Impact of Land-Use on Savanna Vegetation and Populations of Non-Timber Forest Product-Providing Tree Species in West Africa

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Contents

Chapter 1

General Introduction

Savanna ecosystems cover an eighth of the global land surface and support a large proportion of the world’s human population. They are defined as formations with more or less continuous herb cover and a discontinuous woody cover (Scholes and Archer, 1997). The distribution, structure, and composition of savannas depend on climate, topography, soils, geomorphology, herbivores, and fire (Scholes and Archer, 1997; Higgins et al., 2000). In addition, savannas have undoubtedly been shaped by human land-use for thousands of years (Higgins et al., 1999; Shackleton, 2000; Wittig et al., 2007).

Land-use impact in West African savannas

Land-use is the sum of the arrangements, activities, and inputs that people undertake in a certain land-cover type to cultivate, change, or maintain it (Choudhury and Jansen, 1998). In the West African savanna, the most important land-uses comprise agriculture, grazing, fire management, and harvesting of natural products (game and plants). Agriculture is generally practiced in form of shifting cultivation, which consists of the alternation between a short phase of cultivation and a long period of fallow. In this way, shifting cultivation transforms West African savanna areas into mosaic landscapes with croplands, fallows of different ages, and savanna sites that are not used for cultivation due to unfavorable soil and habitat conditions (Pulido and Caballero, 2006). Characteristic for these mosaic landscapes is the preservation of some highly valued tree species (e.g. *Adansonia digitata*, *Parkia biglobosa*, and *Vitellaria paradoxa*) on croplands (agroforestry systems). Grazing activities are mostly extensive in West Africa and take place almost everywhere by domestic animals, mainly cattle, goat, and sheep herds. Animal husbandry is traditionally the domain of the Fulbe in West Africa, which are either settled and partly transhumant or live completely nomadic. In addition to natural fires, people set fires for various reasons: e.g. to clear ground for agriculture, to achieve higher visibility, and to stimulate an off-season re-growth of perennial herbs (Krohmer, 2004; Orthmann, 2005).

During the last decades, the West African savannas were subject to drastic climatic and land-use changes (Hahn-Hadjali and Thiombiano, 2000; Wezel and Haigis, 2000; Gonzalez, 2001; Hickler et al., 2005; Wezel and Lykke, 2006; Wittig et al., 2007; Brink and Eva, 2009; Ouedraogo et al., 2010). Hereby, land-use changes account for 70-80% of the biodiversity changes in savannas (De Chazal and Rounsevell, 2009). The percentage of land intensively used for agriculture has increased in West Africa (Brink and Eva, 2009) and agricultural systems have been intensified due to the growing use of fertilizers and pesticides. At the same time, the length of fallow periods has decreased and soil and vegetation regeneration is much shorter today than it was some decades ago (Wittig et al., 2007). The main reasons for these changes are the rapid population growth and the growing interest in cash-crop production (e.g. cotton). For example, a study in southern Burkina Faso showed that natural habitats were progressively converted to croplands at an annualized rate of 1%, while the population density nearly duplicated from 17 to 30 inhabitants per km^2 from 1986 to 2006 (Ouedraogo et al., 2010). Such changes have enormous ecological, economic, and social consequences, notably because of the importance of savannas for the livelihood of rural people in West Africa by providing timber and non-timber forest products. They are leading, on the one hand, to the loss of natural habitats, biodiversity, and stored carbon and on the other hand to the loss of ecosystem services (Riebsame et al., 1994; Lambin et al., 2003; Brink and Eva, 2009; Ouedraogo, 2010). Furthermore, the reduction of natural resources leads to an increased risk of soil erosion, land degradation, and of natural hazards like floods.

