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Ecosystem services trade-offs from high fuelwood use for traditional shea butter processing in semi-arid Ghana

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ABSTRACT

Traditional production of shea (*Vitellaria paradoxa*) butter uses large amounts of fuelwood. This study examines the effects of shea production on the environment by identifying the ecosystem service trade-offs due to the high fuelwood consumption. Fuelwood species inventories for different land use types and on-site plot-based standing biomass measured. We estimate greenhouse gas (GHG) emissions and changes in carbon stocks for different shea products in rural and urban settings. Results suggest that, processing of shea can cause a significant change of carbon stocks in the four study villages and result in the loss of carbon sequestration ecosystem services. For GHG emissions, rural shea butter processors emit 3.14–3.31 kg CO_2 eq/kg shea butter, while urban processors emit slightly less (2.29–2.54 kg CO_2 eq/kg shea butter). We identify trade-offs with several other provisioning (woodland products), regulating (erosion control) and cultural ecosystem services (religious and spiritual values). Such findings can initiate discussions about the hidden environmental and socioeconomic costs of current shea production practices. Potential strategies to enhance the sustainability of shea production include the adoption of improved stoves, sustainable fuelwood harvesting practices, parkland management, alternative fuels, and product pricing premiums to fund the adoption of cleaner shea processing technologies.

1. Introduction

The importance of traditional biomass fuels such as fuelwood and charcoal in meeting the energy needs of most rural households in developing countries cannot be overemphasized (Food and Agriculture Orgaganizxation (FAO), 2016; Zulu and Richardson, 2013). Fuelwood also contributes greatly to food preservation and livelihood activities in rural and urban settings (FAO, 2010). For example, more than 2.2 million families in Ghana (40% of the total population) depend on fuelwood for cooking and heating (Peprah, 2010). At least 280,000 of these households also use fuelwood for livelihood activities such as smoking fish, making gari (cassava grits fried into small granules and then eaten directly or processed), brewing pito (alcohol made from fermented millet), firing pottery, and extracting oil (from oil palm, coconuts, groundnuts, and shea) (Kwarteng, 2015).

At the same time, deforestation due to growing fuelwood and charcoal use can be a major threat to biodiversity and the provision of ecosystem services, especially in semi-arid landscapes (Adkins et al., 2010; Peprah, 2010; Chidumayo and Gumbo, 2013). Greenhouse gas (GHG) emissions related to deforestation can be as much as 20% of anthropogenic emissions (Gullison et al., 2007; Smith et al., 2014).

Ghana currently experiences a high rate of deforestation possibly having lost as much as 1.99–2.19 % of forest cover annually over the past decades, even though these numbers can be uncertain (Pouliot et al., 2012; Hansen et al., 2009). However, forest loss continues unabated every year despite promoting re-afforestation policies, planting new forests, and creating forest reserves (Oppong-Anane, 2006; Oduro et al., 2015). Additionally, timber exports are high, fuelwood consumption practices are highly inefficient, and ever-harsher weather conditions cause poor forest regrowth and regeneration (Powell et al., 2010; Hawthorne et al., 2011). These contributed singinficantly to Ghana not being able to meet Millennium Development Goal 7 (MDG7) on environmental sustainability (UNDP, 2015).

Reducing fuelwood and charcoal-driven deforestation is a particularly intractable issue in poor rural contexts, where populations are highly dependant on ecosystem services for their

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livelihoods (Adkins et al., 2010; Ros-Tonen and Wiersum, 2005; Wunder et al., 2014; Belcher, 2014; Woollen et al., 2016). This can be a particularly important challenge for Ghana given the ongoing importance of forest resources to most rural households (Appiah et al., 2009; Pouliot and Treue, 2013). However, the direct and indirect environmental impact of fuelwood/charcoal demand for value-added processing of non timber forest products (NTFPs) has rarely been explored in developing countries (Ros-Tonen et al., 2014).

The shea fruit (*Vitellaria paradoxa*) is such a NTFP that depends on fuelwood for its transformation into value-added products such as food (shea butter), edible oil, and raw materials for cosmetics and pharmaceuticals (Lovett and Haq, 2000; Carette et al., 2009; Elias and Carney, 2007). The export of raw shea kernel and shea butter (‘‘*karite*" in French) to international markets in Europe, Asia, and the United States has increased in recent years (Elias, 2015; Jasaw et al., 2015; Ghana Export Promotion Authority [GEPA], 2014; Bello-Bravo et al., 2015). Countries who import shea products subsequently process them into a wide range of food products (including chocolate) and cosmetics (Schreckenberg et al., 2006).

For these reasons, the shea tree is highly valued by rural households in Western and Central Africa. It currently grows throughout northern Ghana (CRIG, 2007; Naughton et al., 2015), with almost every rural household in the region engaging in shea fruit picking, and processing into shea kernels (shea nuts) and/or shea butter. Therefore, shea trees are selectively managed and protected on farmlands, which has resulted in nearly homogenous shea tree stands (Bello-Bravo et al., 2015). Shea is considered a ‘‘female crop" as women predominately collect shea fruits (Elias and Carney, 2007; Boffa, 2015). As a result, most of the shea-related research focuses on how shea production alleviates poverty for rural women, generates employment, and commands a high export value (Chalfin, 2004; Elias and Carney, 2007; Lovett, 2010; Pouliot, 2012; Boffa, 2015; Bello-Bravo et al., 2015).

When it comes to environmental impact, Glew and Lovett (2014) argue that shea is less harmful compared to other vegetable oils such as oil palm. However, few empirical studies have examined the environmental effects of resource consumption during shea processing (Jibreel et al., 2003; Lovett, 2010; Naughton et al., 2017). In particular the high fuelwood consumption during shea processing has been shown to account for at least 74.5% of the carbon footprint of shea butter in cosmetics sold in the United Kingdom (Glew and Lovett, 2014). Recent studies in northern Ghana show that approximately 1.7–2 kg of fuelwood is needed to produce 1 kg of shea butter from raw kernels (Mohammed and Heijndermans, 2013; Jasaw et al., 2015).

However, high fuelwood input for the production of shea butter could have implications beyond direct GHG emissions (Glew and Lovett, 2014). For example, the extraction of fuelwood species from savanna landscapes could exacerbate the high rate of land degradation and desertification already witnessed in the area (Naughton et al., 2017). Fuelwood extraction for shea processing could also exacerbate the loss of habitat, biodiversity, and ecosystem services such as nutrient and micro-climate regulation in areas that already experience such trends (Tom-Dery et al., 2014; Lolig et al., 2014).

The aim of this study is to identify the main ecosystem service trade-offs of shea production in order to facilitate a better understanding of its effects on the environment and rural livelihoods. We mainly focus on how fuelwood use throughout the shea processing chain can affect carbon sequestration. We also quantify the direct GHG emissions of shea processing and provide a rapid assessment on potential effects to other ecosystem services. We focus in rural northern Ghana to illustrate the main effects of high fuelwood consumption in a setting with highly degraded biomass resources and a low regeneration potential for key fuelwood species.

