experience in charcoal production and impressions about availability of species currently used in charcoal production were assessed through interviews based on structured questionnaire. In all, fifty-one and fifty-two charcoal producers were interviewed in Kunsu and Asantekwa, respectively. The types of production were identified as full-time and part-time. Charcoal production was termed full-time if it was the main economic activity of producers and part-time if it was a supplementary economic activity of producers. Type of charcoal production and experience of producers were relevant information in assessing effects of charcoal production on woodlands because the number of years of production facilitates the interpretation of effects of charcoal production on woodland (Thompson et al., 2013). Similarly, the type of production plays a role in understanding the intensity of the effects of charcoal production on woodlands.

Mapping of extent of harvested sites and inventory tree species

The data collection in the field was carried out from January to October 2014. The preferred trees, in terms of species and size, earmarked for charcoal production on a site were marked (Fig. 2) by the charcoal producer. The outer-most trees earmarked for felling on a

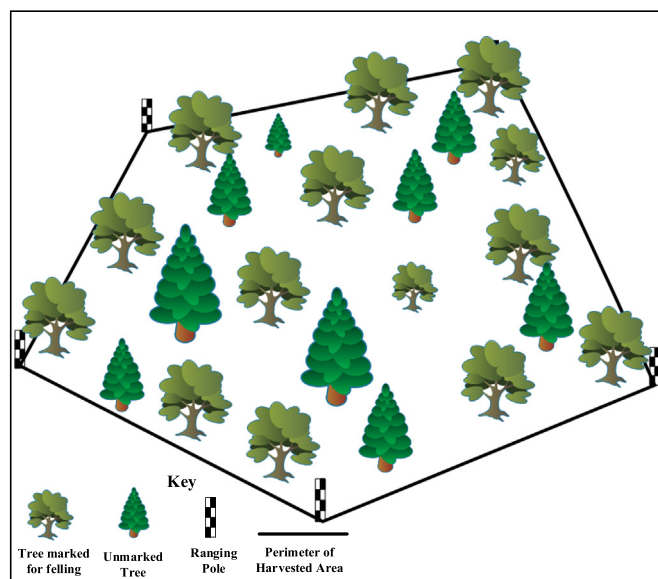


Fig. 2. A setup of harvested area.

site were used as boundary and the extent of the area set-out as a polygon (mostly 4 or 5 sides), (example in Fig. 2). Coordinates of the corners of the polygons were recorded with a hand-held Global Positioning System (GPS), (GPSmap 62s, Garmin, USA) for the extraction of area of the polygons. Each polygon constitutes a single production site.

Inventory of all trees of diameter at breast height (d_{bh} , 1.3 m above ground level) of 5.0 cm or more within the demarcated site was carried out by identifying the tree species and measuring the d_{bh} with a diameter tape (Henry et al., 2010; West, 2009). In the case of forked trees, with two or more stems at 1.3 m or below, each stem was treated as a separate tree and the d_{bh} of each was measured. The minimum d_{bh} of 5.0 cm was based on the smallest tree earmarked for harvesting and because there was the need to compare the basal area of harvested trees with remnant ones (remaining trees after harvest), the same minimum d_{bh} for the harvested trees was used for the remnant trees.

Data processing and analysis

The coordinates were processed in MS Excel, plotted in ArcMap 10.1 and projected using UTM Zone 30N. The points for each harvested site were connected to form a polygon and the area extracted. Non-parametric statistical analysis (1-sample Wilcoxon test in Minitab 16) was used to compare the median of the extent of harvested sites to the IPCC criterion of “devegetation” at 5% error level. The IPCC criterion for “devegetation” is that, the extent of a harvested site must cover 0.05 ha or more and must result from anthropogenic activities. However, the amount of biomass carbon in the harvested trees and the basal area of the harvested trees were compared with those of the remnant trees. The relative comparison used in assessing the changes in biomass carbon stock and basal area of trees at the harvested sites was based on the recommendation of IPCC (2003), that thresholds of “reduction”, “removal”, and “changes” in vegetation may be defined relative to a baseline condition. In this study the baselined condition is amount of carbon in the AGB and the basal area of the remnant trees. The choice of non-parametric statistical analysis was because the sample size ($n = 23 < 30$), is small and test of normality may not be able to reject the null hypothesis even if the data was not normally distributed (Bonnini et al., 2014). It was also informed by preliminary data exploration (Skewness = 0.40, and Kurtosis = −0.93) which showed that the data was skewed to the right, peaked below normal distribution. Hypotheses for the analysis were formulated as $H_0: M \geq 0.05$ ha vs $H_a: M < 0.05$ ha, where M is sample median, population median is 0.05 ha.