Thus, there is an urgent need for the sustainable use and protection of savanna ecosystems. This can be achieved by containing human land-use through the establishment of protected areas, by introducing management systems in human land-use areas that ensure the sustainable use of the natural resources, and by improving agricultural efficiency in forest peripheries (Hutton and Leader-Williams, 2003; Illukpitiya and Yanagida, 2010). Protected areas have been the mainstay of international conservation strategies since the start of the twentieth century, although their history is much older (Adams and Hutton, 2007). Despite their spatial limitation, protected areas play a crucial role, especially in the tropics, in protecting ecosystems within their borders, particular by preventing land clearing and by reducing human land-use activities (Bruner et al., 2001; Struhsaker et al., 2005; Clerici et al., 2007). In West Africa, protected areas were mainly set for the maintaining of viable populations of large, wide-ranging animals. They are managed by controlled fires that are set at an early stage of the dry season to avoid more destructive “late” fires and to open the vegetation for an increasing visibility of animals for tourists. In addition, protected areas in West Africa are influenced by illegal harvesting, hunting, and livestock grazing.

As ecological and social systems are closely linked (Folke et al., 1998) and should not be treated as opposed (Fairhead and Leach, 1996), it is essential to also consider land-use areas in regard to biodiversity protection. Moreover, biodiversity value does not end at the park boundary as human-dominated communal lands adjacent to protected areas can still maintain unique and rich assemblies of species (Caro et al., 2009). Thus, the sustainable use of natural resources in human land-use areas is highly required and can be achieved by giving rural people a direct economic interest in the conservation of species and ecosystems (Margules and Pressey, 2000; Hutton and Leader-Williams, 2003; Hayes, 2006; Kaimowitz and Sheil, 2007; Abensperg-Traun, 2009). Sustainable use is defined by the Convention on Biological Diversity as ”the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations” (Secretariat of the Convention on Biological Diversity, Article 2). Thus, sustainable use is essential not only for the protection of the biodiversity on the long-term, but also for ensuring the availability of natural resources for subsistence and cash income of rural people in the future (Hutton and Leader-Williams, 2003).

In the context of land-use changes, there is an urgent need to better understand and evaluate the impact of land-use on savanna vegetation and diversity and to assess the functioning of protected and communal areas in regard to biodiversity maintenance. While most studies investigated land-use changes in West African savannas with remote sensing approaches (e.g. Braimoh, 2006; Clerici et al., 2007; Wittig et al., 2007; Paré et al., 2008; Brink and Eva, 2009; Ouedraogo et al., 2010), only few studies investigated the impact of land-use on savanna vegetation and diversity based on extensive field data on plant diversity (e.g. Devineau et al., 2009; Paré et al., 2009b). In addition, there is virtually no information about the impact of land-use on the savanna vegetation and diversity from different habitats.

Non-timber forest products and implications of their harvesting

Non-timber forest products (NTFPs) include any products other than timber derived from forest or any land under similar use (FAO, 1995; Choudhury and Jansen, 1998; Arnold and Pérez, 2001). They can be grouped into three categories (Peters, 1994): (1) fruits and seeds, (2) plant exudates (e.g. gums, latexes, and resins), and (3) vegetative structures (e.g. bark, leaves, stem, and roots). NTFPs are gathered from the wild, in agroforestry systems, or are cultivated as semi-domesticated plants in plantations (Choudhury and Jansen, 1998). Due to their wild or semi-domesticated status, they can be distinguished from well-established agricultural crops such as cocoa, coffee, or oil palm. They differ from timber products in terms of the greater variety of products and of species, the shorter frequency of harvesting cycles, and the typically smaller yield per unit area (Shahabuddin and Prasad, 2004).

In Africa and elsewhere in developing countries, rural households use several different NTFPs from a wide range of plant species for both subsistence and commercial use. In West Africa, NTFPs contribute importantly to the livelihoods and welfare of rural people, i.e. as a source for construction material, fodder, food, fuel wood, medicine (Kristensen and Balslev, 2003; Taïta, 2003; Lykke et al., 2004; Belem et al., 2007; Paré et al., 2010; Heubach et al., 2011). They are also widely important as a safety-net during times of need (e.g. crop failure), particularly for poorer groups within the community (Arnold and Pérez, 2001; Shackleton and Shackleton, 2004).