2. Methodology

2.1. Study location

Shea production in Ghana is concentrated in the Upper West, Upper East, and Northern regions. These regions are located within the Guinea Savannah Ecological region, which is dominated by grass and tree species including the shea tree (*V. paradoxa*), various species of acacia (*Acacia farnesiana*), baobabs (*Adansonia digitata*), mahogany (*Khaya senegalensis*), neem (*Azadirachta indica*), mango (*Magnifera indica*), and various fire-resistant tree species. There is a marked change in the plant life of this vegetation zone between the two main seasons of the year (average annual rainfall = 900–1100 mm) (McSweeney et al., 2010). The area is verdant during the rainy season, but the grass dries and most of the deciduous trees shed their leaves during the dry season (harmattan). The dry season also marks harsher weather conditions and rampant bushfires.

Study sites were selected in both urban and rural settings considering their different resource requirements for shea kernel/butter production (Jasaw et al., 2015) (Fig. 1). Urban sites were the major cities of the region, Tamale (Northern Region) and Wa (Upper West Region). Rural sites were the villages of Kpalgun and Zagua (Tolon District, Northern region), and Zowayeli and Baleufili in (West District, Upper West Region). These specific villages were selected because they engage in typical shea processing activities prevalent throughout the shea growing regions of Ghana.

Subsistence farming is the principal livelihood activity in the four study villages. Agroforestry parks and forests outside forest reserves (usually sacred groves) are mostly common pool resources used for the unrestricted harvesting of timber for fuelwood and NTFPs such as shea fruit. Females from every household in the study villages are engaged in shea activities during the shea season (May–August).

Finally, land degradation in all four villages is widespread as only a few dispersed, selectively preserved trees remain. Increased land degradation in the study sites has been attributed in recent years to climate and ecosystem change (Kusakari et al., 2014). Other livelihood activities such as firewood harvesting, charcoal production, farm clearing, stone quarrying, and construction have further modified and degraded the landscape.

2.2. Data collection and analysis

2.2.1. Overall approach

The overall methodology consists of eight different but interrelated steps. These involve land use classification (Step 1–2) (Section 2.2.2), carbon stock estimation (Step 3–4) (Section 2.2.3), quantification of fuelwood use for shea activities (Step 5) and its impact in terms of carbon stock change (Step 6), GHG emissions (Step 7) and trade-offs with other ecosystem services (Step 8) (Section 2.2.4). For Step 1–6, we used the IPCC principles to estimate carbon stock change and GHG emissions from land use and cover change (IPCC, 2014), modified where necessary to fit the specific context of our study. Primary data was collected in 2014 (May–June) and 2015 (February, and July–August) (see Sections 2.2.2–2.2.4 for more details on type and method of data collection).

The results were synthesized using the conceptual framework of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2015). In this framework fuelwood harvesting for shea production can be considered as a direct driver

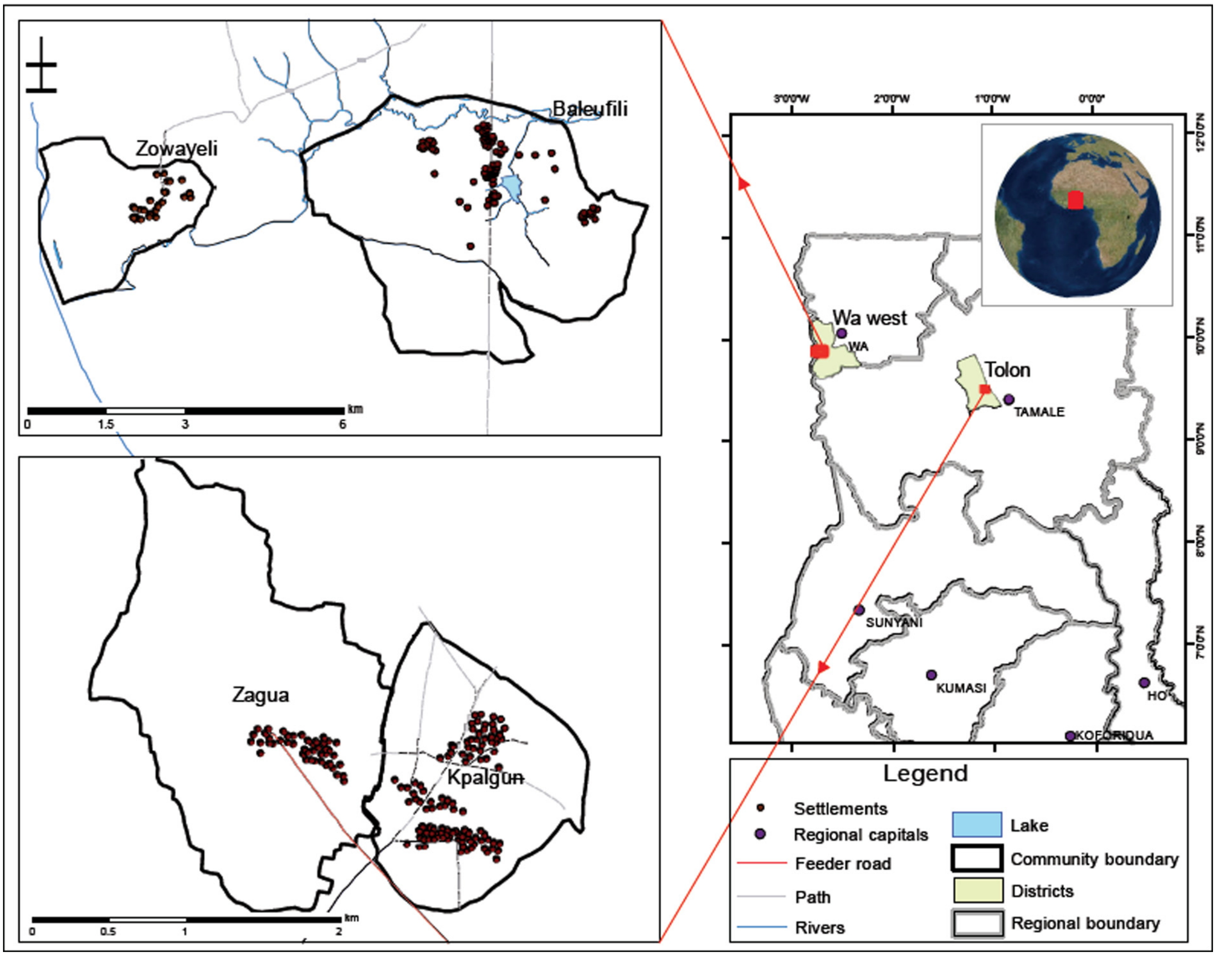

Fig. 1. Map of study sites in Northern Ghana.

of ecosystem change. This ecosystem change can have important ramification for the flow of nature's benefits (i.e. ecosystem services) from the areas of fuelwood extraction.

The main ecosystem service studied is carbon sequestration that is linked to climate regulation, a regulating ecosystem service. In summary, changes in carbon stocks (whether losses or gains) due to fueldwood extraction for shea processing, imply changes in the provision of climate regulation services (Romeu-Dalmau et al., 2016). Through a rapid ecosystem services assessment (e.g. von Maltitz et al., 2016) and review of past studies, we identify potential trade-offs with other ecosystem services such as freshwater (provisioning), erosion control (regulating), religious services (cultural) and a host of other provisioning services such as medicinal plants, construction material and wild fruits, among others.