The cross-sectional area and basal area were computed for individuals (both harvested and remnant trees) and harvested sites, respectively, assuming that the stem of the tree is circular at breast height (1.3 m). The basal area (G , $m^2 \text{ ha}^{-1}$) of each site was computed as (Eq. (1))

$$G_j = \sum_{i=1}^n (\pi d_i^2 / 4 \times 10^4 A_j) \quad (1)$$

where, G_j is basal area ($m^2 \text{ ha}^{-1}$) of site j , d_i is diameter at breast height (cm) of individual i , A_j is the area of site j .

Basal area of harvested and remnant trees were compared using the Mann Whitney two independent samples t-test. While the null hypothesis was formulated as median of basal area of harvested trees is equal to that of remnant trees ($H_0: M_h = M_r$), the alternative hypothesis was that the median of the basal area of the harvested trees is greater than that of the remnant trees ($H_a: M_h > M_r$); where M_h and M_r are the median basal area of harvested and remnant trees respectively.

Spearman rank-order correlation coefficient was used to assess the relationship among extent of harvested site, number of species harvested, mean d_{bh} of harvested trees, basal area of harvested trees and

biomass of harvested trees. It is a non-parametric rank statistic used as a measure of the strength of a monotonic association between two variables (Hauke and Kossowski, 2011). The correlation coefficient and the t statistic were computed using Eqs. (2) and (3).

$$r_s = 1 - (6 \sum d_i^2) / (n(n^2 - 1)) \quad (2)$$

$$t = r_s \sqrt{n-2} / \sqrt{1-r_s^2} \quad (3)$$

where r_s is Spearman correlation coefficient, d is the difference in rank, n is sample size, t is students- t statistic.

The carbon in the harvested trees was estimated based on the AGB of the harvested trees, while that of the remnant trees was estimated using an allometric equation. The mass of each harvested tree was calculated by summing the mass of its trunk, twigs and leaves while that of each remnant tree was estimated using an allometric equation ($AGB = 0.0580 \rho (d_{bh}^2 H)^{0.999}$) developed with the harvested trees. The AGB of both harvested and remnant trees per site was computed by summing the mass of all the individual trees per harvested site and dividing that by the area (Sawe et al., 2014) as given by Eq. (4).

$$AGB = \frac{\sum_{i=1}^n y_m}{A} \quad (4)$$

where AGB is above ground biomass (kg/ha), y_m is the mass of each harvested or remnant tree (kg) and A is the area of the harvested site (ha) and n is the total number of harvested or remnant trees per site.

The biomass carbon (C) was computed using a carbon content (CF) of 47.48% as estimated by (Adu-Bredu et al., 2010) (Eq. (5)).

$$\text{Biomass C} = AGB \times \frac{CF}{1000} \quad (5)$$

where AGB is aboveground biomass (kg), CF is biomass carbon content (fraction).

Results

Experience in charcoal production

Charcoal producers were categorized into full-time and part-time. Full-time charcoal producers were more experienced compared to those in part-time production. The number of years of experience in charcoal production for full-time producers in Asantekwa community ranges from 25 years to 30 years with an average of 27 ± 3 (sd.) years while that in Kunsu community ranges from 1 year to 33 years with an average of 16 ± 9 (sd.) years (Table 1). However, the average number of years of experience in charcoal production for part-time producers was 10 ± 8 (sd.) and 6 ± 5 (sd.) years, respectively. Many charcoal producers in Asantekwa community were more experience than their counterparts in Kunsu and this attributed to the fact that charcoal production in Asantekwa community compared Kunsu community is more expensive. In Kunsu community, charcoal producers either rent woodlands or purchase individual trees before they

Table 1
Number of years of experience in charcoal producers.

Production category	Community							
	Asantekwa				Kunsu			
	Number of years							
	Min.	Average	Max.	sd.	Min.	Average	Max.	sd.
Full time	25	27	30	3	1	16	33	9
Part-time	2	10	34	8	1	6	30	5

can produce charcoal while in Asantekwa community, charcoal producers pay a token for the use of the woodland for charcoal production.

Extent of harvested sites

The extent of harvest for the 23 sites varied from 0.07 ha to 0.48 ha with an average area of 0.23 ha (Fig. 5). The extent of harvested sites was influenced by the distribution of harvested trees (Fig. 3). Larger areas were harvested in Kunsu community (i.e. sites prefixed K) compared to Asantekwa (i.e. site prefixed A). A statistical comparison of extent of harvest of harvested sites with the IPCC criterion of woodland degradation ($n = 23$, $M = 0.23$ [0.17, 0.28] ha, Wilcoxon Stat. = 276.0, $P = 1.00$) did not provide significant evidence ($P = 1.00$) to reject the null hypothesis that the sample median was 0.05 ha or more at 95% confidence level. Hence, the median of the extent of harvested woodland (0.23 ha [0.17, 0.28]) is significantly greater than 0.05 ha. This implies that the harvested sites were degraded as per the IPCC criterion for “devegetation” of woodland.

