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Human impact on population structure and fruit production of the socio-economically important tree *Lannea microcarpa* in Burkina Faso

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Abstract Non-timber forest products (NTFPs) are of high socio-economic value for rural people in West Africa. Main factors determining the status of the populations of socio-economically important tree species providing those NTFPs are human activities. This study assesses the impact of human population density, land use, and NTFP-harvesting (pruning and debarking) on population structure and fruit production of the socio-economically important tree *Lannea microcarpa* that is normally conserved by farmers on fields. We compared *L. microcarpa* stands of protected sites with those of their surrounding communal sites in two differently populated areas in Burkina Faso. Our results reveal an opposed land use impact on the population structure of *L. microcarpa* in the two areas. In the highly populated area, the species population was more stable in the protected site than in the communal site, while the opposite was observed for the less populated area. Trees of the communal sites bore more fruits than trees of the protected sites. Debarking and pruning had a negative impact on fruit production of the species. We conclude that low intensity of human impact is beneficial for the species and that indirect human impact facilitates fruit production of *L. microcarpa*. In contrast, in the densely populated area, human impact has reached an intensity that negatively affects the populations of *L. microcarpa*. While the extent of protecting *L. microcarpa* on fields still seems to be enough to guarantee the persistence of this important species in the less populated area, it is no longer sufficient in the densely populated area.

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Introduction

Non-timber forest products (NTFPs) are of great importance for local people in West African rural areas in terms of food, fodder, medicine, and cash income (e.g. Kristensen and Balslev 2003; Lykke et al. 2004). NTFP harvesting (e.g. harvesting of fruits, leaves, and branches and debarking of stems) strongly influences the structure of plant populations. Furthermore, other human activities such as grazing and agricultural land use also affect species populations (Gaoue and Ticktin 2008; Schumann et al. 2010, 2011).

The rapidly growing human population and increasing exploitation of natural resources in West Africa during the last decades (Brink and Eva 2009; Ouédraogo et al. 2010) raise concerns about the population status of socio-economically important tree species (e.g. Gaoue and Ticktin 2008). To assess the impact of human activities on the population structure of socio-economically important tree species and to estimate their resilience to human activities, knowledge on the population structure and fruit production is required (Cunningham 2001; Peters 1994). Although static information on population structure is not necessarily a good predictor for future population trends (Condit et al. 1998), investigations on population structure are the only pragmatic way to obtain urgently needed data in the absence of long-term studies (Cunningham 2001; Hall and Bawa 1993).

Species responses to human impact are diverse, depending *inter alia* on species' characteristics and ecological preferences (Jurisch et al. 2012; Schumann et al. 2011) and the way and degree of species protection by humans (Ticktin 2004). In West Africa, farmers control tree species' densities and presence in agroforestry land, depending on their preferences and individual species use needs (Augusseau et al. 2006). Several socio-economically important tree species (e.g. *Adansonia digitata*, *Lannea microcarpa*, *Parkia biglobosa*, *Sclerocarya birrea*, *Tamarindus indica,* and *Vitellaria paradoxa*) are protected by farmers when clearing and burning land for fields, whereas other tree species are cut. While some of those preferred tree species are still well preserved under human impact, e.g. *A. digitata* (Dhillion and Gustad 2004; Schumann et al. 2010), *P. biglobosa* (Ulmer 2012), and *V. paradoxa* (Djossa et al. 2007; Ræbild et al. 2012), other important tree species such as *S. birrea* (Gouwakinnou et al. 2009) and *T. indica* (Fandohan et al. 2010) are negatively affected by human activities and are therefore declining. In this context, the question arises whether socio-economically important tree species can persist under increasing human pressure or whether some of them even profit. In order to assess these species-specific responses to human impact, more detailed studies are needed that investigate the populations of socio-economically important tree species in relation to human impact. So far, most of the studies dealing with this topic investigated population structure in relation to human impact (e.g. Djossa et al. 2007; Gouwakinnou et al. 2009), while few studies included the species' fruit production (e.g. Gaoue and Ticktin 2008; Schumann et al. 2010), even though it is a very important component in the life history of plants.

One of these less studied socio-economically important tree species is *L. microcarpa* Engl. and K. Krause, commonly known as African or Wild Grapes. All plant parts of this multi-purpose species are used by local populations in West Africa. *L. microcarpa* is pruned for its wood, leaves, and fruits. The grape-like fruits are eaten fresh or squeezed and drunk as juice, which serves as a source of vitamins, especially for children. They are also used for medicinal purposes. Leaves are used for food, juice, fodder, and medicine and the wood is collected for fire-wood or small constructions. Moreover, the roots and the bark are collected for several medicinal purposes and the bark for making cords (Belem et al. 2008; Mbayngone and Thiombiano 2011; Sawadogo et al. 2012; Vodouhe et al. 2009). Due to its high use value, *L. microcarpa* is mostly protected by farmers during land clearing. Thus *L. microcarpa* might still be well preserved under human impact as demonstrated for *A. digitata* and *V. paradoxa* (Djossa et al. 2007; Schumann et al. 2010). However, a study in a relatively densely populated area in the center east of Burkina Faso (Ky et al. 2009) contradicts with this assumption since ageing populations of *L. microparpa* were found on fields.