Following the IPBES conceptual framework, changes in the flows of these ecosystem services can have important ramifications for the wellbeing of local communities and urban shea processors. Although quantifying these effects on human wellbeing was beyond the focus of this paper, Section 3.2 provides some insights of the expected ripple effects.

2.2.2. Land use classification

Step 1 identified the different land uses in the four study sites. In particular, we undertook participatory mapping with community members in May–June 2015 to identify the different land uses in the four villages (e.g. Klain and Chan, 2012). Boundaries for each land use type were identified with the help of local residents and were recorded using hand-held global positioning system (GPS) equipment.

Step 2 derived the land classification system for the study sites. Coordinates from Step 1, were analyzed with ArcGIS software (v10.2) to combine the data with the land use classification developed by Antwi et al. (2014) for this area. The land classification system used for carbon stock estimation comprises of: (a) agricultural land (farmed areas apart from rice valleys, see maps below), (b) grassland (non-farmed, livestock grazing areas) and savanna woodland (non-farm woodland reserve and sacred groves or areas protected for spiritual purposes). Land use categories such as fallow land, rice valleys, and settlements were not considered for the carbon stock study as they were generally found not contain fuelwood tree species available for harvesting.

2.2.3. Carbon stock estimation

Step 3 estimated through extensive fieldwork in May 2015 and January 2016, the fuelwood species composition and woody biomass stock in the different land use categories identified in Steps 1–2 (Chave et al., 2005). We randomly selected three quadrats (100 m × 100 m) in each village from each land use type that contained fuelwood species, i.e. agricultural land, grassland, and woodland, i.e. 9 plots per village. Key informants in each village assisted with the identification of tree species used for fuelwood. For each fuelwood species we recorded height (H) in meters and diameter at breast height (DBH) in centimeters. Tree species not typically used for fuelwood (e.g., shea, locust bean, and baobab) were excluded from the survey.

Step 4 calculated carbon stocks, in the form of above ground biomass (AGB) and below ground biomass (BGB). Species-specific AGB was calculated from average DBH for all fuelwood species inventoried within a plot using Equation 1 (Brown et al., 1989; Brown, 1997; Chamshama et al., 2004; Malimbwi et al., 1994). BGB was obtained by applying to the AGB component the standard conversion factor of 0.26 for tropical vegetation (Cairns et al., 1997).

$$\textit{Above Ground Biomass}\ (\mathrm{kg}) = 0.2035 * \mathrm{DBH}^{2.3196} \tag{1}$$

It should be noted that fuelwood harvesting did not result in large-scale land conversion/deforestation in the study villages given the scattered nature of trees and the selective logging of fuelwood species. Therefore, we assumed that changes in soil organic carbon (SOC) were minimal. This assumption gets also some credence considering the possible lack of significant differences in SOC content among different land uses in savanna areas of northern Ghana (Bessah et al., 2016). As a result, for the purpose of this study total carbon stocks and carbon stock changes were calculated as the sum of the AGB and BGB components (and their change) for each land use type.

2.2.4. Impacts of fuelwood consumption for shea production

Step 5 estimated fuelwood consumption for shea activities in rural and urban settings. We first conducted household surveys and interviews with 20 randomly selected households per village (July, 2015) to identify fuelwood use practices. We used this survey to identify shea kernel production practices, fuelwood harvesting patterns, and fuelwood allocation to different uses (e.g., household energy needs, shea processing, and other food processing). We identified 6–40 female butter processors in each village through snowball sampling (Thompson and Collins, 2002) because only a small fraction (about 10%) of households processed shea kernels into butter. We also assessed fuelwood consumption levels, as well as the shea butter processing steps in these households. Annual fuelwood consumption was calculated by multiplying the measured dry mass of collected fuelwood per load by the frequency of weekly collection over 22 weeks (i.e., shea fruit availability and processing period). The household fuelwood use patterns for shea activities were then fed into in the Material Flow Analysis (MFA) calculations of Jasaw et al. (2015) that had quantified fuelwood flows for different shea processing technologies in the study sites. MFA is a "*systematic assessment of the flows and stocks of materials within a system defined in space and time*" (Brunner and Rechberger, 2003:3). The study system is defined in Section 3.2.1.

Step 6, builds on the calculations of Steps 4–5 and estimated the carbon stock change in the study sites due to shea activities. We allocated a proportional area of land where live trees were cut due to shea processing activities at the village level, based on the fuelwood species density in the area. This area was used to determine the total loss of biomass that would otherwise be present to sequester carbon (carbon stock loss). This carbon stock loss amount represents the loss of carbon sequestration ecosystem services (regulating services), see Section 2.2.1.

Step 7 used the results of Step 5 as the starting point towards estimating the GHG emissions generated from burning the AGB biomass component. We assumed that the amount of carbon stored in dry wood as the IPCC (2006) default carbon fraction of 0.47 for conversion in tropical and subtropical regions (McGroddy et al., 2004). Therefore, 1 kg of combusted woody biomass produces 3.67 kg of carbon dioxide (Berry et al., 2010). Results were then extrapolated and GHG emissions estimated at the district level based on 75% of total rural adult women who engaged in shea activities. These extrapolations were rather conservative and were based on simple frequency analysis of the interviews in the study sites which showed that females in 90% household in all four villages participated in processing shea fruit into shea kernels, while about 10% further processed the shea kernels into butter. These extrapolations also assumed the same output level per household for all four villages. Extrapolations for the urban areas were based on annual fuelwood consumption levels for 810 processors in Tamale and 117 processors in Wa (Al-hassan, 2012).

Step 8, provided a rapid assessment of other potential ecosystem services trade-offs due to overharvesting of fuelwood for shea activities. We randomly surveyed 20 households in each of the four villages to identify additional ecosystem services that the most popular fuelwood species provide. The responses on use were classified into provisioning, regulating, cultural and supporting services (Fig. 5).

3. Results and discussion

3.1. Fuelwood tree species inventory and biomass stocks

Fig. 2 illustrates the main land uses and Table 1 contains their fraction in the study villages as obtained through Step 1–2 (Section 2.2.2). Table 2 summarizes tree density, average height, and average DBH for the main fuelwood species, as well as biomass stocks and carbon stocks for each of the three major land use types as derived from Step 3–4 (Section 2.2.3).

The highest fuelwood tree species diversity was recorded on agricultural land of Kpalgun and Baleufili. This implies that the practice of planting non-native fuelwood species on agricultural land that is better protected from bushfire may enhance overall fuelwood species diversity on this landscape. However, fuelwood species densities are particularly low (<5 trees/ha) in agricultural and grassland areas of Kpalgun and Zagua. This low density, especially at Kpalgun, may be due to fuelwood species overexploitation on agricultural land and grassland as part of the woodland is inaccessible for fuelwood harvesting as it is a sacred grove (see below).

Overall, villages in the Wa West District (Baleufili and Zowayeli) have higher tree densities in all land use types (Table 2). This could be a result of the Black Volta River that runs through these villages and creates favorable conditions for vegetation growth, as well as the fact that the shea processing population in these villages is smaller than villages in the Tolon area.