The main factor determining the populations of NTFP-providing species is human land-use, such as agriculture, fire, harvesting, and livestock grazing (Lykke, 1998). In recent years, there has been growing concern that populations of NTFP-providing trees are declining due to land-use intensification and over-harvesting (Shackleton and Shackleton, 2004; Shahabuddin and Prasad, 2004; Ticktin, 2004). Therefore, the need for research on their sustainable use is becoming more and more pressing (e.g. Djossa et al., 2008; Ndangalasi et al., 2007; Obiri et al., 2002). Only few studies investigated the impact of land-use and harvesting on the populations of tree species (e.g. Gaoue and Ticktin, 2007; Djossa et al., 2008; Traoré et al., 2008) in West Africa.

Even though NTFP-harvesting may be less damaging than other land-uses like cattle ranching or intensive logging, it is not without impact (Arnold and Pérez, 2001). Harvesting of NTFPs may impact biological processes at individual, population, communities, and ecosystem level (Shahabuddin and Prasad, 2004; Ticktin, 2004). It can directly affect the physiology and vital rates (growth, reproduction, and survival rate) of plant individuals and can change, in turn, the demographic (dynamics and structures) and genetic patterns of populations (Ticktin, 2004). Declining densities and recruitment of harvested species can lead to substantial changes in the structure of ecosystems. Such changes might include a shift in the composition of plant communities as well as lowering of diversity, biomass, and net primary productivity of these ecosystems (Shahabuddin and Prasad, 2004).

Tolerance of plant species to harvesting varies according to the life history of the species (e.g. growth and mortality rates, sprouting ability), to environmental conditions (e.g. climatic and soil conditions), and to the part of the plant that is harvested (Cunningham, 2001; Ticktin, 2004; Neke et al., 2006; Gaoue and Ticktin, 2007; Gaoue and Ticktin, 2010). For instance, populations of perennial herbs can withstand higher rates of harvest than populations of trees that tend to be much slower growing and longer lived (Ticktin, 2004). Harvesting of flowers, fruits, or leaves has far less impact on plant individuals than extraction of bark, roots, or stems in term of plant survival (Peters, 1994; Cunningham, 2001). However, exploitation of flowers, fruits, and leaves can have a significant impact on reproduction, recruitment, and on the population viability over the long-term (Hall and Bawa, 1993; Peters, 1994; Dhillion and Gustad, 2004; Gaoue and Ticktin, 2008). Furthermore, tolerance to harvesting varies according to the harvesting modes (e.g. frequency and intensity of harvesting, size-specific harvesting preferences), in combination with additional human management practices (e.g. fertilization, planting, protection of trees on croplands, and weeding), and in land-use context (e.g. agriculture, fire, grazing, and logging) (Boot and Gullison, 1995; Shahabuddin and Prasad, 2004; Ticktin, 2004; Sinha and Brault, 2005; Gaoue and Ticktin, 2007).

The fact that tolerance to harvesting depends on several factors highlights the importance of jointly considering land-use and harvesting impacts, the protection status, and the life history, when assessing the population status of species and the sustainability of the species use. However, there are no studies in West Africa that have assessed if the response of woody species to land-use and harvesting depends on the protection level and on the life history of species.