The number of trees harvested per site and the sizes of the individual trees harvested are important in assessing degradation due to selective harvesting of trees. In order to use extent of harvested site as a measure of degradation in selective harvesting, there should be evidence that a strong relationship exists between extent of harvested site and both the number of trees harvested and the mean d_{bh} per site. The results (Fig. 5) showed no apparent trend or relationship between extent of harvested sites and number of trees harvested per site in both communities. This suggests that the extent of harvested site is not a good indicator of the number of trees harvested per site. Similarly, no clear relationship was observed between extent of harvested sites and mean d_{bh} in both communities (Fig. 6), which also indicates that extent of harvested is not a proxy for the mean d_{bh} per site.

Results of statistical analysis (Table 2) of the relationship between extent of harvested sites and number of trees harvested per site, mean

d_{bh} and basal area confirmed absence of significant linear relationship between extent of harvest and number of trees harvested per site ($r_s = 0.06$, $P = 0.799$) at 95% confidence level. However, there was strong and significant negative relationship between extent of harvested site and d_{bh} as well as basal area ($r_s = -0.67$, $P = 0.001$).

Basal area

The proportion of tree basal area harvested generally exceeded that of the remnant trees in both communities (Fig. 6). Out of the initial 100% basal area, a maximum of 89.5% (i.e. site A2 of Fig. 6A) and a minimum of 39.8% (A8) were harvested. All producers in Kunsu, except producer K7, harvested more than 50% of the basal area in each site (Fig. 6B). However, four out of the 10 producers in Asantekwa harvested less than 50% of the basal area (i.e. A4, A7, A8, and A10). The medians of the basal area of harvested and remnant trees were $5.2 \text{ m}^2 \text{ ha}^{-1}$ and $2.6 \text{ m}^2 \text{ ha}^{-1}$, respectively, with an estimated difference in medians of 2.7 [$1.4, 4.2$] $\text{m}^2 \text{ ha}^{-1}$. Mann Whitney test ($n = 23$, $M_h - M_r = 265.4 \text{ m}^2 \text{ ha}^{-1}$, $P < 0.001$) of equality of medians showed sufficient evidence ($P < 0.001$) to reject the null hypothesis, that medians of basal area of harvested and remnant trees were equal. It was concluded that the median of basal area of harvested trees is significantly greater than that of the remnant trees at 95% confidence interval.

The medians of the biomass carbon in the harvested and remnant AGB in the 23 harvested sites were 19.68 t ha^{-1} and 6.56 t ha^{-1} respectively with a point estimate of the difference in medians of 12.07 t ha^{-1} [6.20, 18.02]. The Mann Whitney test of significant difference in medians ($n = 23$; $M_{hc} - M_{rc} = 12.07 \text{ t ha}^{-1}$ [6.20, 18.02]; $P < 0.001$) provided sufficient evidence against the null hypothesis, that the difference between the medians of the carbon in the harvested and remnant AGB is zero at 95% significant level. Considering the harvested sites, this generally means that the biomass carbon in the harvested trees is significantly greater than that in the remnant trees at 95% significant level.