Unsurprisingly, tree species density was the highest in woodland areas, especially in Kpalgun due to its very dense sacred grove preserved for spiritual purposes. The main exception were woodlands at Baleufili that exhibit disproportionally low tree density and a relatively small stand of fuelwood species. This is because, in contrast to other villages, residential areas are much more dispersed throughout the landscape (Fig. 1), which means that a higher proportion of the local population has direct access to woodland resources that possibly led to the overharvest of fuelwood species. Average biomass stock ranges between 1.2 and 4.8 t/ha on agricultural land, <0.01–4.1 t/ha in grasslands, and 2.3–13.5 t/ha in woodlands (Fig. 3). This is consistent with the tree densities discussed previously. Yet these values are lower than the AGB estimate of 20–200 t/ha for tropical shrub land provided by Ruosteenoja et al. (2003) in the guidelines for National Greenhouse Gas Inventories (IPCC, 2006). This further attests to the extensive degradation of woodland resources in the study sites. As illustrated in Fig. 3, wood species in the agricultural and grassland have been overly harvested while many of the woodlands contain sacred grooves (spiritual sites) where tree cutting is not usually allowed.

3.2. Carbon stock loss and GHG emissions of shea processing

3.2.1. Rural shea processing

Observations during site visits and expert interviews with rural shea processors suggest that the shea processing chain is similar in

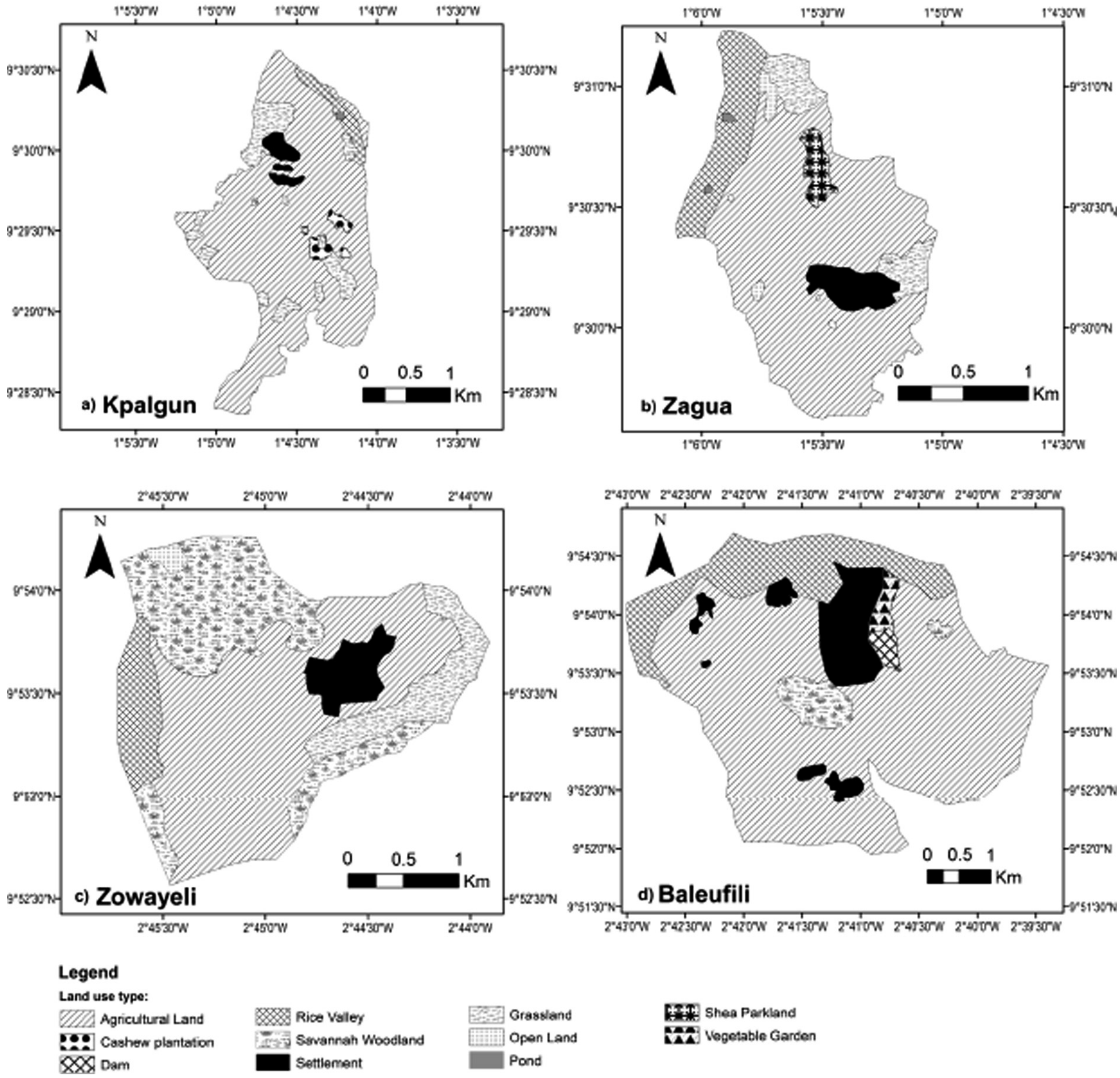

Fig. 2. Land use classification at each rural study site.

Table 1
Fractions (in%) of main land use types in study villages.

Land use type	Tolon District		Wa West District	
	Kpalgun	Zagua	Baleufili	Zowayeli
Agricultural land	82.0	53.7	27.5	50.2
Grassland with trees	9.0	5.6	27.2	9.7
Savanna woodland	0.6	23.4	18.7	26.7
Settlements and others	8.4	17.4	26.6	13.3

all study villages. About 90% of females in each village are involed in shea kernel production. These females typically collect shea fruit from shea parks located in agricultural land or woodland, de-pulp the green flesh in the field or at home, and parboil the nuts. Shea nuts are cooled and cracked, with the obtained kernels sun-dried and bagged for the market (Fig. 4). Some females (approximately 10% in each village) further process the kernels into crude shea butter of higher value. This process involves crushing the shea kernels into grits, roasting the grits, pounding/grinding/milling, kneading/beating, and finally boiling (Fig. 4). Focus group discussions and expert interviews in each village indicate that all females process shea using the same methods, without technological improvements (Section 3.2.2). The shea kernels and butter are then either consumed as food within households or sold to external markets.

On average, in Kpalgun and Zagua approximately 440 kg kernel/year per female is produced and bagged for sale. In Baleufili and Zowayeli females on average produce 200 kg kernel/year. When

Table 2
Fuelwood species and estimated biomass and carbon stock for each land use type in each village (Plots per land use type **N = 3**).