We studied the population structure and fruit production of *L. microcarpa* in relation to human impact in a high and in a low populated area in Burkina Faso in order to predict the resilience of the species to human activities. Specifically, by comparing stands of

Table 1 Number of plots and individuals, individuals per hectare, debarking and pruning intensity, and mean DBH, fruit production, fruit and seed weight of *L. microcarpa* in the different study areas, land use types and habitats

Study area	Land use	Arability	*N* (plots)	*N* (individuals)	Individuals/ha (mean)	% pruned of all trees	% debarked of all trees	Mean DBH (cm]	N (fruit trees)	Mean fruit production per tree	N (fruit weight)	Mean weight of 10 fruits (g)	N seed weight	Mean seed weight (g)
Gonsé	Communal	Arable	10	22	24.44	100.0	27.3	36.3	10	17,472	N/A	N/A	N/A	N/A
Gonsé	Communal	Nonarable	10	22	24.44	86.4	18.2	30.2	10	6,299	N/A	N/A	N/A	N/A
Gonsé	**Communal**	**Total**	**20**	**44**	**24.44**	**93.2**	**22.7**	**33.2**	**20**	**11,885**	**N/A**	**N/A**	**N/A**	**N/A**
Gonsé	Protected	Arable	12	42	38.89	42.9	0.0	25.6	10	7,111	N/A	N/A	N/A	N/A
Gonsé	Protected	Nonarable	11	28	28.28	53.6	0.0	28.2	10	6,045	N/A	N/A	N/A	N/A
Gonsé	**Protected**	**Total**	**23**	**70**	**33.82**	**47.1**	**0.0**	**26.6**	**20**	**6,578**	**N/A**	**N/A**	**N/A**	**N/A**
W Park	Communal	Arable	11	18	18.18	83.3	88.9	50.3	10	30,705	8	8.75	9	0.16
W Park	Communal	Nonarable	10	37	41.11	86.5	51.4	35.9	10	10,399	9	8.11	9	0.13
W Park	**Communal**	**Total**	**21**	**55**	**29.10**	**85.5**	**63.6**	**40.6**	**20**	**20,552**	**17**	**8.4**	**18**	**0.14**
W Park	Protected	Arable	23	35	16.91	0.0	0.0	42.1	17	16,973	6	7.6	7	0.13
W Park	Protected	Nonarable	3	5	18.52	0.0	0.0	32.3	3	1,322	0	0.0	0	0.00
W Park	**Protected**	**Total**	**26**	**40**	**17.09**	**0.0**	**0.0**	**40.9**	**20**	**14,595**	**6**	**7.6**	**7**	**0.13**

N/A data not available

the species of two different land use types (protected area versus communal area) in two different levels of human population density, research questions were:

– Do human population density and land use affect the population structure of *L. microcarpa*?
– Do land use and NTFP-harvesting (debarking and pruning) affect the fruit production and characteristics of *L. microcarpa*?

Methods

Study area

The study was conducted in the North Sudanian zone of Burkina Faso, a West African savanna region, which is characterized by semi-arid climate with a dry period of 6 months from November to April (Guinko 1984). The two study areas were the Gonsé Classified Forest with its surrounding land (hereafter referred to as "Gonsé") and the northern and middle part of the W National Park with its surrounding land (hereafter referred to as "W Park") (Fig. 1). Human population density at Gonsé (86.0 inhabitants per km^2) is nearly four times higher than at W Park (23.5 inhabitants per km^2) (INSD 2012, data from 2006).

Gonsé is located close to Ouagadougou, the capital of Burkina Faso, in the Oubritenga province. It displays an average precipitation of 750 mm per annum with its peak in August (218 mm) and January (0 mm) as the driest month and an average temperature of 28.2 °C (31.2 °C in April and 25.0 °C in January) (Hijmans et al. 2005). According to the soil map of BUNASOLS (1990) mainly Lithosols and soils with a ferralitic pedogenesis (sols ferrugineux tropical lessivés) are present. The latter correspond according to their capacity for cationic exchange and clay activity either to Lixisols or Luvisols. The Gonsé Classified Forest (N 12.4°, W 1.3°; founded 1953) covers 6,000 ha. Due to the high population density and therefore shortage of land, illegal collection of