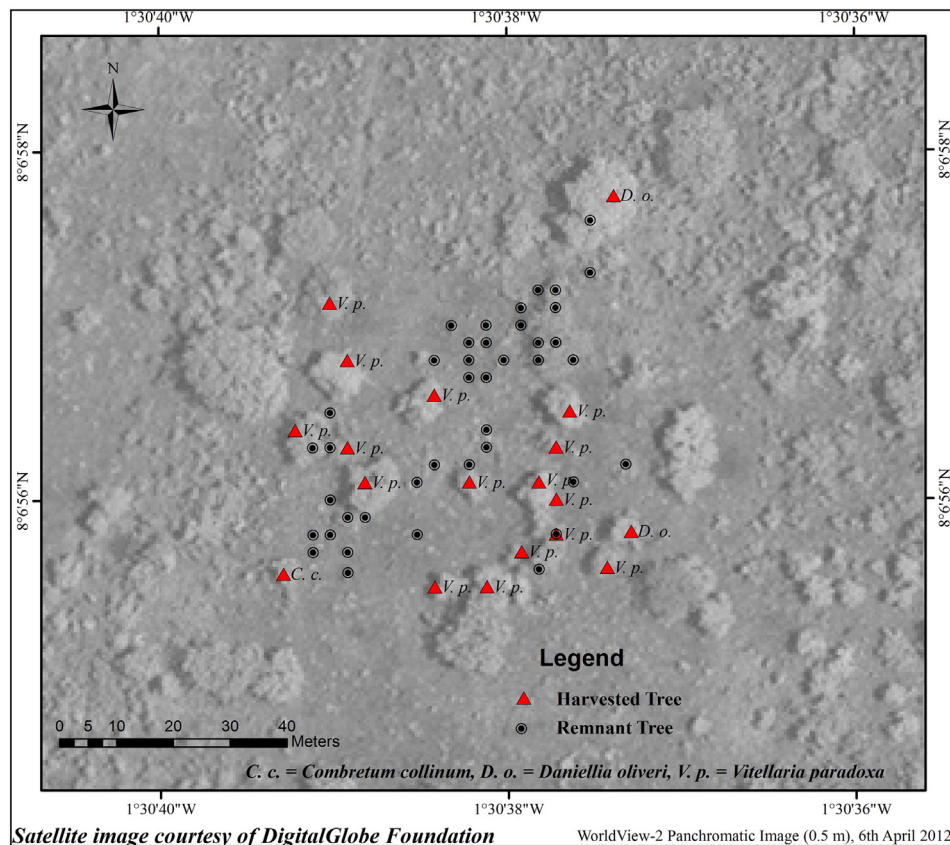


Fig. 3. A WV2 panchromatic image showing spatial distribution of trees at site K10.

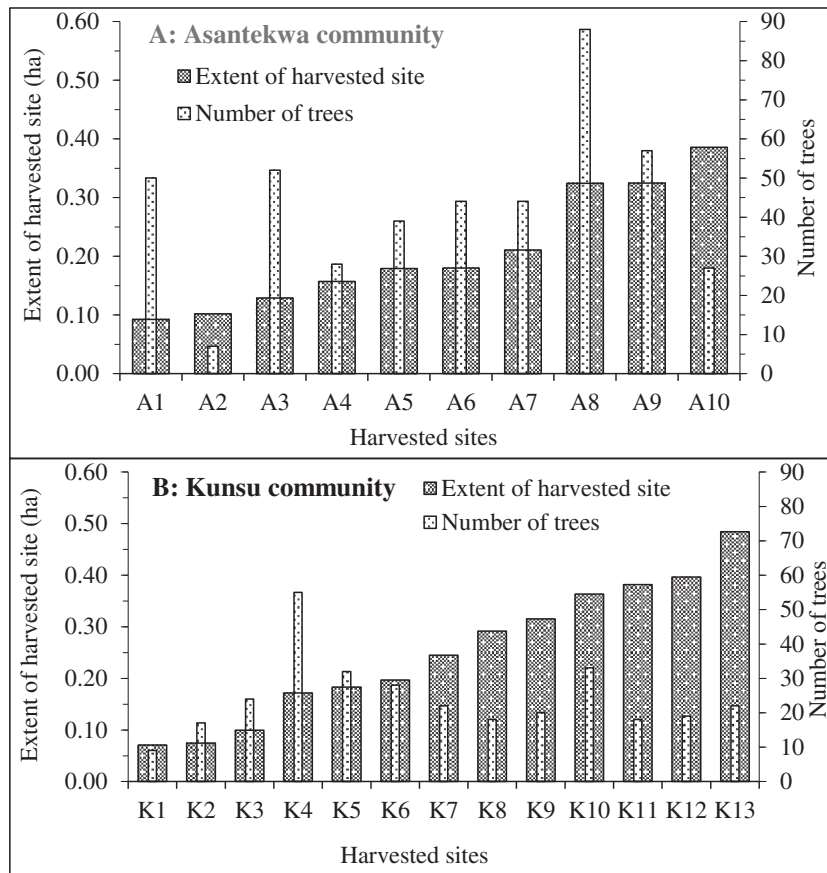


Fig. 4. Relationship between extent of harvested site and number of trees harvested per site.

The proportion of the carbon in AGB of the harvested trees generally exceeded that in the AGB of the remnant trees in both communities (Fig. 7) indicating a reduction in the initial biomass carbon stock of the harvested sites. The reduction exceeded 50% per site except sites A2, A4 and A9 at Asantekwa community (Fig. 7A) and K1 at Kunsu community (Fig. 7B). Also, more biomass carbons were removed through the harvested trees in Kunsu compared to Asantekwa.

Discussion

The study assessed the impact of charcoal production on woodland in terms of extent of harvest and harvested basal area of trees and remnant trees after harvest. The experience of the charcoal producers in Asantekwa and Kunsu communities suggests that charcoal production has been a long term activity in both communities, which can have both positive and negative implications for the state of the woodlands in both communities, depending on the woodland management plans that are put in place.

The statistical analysis of the extent of harvested sites revealed that charcoal production degrades the harvested sites according to the IPCC definition of degradation (IPCC, 2003) since the median of the extent of harvested sites exceeds the IPCC minimum threshold for “devegetation”. A median extent of harvest of 0.23 ha [0.17, 0.28] could have significant negative implications for sustainability of woodland in the area, if extrapolated for a single producer from monthly to yearly basis and also from the individual to the community level. From field observations, it takes between a 21 and 28 days to process trees into charcoal. A producer can process two or three of such single production sessions concurrently depending on the amount of support he or she receives from family members (wife or husband, and children). This translates the median extent of harvested into more than 5.52 ha

(0.23 ha $\times$ 3 $\times$ 8 months, excluding ritual days) per person per year. Considering the average number of years of charcoal production for only full time producers (Fig. 4), it means 223.56 ha and 132.48 ha of woodland have been degraded by charcoal production in Asantekwa and Kunsu in 27 and 16 year respectively. If these degraded sites were not allowed to fallow and regenerate but taken over by farmers, they would have undergone worsening levels of “devegetation”.