Village Name	Land use Type	Fuelwood Species	Species density (trees/ha)	Average Species Height (m)	Ave. Species DBH (cm)	AGB (t/ha)	Total fuelwood Biomass (AGB + BGB) (tons)	Total Carbon stock (tons-C)
Kpalgun	Agricultural land (**4.09 km²**)	Neem (*Azadirachta indica*)	5	2.9	13.9	1.3	685.7	322.3
		Acacia (*Acacia farnesiana*)	3	8.6	9.9			
		African custard-apple (*Annona senegalensis*)	7	6.9	17.7			
		Kapok (*Ceiba pentandra*)	8	7.0	18.1			
		Ebony (*Diospyros mespiliformis*)	6	8.2	19.0			
		African birch (*Annogeissus leiocarpus*)	7	7.6	14.7			
	Grassland (**0.45 km²**)	Baboons breakfast (*Hexalobus monopetalus*)	5	6.4	15.8	<0.01	42.8	20.1
		African custard-apple (*Annona senegalensis*)	3	3.8	23.4			
		Neem (*Azadirachta indica*)	7	5.3	10.2			
		Ebony (*Diospyros mespiliformis*)	3	8.5	19.0			
	Savanna woodland (**0.03 km²**)	Papao (*Afzelia africana*)	250	5.8	8.3	11.1	41.7	19.6
		African birch (*Annogeissus leiocarpus*)	1675	11.7	19.3			
		Wodier (*Lannea humilis*)	50	12.2	35.8			
		African custard-apple (*Annona senegalensis*)	75	7.3	9.5			
		Neem (*Azadirachta indica*)	1300	13.1	75.4			
Zagua	Agricultural Land (**2.32 km²**)	Neem (*Azadirachta indica*)	8	5.4	21.8.	1.2	336.6	158.2
		Ebony (*Diosypros mespiliformis*)	8	1.7	18.3			
		African birch (*Annogeissus leiocarpus*)	28	6.8	17.7			
		Ebony (*Diospyros mespiliformis*)	8	7.4	28.0			
	Grassland (**0.24 km²**)	African custard-apple (*Annona senegalensis*)	16	5.9	13.2	0.4	13.1	6.2
		Ebony (*Diospyros mespiliformis*)	8	5.8	20.7			
		Baboons breakfast (*Hexalobus monopetalus*)	4	6.3	24.8			
	Savanna woodland (**1.01 km²**)	Kapok (*Ceiba pentandra*)	50	5.6	12.6	11.0	1405.4	660.5
		Mahogany (*Khaya senegalensis*)	25	24.0	143.0			
		Neem (*Azadirachta indica*)	950	7.3	18.0			
		Wodier (*Lannea humilis*)	100	7.4	22.8			
Baleufili	Agricultural Land (**4.91 km²**)	Ebony (*Diospyros mespiliformis*)	12	5.8	20.2	5	1569.5	737.7
		Baobab (*Adansonia digitata*)	4	11.5	31.9			
		Mahogany (*Khaya senegalensis*)	20	8.2	25.4			
		Papao(*Afzelia africana*)	16	8.8	28.4			
		Wodier(*Lannea humilis*)	24	7.1	20.5			
		Mahogany (*Khaya senegalensis*)	28	5.4	15.2			
	Grassland (**4.87 km²**)	Ebony (*Diospyros mespiliformis*)	24	8.2	2607	3.2	1947.2	915.2
		Fig. (*Ficus abutilifolia*)	16	10.4	31.4			
		Papao(*Afzelia africana*)	20	13.4	33.2			
	Savanna woodland (**3.35 km²**)	Mahogany (*Khaya senegalensis*)	32	8.4	22.8	2.3	951.8	447.3
		Fig. (*Ficus abupifolia*)	68	7.1	17.1			
		Baboons breakfast (*Hexalobus monopetalus*)	28	6.3	19.1			
Zowayeli	Agricultural Land (**3.25 km²**)	Ebony (*Diospyros mespiliformis*)	36	7.4	24.7	4.8	1971.9	926.8
		Fig. (*Ficus abupifolia*)	60	8.2	27.3			
		Mahogany (*Khaya senegalensis*)	32	9.6	29.1			
	Grassland (**0.63 km²**)	Ebony (*Diospyros mespiliformis*)	40	9.1	26.0	4.1	328.4	154.3
		Wodier (*Lannea humilis*)	56	7.4	19.7			
		Fig. (*Ficus abupifolia*)	36	7.9	23.6			
		Papao(*Afzelia africana*)	24	7.9	24.7			
	Savanna woodland (**1.73 km²**)	Wodier (*Lannea humilis*)	100	11.2	20.7	13.5	2942.0	1382.7
		Baobab (*Adansonia digitata*)	12	8.9	22.5			
		Baboons breakfast (*Hexalobus monopetalus*)	112	8.8	26.5			
		Ebony (*Diospyros mespiliformis*)	68	7.4	25.0			
		Mahogany (*Khaya senegalensis*)	104	10.2	22.6			
		Fig. (*Ficus abupifolia*)	88	11.6	24.1			

it comes to shea butter, households produce on average 350 kg butter/year in Kpalgun and Zagua, and 200 kg butter/year in Baleufili and Zowayeli.

Household surveys captured fuelwood allocation between domestic uses and indicate that shea activities typically account for almost 50% of the total household fuelwood consumption during the shea processing season. Table 3 shows fuelwood consumption for shea kernel/butter production according to field measurements and the GHG emissions during the production of different shea products. Table 4 summarizes the shea kernel/butter output, ABG biomass consumption for different shea products, and the loss of carbon stocks due to shea production in each village.

Household surveys and expert interviews confirm the results of Jasaw et al. (2015) that identified parboiling as the stage with the highest fuelwood consumption during shea kernel production in rural contexts. This activity is typically undertaken on traditional three-stone open hearth stoves, which are usually highly inefficient (Adkins et al., 2010; Ahmad and Puppim de Oliveira, 2015; Bailis et al., 2007; Masera et al., 2007; Smith et al., 2007). On the other hand, roasting and boiling the kernels consume the most fuelwood during shea butter processing. While technological improvements in these stages could reduce fuelwood consumption (see Section 3.2.2), interviews indicated that most rural shea processors cannot afford such technological improvements.

Household surveys and expert interviews also suggest that fuelwood is primarily sourced from within each village's own woodlands. Neighboring community woodlands sometimes serve as secondary sources when needed. As these woodlands are