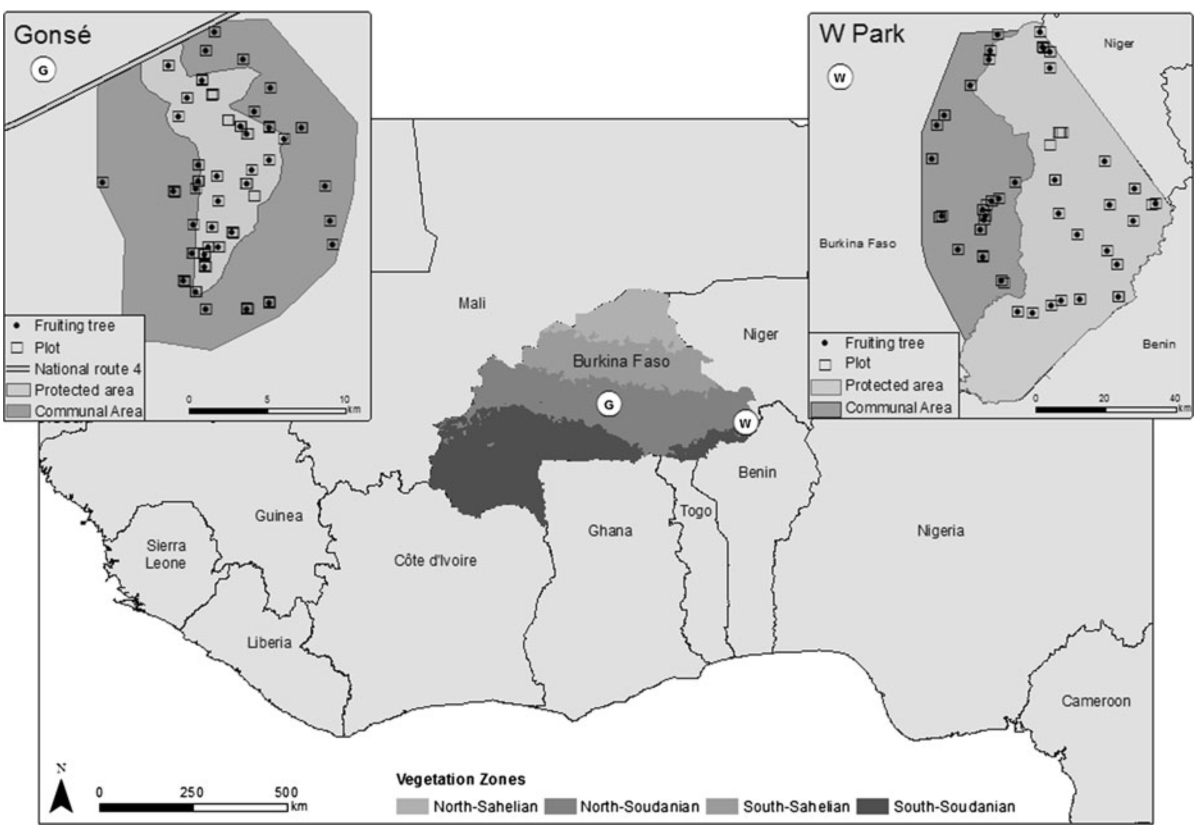

Fig. 1 Map showing study sites (*G* Gonse and *W* W. Park) in Burkina Faso. *White square* represents the positions of the sampled plots and "*filled circle*" of the fruiting trees. Source of vegetation zones: (Guinko 1984)

wood and grazing of domestic animals constitute the problems in Gonsé and the forest authorities find it difficult to keep the people out of the protected area.

The W Park is located in the south-east of the country in the Tapoa province and displays average annual precipitation of 800 mm with its peak in August (227 mm) and January (0 mm) as the driest month and an average temperature of 28.2 °C (32.4 °C in April and 25.3 °C in January) (Hijmans et al. 2005). The main soil types in the study site are Luvisols, Lixisols, and Leptosols (Traoré 2008). The transfrontier W National Park is shared by Burkina Faso, Benin, and Niger. The Burkina Faso part (N 11.8°, E 2.2°; founded 1954) covers an area of 350,000 ha. Despite poaching, illegal logging, and introduction of livestock the park appears to be relatively well protected.

In both study areas, the vegetation types are mainly shrub and tree savannas. The communal land around the protected areas mainly consists of typical West African agroforestry systems managed by subsistence farmers. The fields are cultivated with crops (primarily sorghum, millet, peanuts, and cotton) accompanied by scattered useful trees (e.g. *V. paradoxa*, *P. biglobosa*, *T. indica*). Periods of cultivation alternate with fallow phases. Fires are used to clear fallows for cultivation ("slash-and-burn"), but also to prepare fields for sowing at the end of the dry season. The protected areas are managed to provide water supply, controlling of fire, preventing from poaching, and other illegal activities. Early fires are set at the end of the rainy season to decrease the fuel load in case of accidental late fires and to open the vegetation for improving the visibility for tourists to spot animals (W Park) (Clerici et al. 2007).