However, examination of the relationship between extent of harvested sites and number of trees harvested per site showed no relationship between the two, suggesting that the extent of harvested sites cannot be used as a proxy for the number of trees harvested. This shows that the extent of harvested sites is an inappropriate measure of impact of charcoal production on woodland as supported by de Waroux and Lambin (2012); El-Juhany (2009) and Houghton (2005). Relating extent of degraded woodland to extent of harvested sites may not be relevant for current needs of quantifying biomass removed or C emitted from woodlands through anthropogenic activities as admitted by Griscom et al. (2009). Furthermore, the use of the extent of harvested site as an indicator of “devegetation” makes it difficult to exclude the effects of other land uses such as farming since the area indicator does not take into account the biomass removed in terms of number and size of trees at the time of harvest.

Generally, tree harvesting for charcoal production is selective (Hosier, 1993) and the extent of harvested sites is influenced by the spatial distribution of preferred trees. For the same number of preferred trees and sizes, the extent of harvest is larger in woodlands where the preferred trees are dispersed compared to woodlands where the preferred trees are dense. Thus, extent of harvest reflects the spatial dispersion of harvested trees rather than extent of “devegetation”. The implication of this finding is that the actual “devegetated” sites may not be identified on the basis of the extent of harvested sites in the

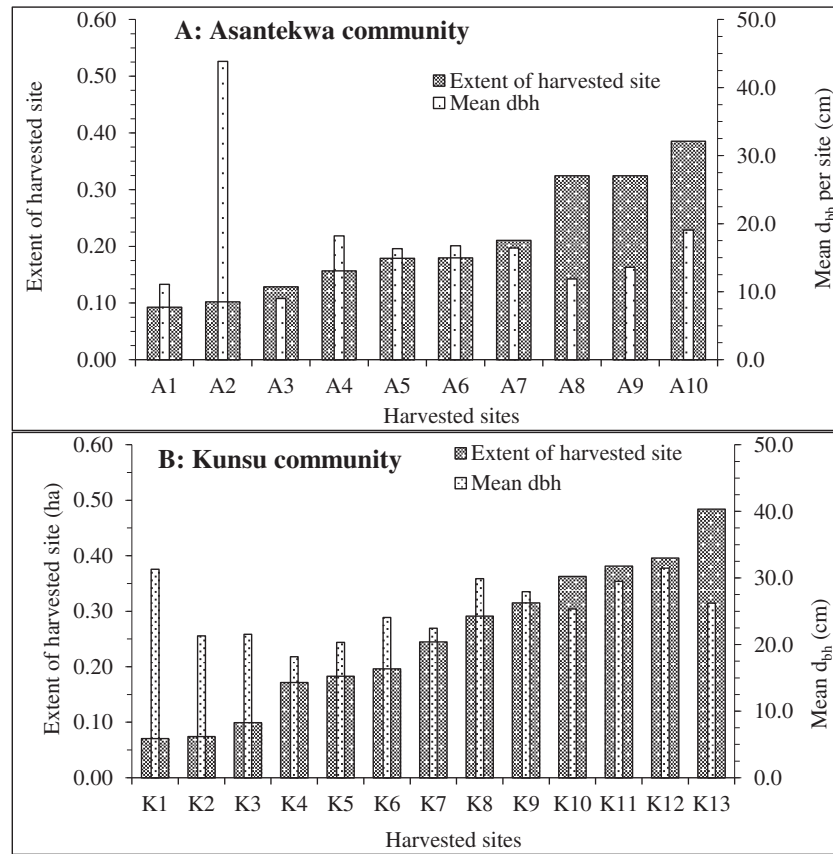


Fig. 5. Relationship between extent of harvest and mean d_{bh} .

case of selective harvesting of trees as normally done in charcoal production. This is because many big trees could be harvested in sites less than 0.05 ha and yet not be considered “devegetated” while few but big and dispersed preferred trees could be harvested among a lot of non-preferred trees, in which case such sites would be considered “devegetated” because they are greater than 0.05 ha.

Since the same quantity of fuel was used (4.5 l) in each harvested site, two reasons account for the observed variation in the extent of harvest, assuming that the efficiencies of the chainsaws used in felling the trees were comparable. First, for the large harvested sites observed, either many smaller trees were harvested compared to bigger trees or large sparsely distributed trees were harvested. This explanation is supported by the absence of association between extent of harvested sites and number of species harvested per site because, for the same extent of harvested site, varied number of trees can be harvested depending on the size of the preferred trees. Second, for the small harvested sites observed, many large densely distributed trees were harvested compared to small trees. This is further revealed by the negative but significant association between extent of harvested sites and DBH though the relationship is weak. This points out that our findings do not support the use of count of trees harvested as a measure of impact of charcoal production on woodland and suggest the inclusion of size of harvested trees in assessing “devegetation” due to selective harvesting. However, this view contradicts the approach of *de Waroux and Lambin (2012)*; *Kouami et al. (2009)* and *Hosier (1993)*.