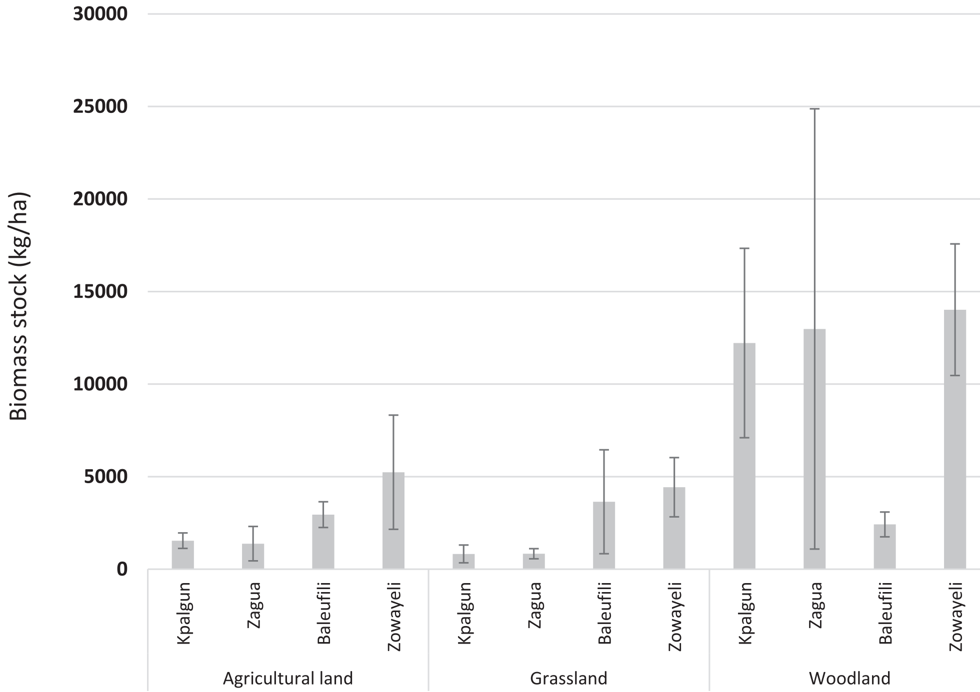

Fig. 3. Biomass stocks and standard deviation in each rural study site (n = 3 plots for each land use type).

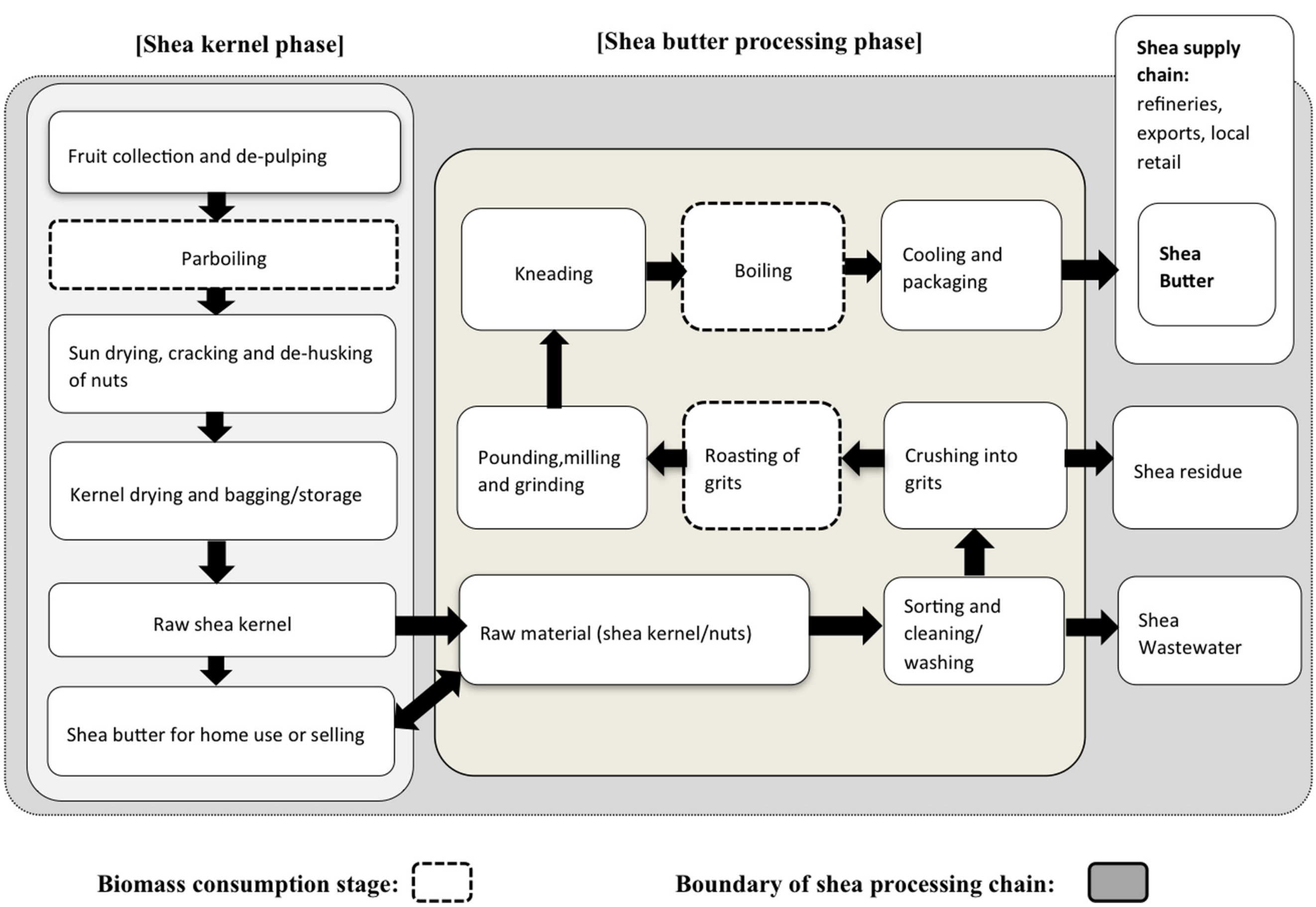

Fig. 4. Typical shea kernel and butter processing chains.

Table 3
Fuelwood use per kg of shea product output (kernels and butter) in rural and urban locations.

Location		Shea kernel production		Shea butter production	
		Fuelwood consumption (kg fuelwood/kg shea kernel)	GHG Emission (kg CO_2 eq/kg shea kernel)	Fuelwood Consumption (kg fuelwood/kg shea butter)	GHG Emission (kg CO_2 eq/kg shea butter)
Tolon (Rural)	Kpalgun	0.58	1.06	1.83	3.16
	Zagua	0.62	1.13	1.92	3.31
Wa West (Rural)	Baleufili	0.70	1.28	1.82	3.14
	Zowayeli	0.76	1.39	1.83	3.16
(Urban)	Tamale	–	–	1.33	2.29
	Wa	–	–	1.47	2.54

Table 4
Annual biomass consumption in the shea industry for rural and urban locations.

Location		Unit of Analysis	Shea kernel output (t/year)	Shea butter output (t/year)	Fuelwood consumption (t/year)	Carbon stock loss (tC/year)
Northern Region (Rural)	Kpalgun	Individual shea processor	0.4	0.4	0.4	
		Village-wide shea processors (N = 375)	168.5	139.5	167.3	78.63
	Zagua	Individual shea processor	0.4	0.3	0.4	
		Village-wide shea processors (N = 153)	67.4	51.5	68.5	32.20
(Urban)	Tamale	Individual shea processor	–	1.8	0.8	
		Average number of butter processors (N = 810)	–	1490.4	648.0	304.56
Upper West Region (Rural)	Baleufili	Individual shea processor	0.2	0.3	0.3	
		Village-wide shea processors (N = 168)	37.1	52.9	56.7	26.65
	Zowayeli	Individual shea processor	0.2	0.1	0.2	
		Village-wide shea processors (N = 55)	9.9	5.1	10.6	4.98
(Urban)	Wa	Individual shea processor	–	0.9	0.5	
		Average number of butter processors (N = 117)	–	110.4	59.6	28.01

Note: Carbon stock loss denotes only the amount of fuelwood burnt (AGB element).

communally owned in each village, there is no restriction on the quantity of fuelwood that each household can harvest. What is interesting is that, according to community interviews fuelwood harvesting has shifted from selectively harvesting branches to facilitate regrowth, to cutting down live trees. This could result in the complete removal of trees from the landscape that offers little to no possibility of rapid tree re-growth, especially in the context of prolonged drought, rampant bushfires, and dry weather conditions encountered in the study site (Tom-Dery et al., 2014) (see also Section 2.1). Furthermore, dry vegetation (mostly grass) is very susceptible to wild bushfires during the dry season (December–March) that burn tree stumps further slowing down regrowth rates (Chomitz and Griffiths, 1997).