Studied species

Lannea microcarpa Engl. and K. Krause (Anacardiaceae) is a dioecious tree species, which grows up to 16 m high. The leaves are up to 25 cm long and are comprised of 1–3 pairs of asymmetrical leaflets and one terminal one. Foliation starts shortly after flowering at the end of the dry period. The green yellowish flowers are small and inconspicuous. The edible fruits are ellipsoid drupes of ca. 1 cm length, bundled as racemes of 3–25 fruits, which turn from green to purple-black during the ripening process. Fruit maturity coincides with the beginning of the rainy season (Sacandé 2007).

Lannea microcarpa occurs in the Sudanian zone of West Africa. The northern limit of its habitat is the Sahelo-sudanian zone (500–900 mm) and the southern limit is the Guinean zone (>1,100 mm). In its distribution area, the species is rare, but locally abundant (Arbonnier 2000). Although preferring deep soils, *L. microcarpa* can also grow on uncultivable and lateritic soils (Sacandé 2007).

Data collection

We sampled 90 plots (Gonsé: 20 on communal and 23 on protected land; W Park: 21 on communal and 26 on protected land; Tabel 1) including stands of *L. microcarpa* (43 in W Park and 47 in Gonsé) and measuring 30 m × 30 m. A stand denotes a group of individuals growing geographically close together (approximately in a radius of 100 m). Since, in both study areas, there are no obvious reproductive barriers, we assumed that gene flow is possible and all studied *L. microcarpa* individuals of each area belong to one population. Due to rareness and uneven distribution of *L. microcarpa* and difficult logistic conditions, it was impossible to apply a structured sampling design. Therefore, we selected the plots by driving along the main roads and accessible paths searching for *L. microcarpa* trees. To account for a spatially sound distribution, two plots were ideally more than 1,000 m (Gonsé) and 2,000 m (W Park) apart. Where keeping this distance did not give us enough data, we reduced the spacing down to 500 and 1,000 m, respectively. We differentiated between two types of land use, "protected" (inside the borders of the protected area) and "communal" (land surrounding the protected area including fields and fallows). For the estimation of the fruit production and weight, we further distinguished potentially arable land (fields and fallows on medium to moist soils in the communal area and habitats on similar soils in the protected area, "arable") and non-arable land (laterite and granite soils, "non-arable") to take arability into account. Within each plot, we measured the diameter at breast height (DBH) for each individual with a DBH>5 cm. Tree height correlates strongly with DBH (e.g. Schumann et al. 2011). Thus, we measured only DBH. Moreover, we examined the studied trees for signs of pruning and debarking by humans.

Fruit production was determined for 80 individuals in total, 20 for each land use type per area (see Fig. 1

and Table 1) and 10 for each land-use-arability-combination (except in the protected area of W Park, where we found 17 individuals on arable and only three on non-arable land). We randomly selected one fruiting individual per plot, if present (note that only female individuals of the dioecious species bear fruits). As the complete counting of all fruits per tree would have taken a disproportional effort (up to 100,000 fruits per tree), we estimated the fruit production as follows: we counted the number of single fruits on 20 racemes and the number of racemes on two representative branches. By multiplying the average number of fruits by the average number of racemes by the number of branches, we had an estimation of the number of fruits of the whole tree. For each tree, two persons did the counts independently for the same branches. The mean of the two counts was used for the analyses.

Data for fruit and seed weight were collected only in the W Park. We sampled 23 of the trees already used to determine the fruit production and representative for the respective land use type (17 on communal land and six on protected land), of which we collected 100 ripe fruits each. Seed and fruit weight were used as a measure of fruit quality. We determined the weight of ten fruits (10 replicates) immediately after collection in the field. The pulp of 10 fruits per individual was removed and the seeds were air dried and weighed in the laboratory of the Goethe-University Frankfurt am Main, Germany.

All data were sampled from April to June 2011.

Data analysis

Population structure

For each plot, we determined the frequency of individuals per DBH size class and extrapolated the data towards a 1-hectare scale. The following size classes were used: 5.0–14.9, 15.0–24.9, 25.0–34.9, 35.0–44.9, 45.0–54.9, 55.0–64.9, 65.0–74.9, 75.0–84.9 cm, and >85.0 cm. The size class distributions were pictured for each area and land use type as histograms. Additionally, we applied Kolmogorov–Smirnov tests to check for significant differences in the shape of the size class distributions between the land use types within and among the study sites.

We tested significant differences of the density (individuals per hectare) between the land use types within and among the study sites using Wilcoxon test.

Fruit production

We analyzed the effects of area, land use, arability, and direct human use (debarking and pruning) on the fruit production. For initial data exploration we followed the guideline by Zuur et al. (2010), based on this we applied a modeling approach using generalized linear models (GLM) of the negative binomial family (count data). We set up a model using fruit number as dependent variable and DBH, land use, arability, area, pruning, and debarking as explanatory variables. We allowed two-way-interactions between DBH and all other explanatory variables as well as land use × arability, arability × pruning, arability × debarking, and pruning × debarking. This model was simplified by leaving out non-significant explanatory variables as long as AIC decreases and tested if this simplification is supported using the R-function anova for model comparison (Crawley 2007; Zuur 2009).