Our finding further points to the significance of biomass carbon stock and basal area as an appropriate measure of “devegetation” due to selective harvesting of trees as in charcoal production. The biomass carbon stock and basal area take into account the extent of harvested sites, number and sizes of harvested trees. Comparison between basal areas of harvested and remnant trees of the same sites shows that basal area of harvested trees is significantly greater than that of the

remnant ones. Generally, this is attributed to the fact that either many small trees, bigger ones or both are harvested per site compared to the remnant trees for the same site. Significant reduction in basal areas of the harvested sites re-emphasizes the observation of *El-Juhany (2009)* and *Houghton (2005)* that degradation due to selective harvesting manifests in changes in biomass (basal area is a proxy for biomass) rather than changes in extent of woodland. On the basis of the significant reduction in the basal area of trees at the harvested sites, charcoal production degrades the harvested sites.

However, it is worth emphasizing that none of the sites showed zero basal area after harvest (i.e. total clearance, the worst case scenario of woodland degradation), and this is a significant revelation for sustainable woodland management. Our view is emphasized by *Guariguata and Ostertag (2001)* that the regeneration capacity of woodlands is generally high if the land use before abandonment is not severe. Our findings and the observation of *Guariguata and Ostertag (2001)* suggest that the impact of charcoal production on woodland may not be as alarming as it is generally perceived especially when the extent of harvested site is considered as the criterion of “devegetation”. This evidence also supports the view of *Kambewa et al. (2007)* and *Mwampamba et al. (2013)* that the impact of charcoal production are often over-generalized. This implies that degradation of harvested woodlands is an issue of post-harvest management as observed by *(Chidumayo and Gumbo, 2013)* and not charcoal production *per se*. Therefore, if harvested sites are protected and allowed to fallow, long term or permanent degradation can be minimized and charcoal production would be sustainable.

Generally, the results have revealed that significant amount of the AGB carbon from the harvested trees is removed through charcoal production, compared to what is observed in similar areas. Although the maximum number of trees harvested per site is less than the number of trees recorded by *Sawe et al. (2014)* in Miombo Woodlands in

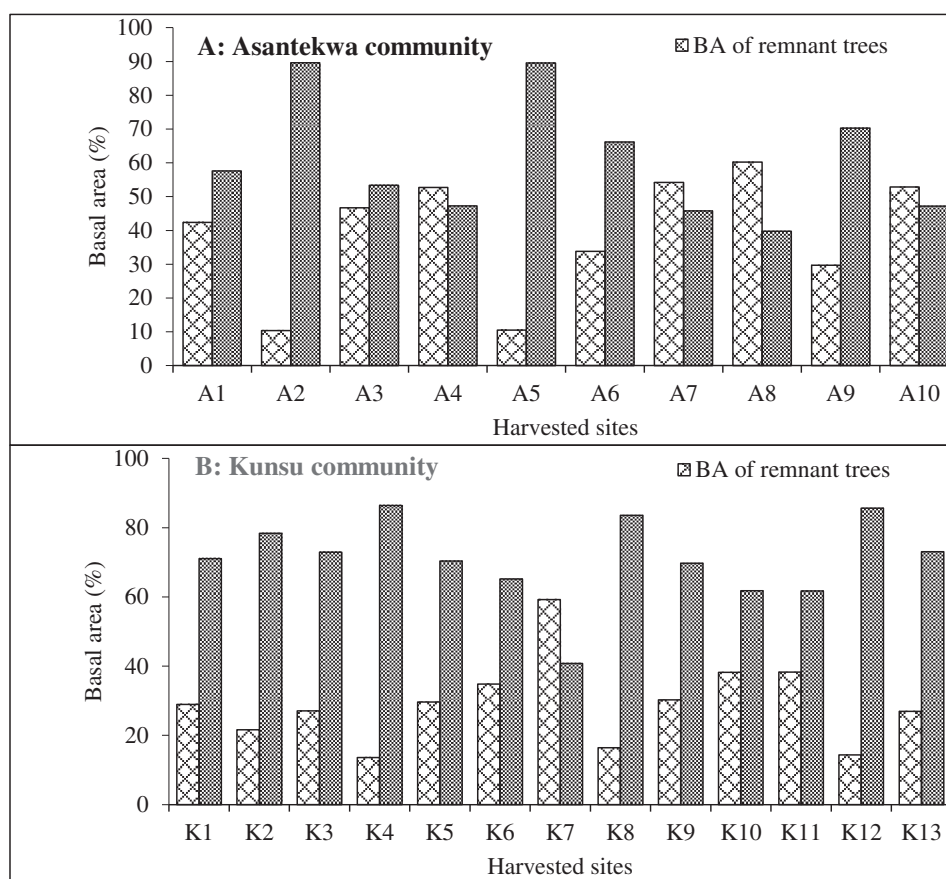


Fig. 6. Comparison between BA of harvested and remnant trees.