Harvesting is considered ecologically sustainable if it has no long-term destructive effect on the reproduction and recruitment of individuals being harvested in comparison to equivalent non-harvested individuals (Hall and Bawa, 1993). Furthermore, harvesting should have no adverse effect on other species in the community or on ecosystem structure and function. Biological knowledge can inform how to move the ways and rates at which natural resources are used towards greater ecological sustainability (Hutton and Leader-Williams, 2003). Important additional information can be provided by local people. Traditional ecological knowledge and opinions on use-preferences, management strategies, and their impact on the resource are crucial elements for producing culturally and ecologically rational conservation and management strategies (Lykke et al., 2004; Gaoue and Ticktin, 2009). People living in natural environments in West Africa have a profound knowledge of plant resources due to their frequent use of wild plants and due to a consistent transmission of knowledge from generation to generation (Lykke, 2000; Paré et al., 2010). A comprehension of local people gives management strategies a better chance for success (Lykke, 2000; Ticktin et al., 2002; Kristensen and Balslev, 2003; Kaschula et al., 2005; Kaimowitz and Sheil, 2007). Thus, it is important to combine ecological and ethnobotanical knowledge in order to provide appropriate management recommendations that are reliable in a specific area under specific circumstances. However, only few studies (e.g. Lykke, 1998) included ecological and ethnobotanical knowledge when assessing the population status and sustainable use of species in West Africa.

This thesis

The major objective of the present thesis was to study the impact of land-use on savanna vegetation and diversity as well as on populations of two important non-timber forest product-providing tree species in a semi-arid savanna area in West Africa. The study area was located in the south-eastern part of Burkina Faso, in the North Sudanian zone, and comprised the protected W National Park and its adjacent communal area.

Two tree species were used as model systems: *Adansonia digitata* L. (Fig. 1a), commonly known as baobab, monkey bread or upside-down tree and *Anogeissus leiocarpa* (DC.) Guill. & Perr. (Fig. 1b), commonly named as African birch. Both species provide several NTFPs and are therefore highly used by the local population. These species were chosen as they show different levels of human protection and opposed life histories and may therefore react differently to land-use and harvesting. *A. digitata* is protected on croplands by farmers during the agricultural cycle of cultivation and fallows, while *A. leiocarpa* is not or only partly preserved. *A. leiocarpa* is a pioneer species (i.e. high seed production and asexual regeneration) that displays high recruitment and *A. digitata* is a long-lived species, with extremely low adult mortality rates and low recruitment rates. Further information of the studied species and the study area are provided in the methods sections of the following chapters.

Fig. 1 *Adansona digitata* (a) and *Anogeissus leiocarpa* (b).

Outline of the thesis

The present thesis consists of five studies:

The first study deals with the impact of land-use on the West African savanna vegetation **(chapter 2)**. In cooperation with a colleague from Burkina Faso (Blandine Nacoulma), I compared the vegetation and diversity of the protected W National Park with those of its surrounding communal area. We studied which environmental factors determine the occurrence of the different vegetation and tested if land-use has an impact on vegetation structure and diversity pattern and if this impact differs between the different vegetation types and between the woody and the herb layer. In addition, the influence of land-use on the occurrence of life form types and tree species with high value for local people was studied. The results of this study help to understand and evaluate the influence of land-use on savanna vegetation and provide insights on what kind of management activities may be most appropriate.

The following two studies cover the impact of land-use – and in particular of harvesting (debarking and chopping/pruning) - on populations of *Adansonia digitata* **(chapter 3)** and *Anogeissus leiocarpa* **(chapter 4)**. Stands of the protected W National Park were compared with those of surrounding communal area (in fallows, croplands, and villages). Hereby, I studied the population structures of these two important tree species and combined it with rates and patterns of harvesting. These studies provide an assessment of the current population status of these species, their harvesting tolerance, to what extent their actual use is sustainable, and which management strategies may foster their conservation.

The subsequent two studies address uses and management strategies of *A. digitata* **(chapter 5)** and *A. leiocarpa* **(chapter 6)**. Quantitative ethnobotanical surveys among the Gulimanceba people were conducted in order to document uses of the different plant parts, harvesting modes, perceptions about the population status, and conservation status of both species. In this context, knowledge distribution on a small-scale, i.e. differences in knowledge between gender, generations, and villages, were investigated. As a result, I provide a coherent synergy between the obtained ethnobotanical knowledge and ecological findings (chapter 3 and 4) of both species in order to provide appropriate management recommendations that are reliable under currently practiced management strategies.

Finally, an overarching synthesis is provided in **chapter 7**.