Fruit and seed weight

We analyzed the effects of land use, arability, pruning, debarking, and DBH on the fruit weight and seed weight using linear models (LM) with log-transformed data to reach the model presumptions. We set up a model using DBH, land use, arability, pruning, and debarking and allowed for two-way-interactions between DBH × pruning as well as DBH × debarking. This model was simplified according to the above described procedures.

All statistical analyses were done using R 2.15.0. (R Development Core Team 2011).

Results

Population structure

In total, we found 209 individuals of *L. microcarpa* in the 90 sampled plots. The number was highest in the protected area of Gonsé (33.82 individuals per hectare) and lowest in the protected area of W Park (17.09 individuals per hectare) (Table 1).

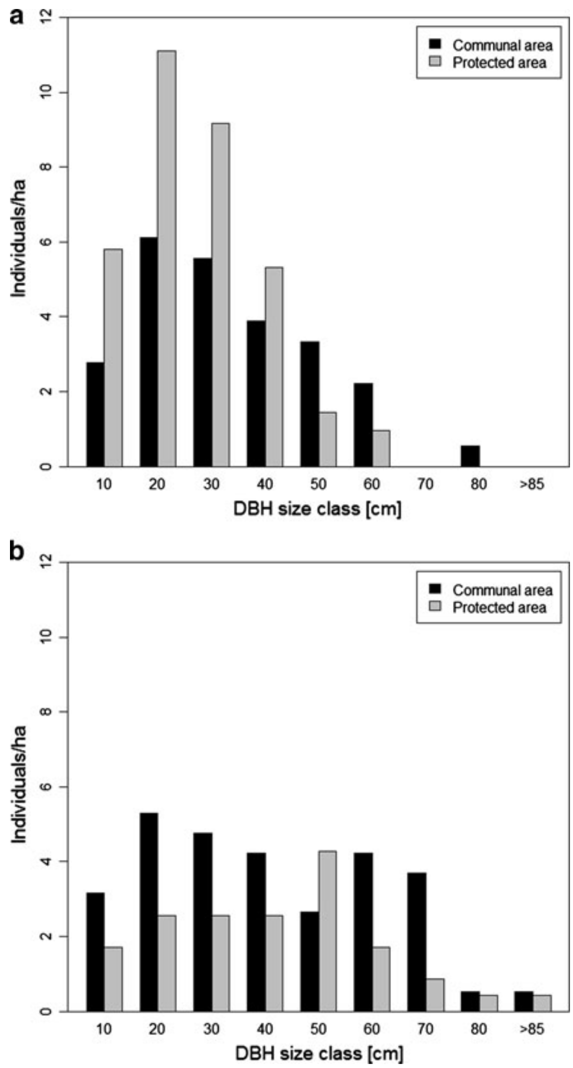

Fig. 2 DBH size class distributions of *L. microcarpa*, grouped by land use type for Gonsé **a** and W Park **b** in Burkina Faso DBH size classes: 10 = 5.0–14.9 cm, 20 = 15.0–24.9 cm, 30 = 25.0–34.9 cm, 40 = 35.0–44.9 cm, 50 = 45.0–54.9 cm, 60 = 55.0–64.9 cm, 70 = 65.0–74.9 cm, 80 = 75.0–84.9 cm, and > 85 = > 85.0 cm

In Gonsé, we detected no significant differences in the size class distributions between communal and protected land (KS-Test: $D = 0.181$, p value $= 0.342$). Both land use types displayed almost a reverse-J shaped distribution curve when only considering the larger size classes (Fig. 2a). However, there was generally a higher number of individuals per hectare on protected land (33.82 individuals per hectare) than on communal land (24.44 individuals per hectare). Nevertheless, the density of *L. microcarpa* did not differ significantly between the communal and protected area ($W = 179$, p value $= 0.203$).

In W Park, both land use types displayed flat distribution curves. Here, we also did not find a significant difference (KS-Test: $D = 0.109$, p value $= 0.946$) in the size class distribution between the two land use types. However, there was a visually recognizable higher number of trees of smaller size classes in relation to bigger sized trees on communal land than on protected land (Fig. 2b). Contrary to Gonsé, there was a significantly ($W = 391$, p value $= 0.006$) higher number of individuals per hectare on communal land (29.10 individuals per hectare) than on protected land (17.09 individuals per hectare).

Comparing the size class distributions on communal land of the two study areas, we did not detect significant differences (KS-Test: $D = 0.196$, p value $= 0.308$). Apart from the smallest class (5–15 cm), the distribution curves descended more or less from small to large classes. The density also did not differ significantly between the two communal areas ($W = 186$, p value $= 0.522$).