Tanzania, the amount of C associated with the removal of trees in this study far exceeds that observed by Sawe et al. (2014). The difference is attributed to differences in d_{bh} and wood density of harvested trees per site as observed in both studies. It is most likely that large trees of high wood density are harvested for charcoal production in the Forest-Savannah Transition Zone of Ghana compared to those harvested in the Miombo Woodlands of Tanzania. This reveals serious consequences of charcoal production for biomass carbon emission but as indicated by Dyer et al. (2010), selective harvesting of trees decreases the AGB (carbon for that matter) temporarily and proper management of the harvested sites can reverse the initial decrease in AGB.

Assessment of the impact of charcoal production on woodlands by comparing the extent of harvested sites with the IPCC criterion for degraded woodlands (absolute comparison) as well as comparing the basal area and the carbon in the harvested trees with the basal area of and carbon in the remnant trees (relative comparison) is innovative and relevant. The relative comparison has made it possible to isolate the effect of other land uses in the area such as slash and burn farming, lumbering, grazing and focus only on that of charcoal production since it compares harvested with the remnants after harvest. The relative comparison measures the actual impacts of charcoal production on woodland at a point in time and if repeated for a number of years, will

provide a better understanding of the long term effects of charcoal production on woodlands compared to the absolute comparison. Therefore, the relative comparison minimizes the overgeneralization of the impact of charcoal production on woodlands, which has contributed largely to the negative outlook on charcoal production as reported in literature (Chidumayo and Gumbo, 2013; Griscom et al., 2009; Mwampamba et al., 2013; Oduori et al., 2011). Notwithstanding the relevance of the relative methods in assessing degradation associated with charcoal production, care must be taken not to make emphatic conclusions about the impact of charcoal production on woodland based on a single assessment since the activity of harvesting trees must be a long-term activity as defined by IPCC (2003). However, the absolute method has a limitation in a situation of repeated harvesting as is done in the study area. In an unmanaged woodland, it is unlikely that the harvested site will be allowed to regain its original status before the interference of human activities. Therefore, if a threshold is set based on a primary woodland, the effect of a second or third cycle of harvest will be overestimated due to cumulative effect from previous harvest if the extent of harvest, basal area or the biomass carbon stock is compared with such a threshold.

Although high resolution images are cable of detecting changes in the harvested site as in Bolognesi et al. (2015) in Somalia, it was not possible to use them due to none availability of such images for the entire study area for the required pair of dates (before and after harvest). This made it impossible to detect changes in the harvested sites using earth observation methods. These challenges are not peculiar to the current study area alone but were also mentioned in Somalia (Oduori et al., 2011; Rembold et al., 2013; Bolognesi et al., 2015). Therefore, manual field measurement as demonstrated in this study is still a necessary methodology for assessing the effects of charcoal production on woodlands, even in the midst of earth observation methods, in areas where

Table 2
Spearman correlation between extent of harvested site and other indicators of degradation.

Other indicators of degradation	Extent of harvested site
	Correlation coefficient (P-value)
No. of Sp.	0.06 (0.799)
Mean d_{bh}	−0.67 (0.001)
Basal area trees	−0.67 (0.001)