Chapter 2

Impacts of Land-Use on West African Savanna Vegetation: A Comparison Between Protected and Communal Areas in Burkina Faso

with B.M.I. Nacoulma, S. Traoré, M. Bernhardt-Römermann, K. Hahn, R. Wittig, A. Thiombiano

Biodiversity and Conservation (accepted)

Abstract

Biodiversity matters in many aspects for human well-being by providing timber and non-timber products. The most important ecosystems providing these products in West Africa are savannas. In the context of land-use changes, there is an urgent need to understand the impact of land-use on savanna vegetation and biodiversity. This study assesses the impact of land-use on savannas by comparing protected and communal area. Vegetation relevés were performed in the W National Park and its surrounding communal area in Burkina Faso. Vegetation types were established using ordination and clustering methods. We analyzed which environmental factors determine the occurrence of the vegetation types and whether land-use has a specific effect on diversity of vegetation types occurring in both areas. Furthermore, we tested the effect of land-use on vegetation structure and the occurrence of life forms and highly valued tree species. Our results reveal five vegetation types occurring in both areas. Elevation and soil characteristics played the most important role for the occurrence of the vegetation types. Land-use had an effect on vegetation structure, diversity, and the occurrence of life form and highly valued species. The findings suggest that traditional human land-use does not automatically lead to loss of species and degradation of savanna habitats and that combination of communal and protected areas may be of great importance for the conservation of broad spectrum of biodiversity. Our study demonstrates the complexity of land-use impact on biodiversity patterns and provides insights on what kind of management activities may be most appropriate in both areas.

Introduction

Biodiversity matters in many aspects for human well-being by providing timber and non-timber forest products (NTFPs) for multi-uses (Millennium Ecosystem Assessment, 2005). In West Africa, rural households use several different NTFPs from a wide range of plant species to meet their everyday needs, e.g. as a source of construction material, fodder, food, fuel wood, medicine, and as a source of additional incomes (sales in local markets) (Kristensen and Balslev, 2003; Taïta, 2003; Belem et al., 2007; Paré et al., 2010). The most important ecosystems providing timber and NTFPs in the West African Sudanian region are savannas. The distribution, structure, and composition of savannas depend on climate, topography, soils, geomorphology, herbivore, and fire (Scholes and Archer, 1997; Higgins et al., 2000; Van Wilgen et al., 2003). In addition, savannas have undoubtedly been shaped by human land-use since thousands of years (Higgins et al., 1999; Shackleton, 2000; Wittig et al., 2002; Wittig et al., 2007) and this continuing process should not be neglected when trying to predict their future development (Heubes et al., 2011). Human land-use impact and abiotic as well as biotic factors interact, making it difficult to identify, isolate, or quantify the key determinants of savannas and their biodiversity (Scholes and Archer, 1997; Higgins et al., 1999).

In the West African savanna, the most important land-uses comprise agriculture, grazing, harvesting, and logging. Agriculture is generally practiced in form of shifting cultivation, which consists of the alternation between a short phase of cultivation and a period of fallow. In this way, shifting cultivation transforms savanna into mosaic landscapes with croplands, fallows of different ages, and non-arable savanna sites. Grazing activities by livestock breeding are mostly extensive and take place almost everywhere in the mosaic landscape. In addition to natural fires, people set fire for various reasons, e.g. to clear ground for agriculture and to achieve higher visibility for hunting. In protected areas, controlled fires are set annually at an early stage of the dry season for management purposes (avoidance of more destructive “late” fires). In addition, protected areas are influenced by water provision, poaching as well as by illegal harvesting and livestock grazing.