Size class distributions on protected land, however, diverged a lot between the study sites (KS-Test: $D = 0.379$, p value $= 0.001$). In Gonsé, smaller trees (5–25 cm DBH) were relatively more numerous than bigger trees. On protected land of the W Park, medium-sized trees (45–55 cm DBH) made up the most frequent class. The density differed significantly between the two protected areas ($W = 455$, p value $= 0.001$).

Debarking and pruning

While *L. microcarpa* trees were not pruned in the protected area of the W Park, nearly half of the trees showed signs of pruning in the protected area of Gonsé (Table 1). In contrast, in both areas the majority of the studied trees were pruned in the communal land. In both areas, debarking was only detected on communal land and not in protected areas. In Gonsé, about 23 % of the trees on communal land were debarked, while on communal land in the W Park this number was nearly tripled (Table 1).

Fruit production

We detected DBH, land use, arability, debarking, pruning, and the interaction of land use and pruning as important factors influencing the fruit production of *L. microcarpa* (Table 2).

Trees fruited with a minimum DBH of 12 cm (not presented in Table 1) and fruit production increased with increasing DBH. In both areas, trees on communal land bore more fruits (on average 16,219 fruits per tree) than those on protected areas (10,586), whereas fruit production on arable land was more than twice as much (17,890 fruits) as on non-arable land (7,012). Debarking as well as pruning reduced the fruit production. Furthermore, pruned trees on protected land had a higher fruit production than unpruned trees on communal land.

Fruit and seed weight

We detected DBH, pruning, and debarking as influencing the fruit weight of *L. microcarpa* in the W Park (Table 3). DBH had a positive effect, so that trees with a greater diameter bore heavier fruits. The effect of pruning was also positive, while debarking had negative effects on the weight of the fruits. However, looking at the combined effects of pruning and debarking, we found these two factors as cancelling each other out. The absence of pruning and debarking at the same time had the same effect as the presence of both (Table 3).

Land use, arability, and debarking significantly influenced the seed weight of *L. microcarpa* (Table 4). Seeds were heavier on communal than on protected areas (Table 1) and heavier on arable than on non-arable land. Debarking reduced the seed weight of *L. microcarpa*.

Table 2 Results of the GLM for fruit production of *L. microcarpa*

	Estimate	SE	z Value	*p* Value	
Intercept	8.94	0.55	16.3	<0.001	***
DBH	0.05	0.01	6.7	<0.001	***
Land use (protected)	−1.66	0.50	−3.3	<0.001	***
Arability (non-arable)	−0.58	0.24	−2.4	0.017	*
Pruning (yes)	−0.97	0.46	−2.1	0.034	*
Debarking (yes)	−0.80	0.34	−2.4	0.018	*
Land use (protected): Pruning (yes)	1.27	0.57	2.2	0.027	*

SE Standard error, Residual deviance = 89.7 on 72 df

Discussion

Human impact on population structure of *L. microcarpa*

The differences in population structures and densities of *L. microcarpa* in the protected sites of the two study areas, which can be seen as baseline data, may be explained with the distribution description of Arbonnier (2000) who stated that *L. microcarpa* is rare, but locally abundant. In fact, the species is relatively common in Gonsé, while it is comparatively rare in the W Park area. Additionally, the differences in population structure between the two protected areas might be explained by the different vegetation cover of the two sites. The high human pressure (e.g. logging and grazing) has led to an opening of the vegetation (Shackleton 1993) in the protected area of Gonsé, whereas the relatively good protection status of the W Park allows the development of a dense woody vegetation with a 2–3 m tall and dense grass layer

Table 3 Results of the LM for fruit weight of *L. microcarpa*

	Estimate	SE	z Value	*p* Value	
Intercept	1.82	0.08	24.1	<0.001	***
DBH	0.01	0.00	3.6	0.002	**
Debarking (yes)	−0.26	0.07	−3.9	<0.001	***
Pruning (yes)	0.26	0.06	4.1	<0.001	***

SE Standard error $r^2 = 0.60$, F value 9.35 on 3 and 19 df, p value < 0.001

Table 4 Results of the LM for seed weight of *L. microcarpa*

	Estimate	SE	z Value	*p* Value	
Intercept	5.17	0.08	65.8	<0.001	***
Land use (protected)	−0.31	0.09	−3.3	0.003	**
Arability (non-arable)	−0.28	0.07	−3.9	<0.001	***
Debarking (yes)	−0.19	0.07	−2.5	0.022	*

SE Standard error, $r^2 = 0.46$, F value 5.49 on 3 and 19 df, p value $= 0.01$

(Nacoulma et al. 2011). An opening of the vegetation cover reduces biomass and therefore fire intensity and shade, which may be beneficial for the germination, growth, and survival of seedlings of *L. microcarpa*, as shown for many other West African tree species (Jurisch et al. 2013). In accordance with our results, a study in the eastern center of Burkina Faso (Ky et al. 2009) also found more stable populations of *L. microcarpa* in open savanna vegetation than in dense savanna vegetation.