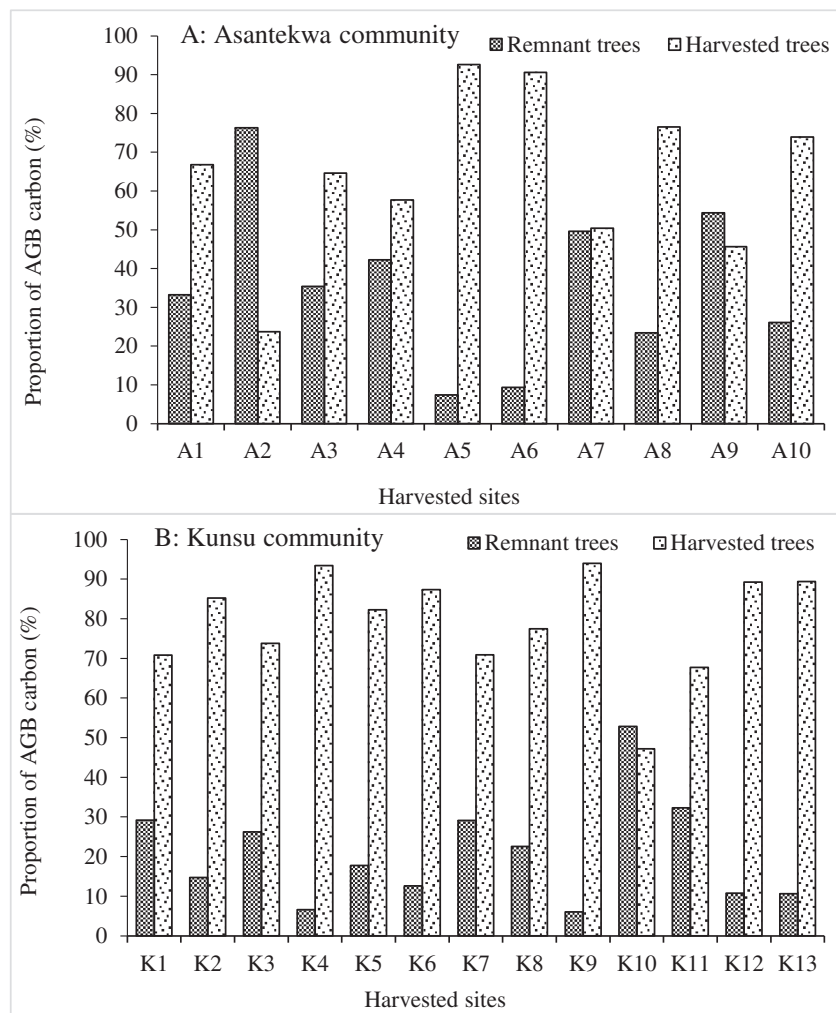


Fig. 7. Proportion of carbon in harvested and remnant trees per site.

high resolution images are unavailable, limited by the extent of the study area or the cost of acquisition.

Also, comparison of the indicators of degraded woodlands (extent of harvested sites, basal area and biomass carbon stock) in this study is relevant for scientific discourse on the best way to assess the impacts of charcoal production on woodland. The use of all these indicators in literature (El-Juhany, 2009; Hosier, 1993; IPCC, 2003; Miettinen et al., 2014) makes comparison of different studies on the impact of charcoal production on woodland difficult, which subsequently contributes largely to the varying views on the extent of devegetation attributed to charcoal production, especially in Africa.

Conclusions

The study assessed the impact of charcoal production on woodlands based on the IPCC (2003) indicators of “devegetation” and argued that the area indicator is not a good measure of “devegetation” in the case of selective felling of trees, although many countries would rely on it in the implementation of REDD+ programmes. The study proposed basal area as a suitable measure of “devegetation”. The findings of the study show that the harvested sites were degraded on the basis of the IPCC indicators of “devegetation” and that charcoal production has the tendency of degrading woodlands. The use of the area as an indicator of devegetation over-emphasizes the impact of charcoal production on woodlands since the area indicator does not take into account the amount

of wood harvested. Strict application of the area indicator alone for assessing devegetation can trigger the banning of charcoal production and intensify existing confrontation between state institutions mandated to manage woodlands and charcoal producers. The basal area and the amount of biomass carbon removed are better indicators of the impact of charcoal production on woodland compared to the extent of harvested site. The comparison of the basal area of harvested and remnant trees as well as the comparison of the carbon in harvested and remnant trees provides actual impacts of charcoal production on woodland since it isolates the impact of charcoal production from those of other land uses. Although the three indicators of the impact of charcoal production on woodlands supports the hypothesis that charcoal production impacts negatively on woodland, the amount of carbon in the remnant trees and the basal area of the remnant trees also provide evidence that the situation is not as serious as generally portrayed. The presence of remnant trees therefore provides motivation that the harvested sites can recover from the impact of the selective harvesting, if they are protected from further degradation. This has significant relevance for the outlook on charcoal production and the long-term sustainability of both woodlands and charcoal production. Although, the study supports the hypothesis that charcoal production degrades woodlands, it must be emphasized that the evidence of impact of charcoal production on woodland provided here, is basis for management of woodlands and not basis for halting it.

Acknowledgments

We are indebted to the Federal Ministry of Education and Research (BMBF) WASCAL-BMBF of Germany, which fully and solely funded the study through the West African Science Service Centre for Climate Change and Adapted Land use (WASCAL) under WASCAL Graduate Research Programme on Climate Change & Landuse (CCLU), Kwame Nkrumah University of Science and Technology, Kumasi. We are thankful to Kwame Nkrumah University of Science and Technology for offering the lead author the opportunity to be part of WACAL GRP CCLU. We are also grateful to the University for Development Studies, Tamale – Ghana, for granting the lead author study leave with pay to enable him to conduct this study without any conflict of interest and also to the Faculty of ITC, University of Twente, Enschede – The Netherlands, for allowing us to use their facilities during the writing of this manuscript. We are equally thankful to the Forestry Research Institute of Ghana (FORIG), for allowing us to use their laboratory for wood density analysis. We appreciate the support of the Kintampo Municipal Assembly, Kintampo Forest District office, chiefs, assemblypersons (local government representatives) of Asantekwa and Kunsu communities, charcoal producers as well as all those who assisted in one way or the other during the data collection and writing the manuscript.

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