It is worth mentioning that studies about the GHG emissions of shea value chains are limited and sometimes focus only on downstream activities after the butter production stage. For example, industrial reports from OLVEA Burkina Faso in 2011 reported emissions of only 0.1 kg CO_2 eq/kg raw shea butter received in French ports (cited in Glew and Lovett, 2014). Very few studies have undertaken full life cycle assessments (LCAs) to either to quantify the GHG emissions of the entire shea value chain (Glew and Lovett, 2014) or compare the impacts of different shea kernel/butter production pathways (Naughton et al., 2017). In one of the few such studies, Glew and Lovett (2014) used the British standard PAS2050 LCA to quantify the GHG emissions of shea butter that reached UK shelves and found that approximately 74.5% of these emissions are due to the fuelwood used for shea kernel/butter production, indicating the very important effect that shea kernel/butter production has on the overall carbon footprint of shea products.

3.2.2. Urban shea processing

Expert interviews suggest that urban shea processors only produce shea butter and not the shea kernel as the shea trees are mostly found in the rural areas. Essentially, the processors buy raw shea kernels from rural suppliers and process them into butter throughout the year. On average each individual producer in Tamale produces 1840 kg of processed handcrafted butter per year, with an estimated average of 18 processors working in each of the 45 shea butter processing centers (Tamale-MTDP, 2013). In Wa there are 13 processing centers with an average of nine members, each producing on average about 944 kg of handcrafted shea butter per year. The processed handcrafted butter is mainly exported or sold to local agro-industrial processors who subsequently convert it into other value-added products such as cosmetics (e.g., hand cream, body lotion, shampoo) and confections (Fig. 4).

Fuelwood for shea processing is transported to urban areas in market trucks or sold by head porters at negotiated prices. Fuelwood is obtained from rural areas in each region, but unlike the rural study sites the exact location and woodland supply capacity cannot be traced since they can come from multiple sources. Therefore, changes in carbon stocks for shea butter production could not be calculated through the exact methodology described in Section 2.2.4 and 3.2.1. Consequently the results obtained for urban processors contain significant assumptions and should be interpreted accordingly (Table 4).

Processors in Tamale town consume approximately 43 kg of fuelwood per bag of kernel, or 1.33 kg fuelwood per kg of shea butter. Meanwhile, processors in Wa town consume approximately 53 kg of fuelwood per bag of kernel, or 1.47 kg of fuelwood per kg shea butter (Table 3). These amounts were multiplied by the average annual kernel/butter quantity processed by an individual processor to obtain the average annual fuelwood consumption (Table 4). However, unlike rural processors that produce shea butter for only 22 weeks during the shea season, urban processors produce shea butter throughout the year. For this reason the total annual biomass quantity for urban processors is very high in both Tamale and Wa (Table 4).

It should be noted that urban shea butter processors consume on average less fuelwood per kg of shea butter compared to rural processors (Table 3). This is because many urban shea processors use improved equipment such as roller stoves with metallic cylindrical chambers placed over an enclosed burning compartment for roasting the kernel grits (Jasaw et al., 2015). Mud stoves and roller roaster stoves could reduce fuelwood consumption by 60% (Jasaw et al., 2015). However, three-stone hearth stoves are still commonly used in many urban processing centers for other stages of the shea butter production process such as boiling, Other innovative practices that increase fieldwood use efficiency during shea butter production include mechanical presses, solar frying of kernel grits, and the Bridge Press that bypasses the roasting stage during butter production (e.g. Otte, 2014), as well as best practices for waste re-use (Noumi et al., 2013).

3.3. Trade-offs with other ecosystem services

A household survey identified the other uses of (and benefits derived from) the most popular fuelwood species used for shea processing in rural communities (Section 2.2.4). This survey suggests that apart from biomass for fuel, fuelwood species can provide nine other ecosystem services (Fig. 5). These ecosystem services represent all of the main ecosystem service categories, i.e. provisioning, regulating, and cultural services.

In particular, fuelwood species are mostly associated with provisioning services as they are important sources of livestock feed, medicinal substances, food (especially fruits), and construction materials. Forage-related services from almost all species (except Acacia and Neem) are particularly important for local livelihoods as the study villages are located in the savanna area of Ghana, where many households keep farm animals such as goats, sheep, and cattle. Many households in the Tolon District use thatched roofs, with ebony and mahogany widely used for rafters in roofing (interestingly these are also the most preferred fuelwood species by shea processors). Almost all respondents indicated that this particular ecosystem service decreases as fuelwood harvesting continues.

Apart from provisioning services, the survey identified that fuelwood species can also provide regulating services such as shade, erosion control, and windbreaks (Fig. 5). For example, many village residents use the shade provided by these trees as the area receives plentiful sunshine during the long dry season (December-May) while they can also serve as windbreaks during rainstorms. These trees also possibly provide services related to the regulation of hydrological cycles, even though this was not directly expressed in the household surveys. However our observations in the area suggest that in recent years, it easy to see village residents travel over long distances in other to fetch potable drinking water from boreholes or dugouts (Boafo et al., 2014). In the Kpalgun and Zagua villages where low biomass stock and fuelwood species is recorded (Section 3.1), water scarcity is more visible. This possibly reinforces the sponge theory that biomass maintain dry season flows and that extensive biomass removal leads to lowered groundwater levels,