In both areas and land use types, we found an underrepresentation of the smallest size class (DBH: 5–15 cm) of *L. microcarpa*. The lack of this size class can be related to different factors. Firstly, it could be explained by the fact that local people preferably cut the trunks of these pole-sized trees, because they are suitable for construction. Similarly, other studies on several socio-economically important trees have reported that these small sized stems are the most frequently cut due to the ease of their transport and to the value for construction (Lykke 1998; Obiri et al. 2002; Schumann et al. 2011). Secondly, the lack of this small size class may indicate recent recruitment failure of *L. microcarpa*. This failure might be related to farmers' practices of removing recruiting individuals during land preparation for agriculture, while they mostly preserve adult trees as they already bear fruits and are therefore of higher immediate value. In addition, *L. microcarpa* seems to generally display low recruitment (e.g. Ouédraogo 2006) as its seeds have very low germination rates due to their high oil content (about 35 %) which causes them to lose viability quickly in one hand and in another hand due to physical dormancy (Neya 2006; Sacandé 2007).

When comparing the population structures of the two land use types for each study area, it can be stated that the protected site of the densely populated Gonsé area displayed relatively more stable population structure than the communal site. The opposite was true for the less populated W Park area. Based on this opposing land use impact on population structure of *L. microcarpa* of the two differently densely populated areas, it can be concluded that human impact leads to a promotion of *L. microcarpa* in less populated areas. In contrast, human impact has reached an intensity that starts to negatively affect *L. microcarpa* in the densely populated area. This is in accordance with the study of Ky et al. (2009) who also found that human activities negatively affect *L. microcarpa* in a relatively densely populated area in Burkina Faso. This increased human impact includes a strong extension and intensification of fields (Brink and Eva 2009) and at the same time a shortening of fallow periods. The shortened fallow periods may hamper a successful establishment of *L. microcarpa* as the species will have not enough time to regenerate successfully during the fallow period.

Based on these results, we conclude that stands of *L. microcarpa* are negatively affected by high human population density and thus strong human impact, and as a consequence show a tendency of declining. On the contrary, low human impact is beneficial for *L. microcarpa* and allows the maintenance of this important species. In both areas, the species is preserved on fields when clearing for cultivation. While this extent of protecting seems to be adequate to maintain stable populations of *L. microcarpa* in the less populated area, it is no longer sufficient in the densely populated area.

Human impact on fruit production of *L. microcarpa*

In both areas, trees of the communal areas bore more fruits than trees of the protected areas, despite the higher harvesting intensity in the communal areas. In addition, trees of the communal area in the W Park had heavier seeds than those of the protected area. This indicates that human activities have a positive influence on the fruit production of *L. microcarpa*. This positive human influence is rather indirect and can be explained at least partly by the opening of the vegetation through logging and livestock grazing in the communal areas. With this opened vegetation, communal areas provide more favorable conditions due to reduced competition from other species. The trees have better access to light, water, and nutrients – especially on fields - and can therefore invest their resources more into reproduction in terms of quantity (fruit production) as well as quality (seed weight). During the dry season and after crop harvesting, there is even no competition on fields. Moreover, *L. microcarpa* trees benefit indirectly from favorable human activities on fields, as for example ploughing and fertilizing of the soil for higher crop yield. A selective protection of high-yield trees and an elimination of low-yield trees by farmers on fields might additionally explain the higher fruit production of *L. microcarpa* on communal land than on protected land.

Predation of green, unripe fruits *of L. microcarpa* by birds, baboons, bats, and other mammals, although not quantified in our study, may also explain the lower number of fruits in the protected areas as shown for *L. acida* with similar fruits (Kunz et al. 2008) and for other socio-economically important tree species, i.e. *A. digitata* and *P. biglobosa* (Kunz and Linsenmair 2007; Venter and Witkowski 2011).

Contrary to our results, other studies on socio-economically important tree species did not find a significant impact of land use on fruit production (e.g. for *A. digitata*, Dhillion and Gustad 2004; Schumann et al. 2010; Venter and Witkowski 2011) which demonstrates the species-specific responses to human impact.

In both the communal and the protected area of the W Park, *L. microcarpa* produced considerably more fruits with heavier seeds on arable than on non-arable sites. Arable land has better soil conditions (e.g. deep soils with high clay content) than non-arable sites (e.g. shallow and rocky soils with low clay content). Higher soil quality (high nutrient and water availability) permits higher quantities of fruits and at the same time higher qualities of the seeds. Assogbadjo et al. (2005) found also higher productivity of *A. digitata* on sites with fertile soils (e.g. high clay content and percentage of nitrogen and of organic carbon and matter) than on sites with poor soils.

Regarding harvesting influences, our results reveal that both debarking and pruning had a negative impact on fruit production of *L. microcarpa*. However, while debarking reduced the overall fruit production, the effect of pruning was more differentiated. *L. microcarpa* seems to respond to pruning with lower fruit quantity (lower fruit production), but with higher fruit quality (bigger and juicier fruits). The higher fruit quality might be explained by the reallocation of resources or stored reserves from fruit quantity to fruit quality. However, this beneficial effect of pruning strongly depends on the pruning age and should be consequently taken into account in further studies (see e.g. Bayala et al. 2008). The lower fruit amount indicates that *L. microcarpa* does not fully compensate the loss of fruit-bearing branches by higher production of fruits on the remaining branches. In fact, the trees are weakened by the removal of photosynthetically active plant parts and reduced photosynthetic capacity (Gaoue and Ticktin 2008).

The way in which pruning affects fruit production varies strongly between tree species. While *Afzelia africana* and *Khaya senegalensis* also showed a decreasing fruit production (Gaoue and Ticktin 2008; Nacoulma 2012), an increased fruit production was detected for slightly pruned (1–25 % of crown pruned) adult trees of *A. digitata* (Schumann et al. 2010) and an unchanged fruit amount for half-pruned (50 % of crown pruned) trees of *P. biglobosa* and *V. paradoxa* (Bayala et al. 2008). However, intensive pruning severely affected the fruit production of all three species and this suggests that pruning intensity is an important factor in the management of the species.

In protected areas, pruning increased the number of fruits in our study areas. As inside the protected area pruning is prohibited, people who prune illegally may do it less intensively. This low-intensive pruning may stimulate fruit production. As we found only few trees with more than 25 % of the crown pruned, which would still be "slight pruning" according to Bayala et al. (2008) and Schumann et al. (2010), we conclude that *L. microcarpa* seems to be quite sensible to pruning compared to the above mentioned species. Moreover, it has to be considered that *P. biglobosa* and *V. paradoxa* are pruned for management purposes (e.g. rejuvenation of old trees, increase of fruit production, Timmer et al. 1996), while *L. microcarpa* is mainly pruned with the intention of collecting wood, leaves, and fruits.

The bark is an organ protecting the plant from being attacked by predators, fire, and dehydration. The removal of the bark increases the risk of infections by insects, bacteria, and fungi of the tree, which weaken the individual tree. Further, depending on the depth of the cut, the vascular strands may be damaged, which can interrupt the transport of water, nutrients, and photosynthates. This might explain the lower fruit production of *L. microcarpa* under debarking influence. Thus, *L. microcarpa* does not seem to be resilient to debarking as shown for other West African tree species, e.g. *A. digitata and K. senegalensis* (Gaoue and Ticktin 2008; Schumann et al. 2010). Lamien et al. (2006) even demonstrated that girdling increased the number of fruits of *V. paradoxa* in western Burkina Faso.

The resilience of tree species to debarking depends a lot on the species-specific ability of wound recovery after bark harvesting (Delvaux et al. 2009). For example, the fruit productions of *A. digitata* and *K. senegalensis* were not influenced by debarking, which could be related to their ability of complete wound recovery after debarking (Delvaux et al. 2009).

In contrast, the fruit amount of *A. africana* was highly negatively influenced by debarking (Nacoulma 2012); and Delvaux et al. (2009) found indeed a very poor wound recovery after bark harvesting for this species. Similarly, *L. microcarpa* might also not be able to easily seal off debarked wounds. More experimental studies are, however, necessary to verify this assumption. Moreover, further multi-year studies will bring more information about the nature of the fruit production of *L. microcarpa* (e.g. if it is irregular, alternate or cyclic).

Conclusion

Our study describes the population structure and fruit production of the socio-economically important tree species *L. microcarpa* in relation to human impact and estimates its tolerance to human activities. Based on our results, we conclude that low human population density and thus, low-intensity human impact is beneficial for *L. microcarpa* and that indirect human impact (e.g. opening of vegetation) facilitates the fruit production of *L. microcarpa*. In contrast, high intensity of human impact in densely populated areas negatively affects *L. microcarpa* and direct human activities (pruning and debarking) reduce fruit production. While the measure of protecting adult trees of *L. microcarpa* still seems to be enough in the low-population area, it is no longer sufficient in the densely populated area. To ensure the sustainable management and productivity of this economically important species, adaptive research leading to modified harvesting and management techniques is required. This is especially true in the light of predicted increased human impact in the future, due to rapidly growing human population and increasing exploitation of natural resources. More information about the species' characteristics (e.g. germination, survival, and growth) is required to accurately predict the increased human influence on the persistence of this important species in the future. The results of this study could be used as the basis in the formulation of management recommendations for *L. mirocarpa*.

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