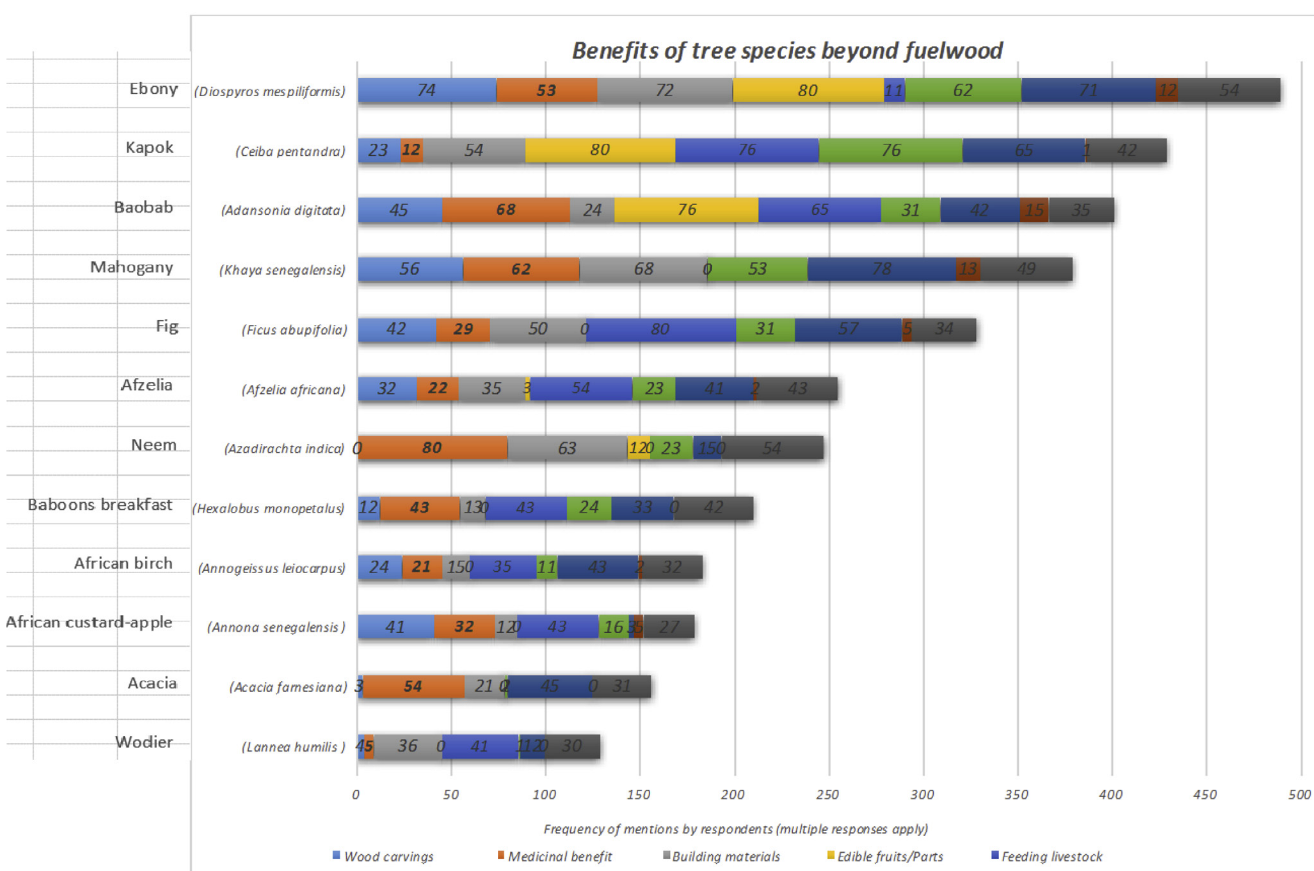

Fig. 5. Main ecosystem services provided by the main fuelwood species (except fuelwood and carbon sequestration).

perennial streams becoming intermittent and springs drying up (Galudra and Sirait, 2009; Locatelli and Vignola, 2009; Calder et al., 2004).

The above imply that broader ecosystem services trade-offs can materialize due to high fuelwood use for shea processing (Section 3.2). As fuelwood collection and consumption are intricately linked to the management of common areas (Section 3.2.1), the increasing demand for fuelwood from such areas can lead to the degradation of biomass resources. Wood collection in semi-arid contexts (such as our study sites) can potentially exceed sustainable yield, especially if tree-felling is performed. For example, Boafo et al. (2014) observed the growing scarcity of critical provisioning ecosystem services in our study sites through the increased distance that rural households have to cover to access fuelwood, bush meat, building materials, food, and fodder. Such increases in the distance to access fuelwood resources can be seen as a proxy indicator for their depletion locally (Boafo et al., 2014).

However, apart from sacred groves, no formal tree conservation efforts were observed in the study villages. Community-based woodland management that includes mechanisms to protect them from bushfires, harvest branches (instead of whole tree-cutting), and rotate harvested plots/areas to facilitate regrowth could possibly guarantee a sustainable fuelwood supply for the shea industry. Furthermore, afforestation with species that mature rapidly and/or non-native species adaptable to savanna areas can possibly accumulate biomass more rapidly than natural regeneration processes (Marin-Spiotta et al., 2007). The careful implementation of such management schemes and introduction of species could restore the declining ecosystem services, but further research will be needed to ascertain the actual potential and local acceptability.

4. Conclusions

Our study quantified fuelwood use during shea processing in rural and urban settings of northern Ghana. We calculated two different metrics related to the climatic effects of shea production, changes in carbon stocks (tC/ha) and direct GHG emissions (kg CO_2eq/kg shea kernel and shea butter). The former metric relates to the loss of a regulating ecosystem service (carbon sequestration) and the latter to the direct emissions of different shea products and production processes.

Fuelwood use for shea processing is responsible for the significant decline of carbon stocks across different land uses in the study villages (and most likely in the entire study districts). This is an important trade-off between the value-addition in a provisioning ecosystem service (shea fruit) and the climate regulation services offered by local ecosystems. Fuelwood use for shea kernel/butter processing therefore, can also have important consequences for other provisioning (e.g. woodland products), regulating (e.g. erosion control) and cultural ecosystem services (e.g. religious and spiritual values). Rural butter processors emitted 3.14–3.31 kg CO_2eq per kg crude shea butter, while urban processors slightly less (2.29–2.54 kg CO_2eq per kg crude shea butter). This variation is largely due to the fact that urban processors tend to adopt technological improvements that increase fuelwood use efficiency (see below). Such technological improvements are not usually affordable for rural processors.

As stakeholder efforts continue on strategies to diversify rural incomes and boost economic development (Section 1), the expansion of shea production under current processing protocols will most likely cause large increases in fuelwood demand for shea processing, with knock-on effects on habitat change and land degradation. This will possibly exarcebate the existing ecosystem services trade-offs under current fuelwood harvesting practices (e.g. live tree-cutting) and the processing equipment used .

Fuelwood comes at a higher price that further increases the production cost for shea butter, thus, reducing the profit margin and overall income of shea processors. In this respect, income from rural shea processing could decline in the current context of weak market linkages and threaten the sustained production of shea and its poverty alleviation potential.

In order to mitigate the negative effects of shea processing different technological and management measures can be implemented, both at the process and the landscape scale. Regarding technological measures, the adoption of improved stoves and alternative fuel options (e.g. dry shea residues, solar cookers) could reduce fuelwood consumption. To be able to fund the widespread adoption of such technological measures a practical proposition would be to add a premium to the price of shea butter exports. This premium can be re-invested within Ghana to disseminate such technological improvements to those processesors that do not have the necessary economic means. Potential measures that can guarantee the sustainable supply of fuelwood to the shea industry would be to promote community-based woodland management that includes mechanisms to protect from bushfires, harvest branches (instead of live tree-cutting), and rotate harvested plots/areas to facilitate biomass regrowth. There need to do significant research before the wide-scale promotion of such mitigation options in northern Ghana, including studies about their acceptability by local communities.

Finally, our results can contribute to future LCAs and carbon footprint studies that can quantify better the climatic impacts of the shea industry. This can serve as a guide to help local communities, governments, and the private sector to reduce the largely unknown environmental burdens of shea value chain (and the subsequent effects on the wellbeing of local communities), while maximizing shea's contribution to rural development.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoser.2017.09.003.

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