In the last decades, West African savannas were subjected to swift land-use changes (Wittig et al., 2007; Paré et al., 2008; Ouédraogo et al., 2010) due to the rapid human population growth and the growing interest in cash-crop production. Such changes have enormous ecological, economic, and social consequences. Thus, the protection of savannas is essential for the protection of the biodiversity and to ensure the availability of natural resources for subsistence and cash income of rural people in the future. Protection can be achieved by reducing human land-use through the establishment of protected areas. Such areas play a crucial role in protecting ecosystems and their biodiversity within their borders, especially by preventing land clearing and by reducing human land-use activities (Bruner et al., 2001; Struhsaker et al., 2005; Clerici et al., 2007). However, as ecological and social systems are closely linked (Folke et al., 1998) and should not be treated as opposed (Fairhead and Leach, 1996) it is essential to also consider land-use areas in regard to biodiversity protection. Moreover, biodiversity value does not end at the park boundary as human-dominated communal lands adjacent to protected areas can still maintain unique and rich assemblies of species (Caro et al., 2009). The ecological integrity of a protected area strongly depends on the ecological function that its surrounding communal area can perform (Clerici et al., 2007).

In the context of land-use changes, there is an urgent need to understand and evaluate the impact of land-use on savanna vegetation and to assess the functioning of protected areas as well as of communal areas. In West Africa, vegetation studies mostly focused either on protected areas including hunting zones, classified forest, and National Parks (e.g. Mahamane, 2005; Ouoba, 2006; Gnoumou et al., 2008; Mbayngone et al., 2008; Ouédraogo et al., 2011) or on their surroundings (e.g. Hahn-Hadjali, 1998; Wittig et al., 2000). Only a few studies (e.g. Devineau et al., 2009; Paré et al., 2009b) compared the vegetation and diversity of a National Park with its surrounding communal area. In addition, there is virtually no information about the impact of land-use on the vegetation and diversity from different habitats.

In this study, we investigate the impact of land-use on savanna vegetation by comparing the W National Park of Burkina Faso with its surrounding communal area concerning vegetation and phytodiversity. The results provide insights on what kind of management activities may be most appropriate. Specifically, the following questions are addressed:

(i) What are the specific environmental factors determining the occurrence of different vegetation types?

(ii) Does the communal area differ from the protected area in vegetation structure and phytodiversity? We assume that the land-use impact is vegetation type specific.

Furthermore, we presume that the occurrence of hemicryptophytes and therophytes differ between communal area and protected area.
(iii) Are tree species of high value for local people more endangered in the communal area compared to the protected area?

Methods

Study site

The study site was located in the south-eastern part of Burkina Faso in the province Tapoa (11°35’-12°22’ N and 1°46’-2°23’ E) and covered an area of 4800 km^2 (Fig. 1). It comprised the W National Park, its hunting zones, and its surrounding communal area. The W National Park is a trans-boundary (Benin, Burkina Faso, and Niger) biosphere reserve of UNESCO-MAB (Man and the Biosphere Program, November, 2002). The communal area comprised the area outside of the National Park and the hunting zone. It included croplands, fallows of different ages, non-arable savanna sites, and small buffer areas. Annual mean temperatures are between 26°C and 29°C and average annual precipitation between 750 and 950 mm. The length of the dry season is 6–7 months from November to April. The vegetation is composed of a mosaic of various types of savannas (woodland, grass, shrub, and tree savanna), dry and gallery forests. The main soil types in the study site are Luvisols, Lixisols, and Leptosols (Traoré, 2008). Human population density is about 16 inhabitants per km^2 in the province Tapoa (INSD, 2007). People live mainly from agriculture (cereals and cotton) and extensive livestock breeding. Livestock density (mainly cattle, sheep, and goats) in the province Tapoa is about 50.28 per km^2 (ENEC, 2003).

The park and the hunting zones are managed by water provision and prescribed fires that are ignited in October or November every year. Park managers set early fires to open the vegetation and increase the visibility of animals for tourists (Clerici et al., 2007), to mitigate the effect of accidental late fire, and also to stimulate an off-season re-growth of perennial herbs. Livestock grazing, hunting, and fuel wood extractions are prohibited in the park, while exploitation of baobab fruits and straw by neighboring local communities is authorized and regulated. Nevertheless, poaching as well as illegal harvesting and livestock grazing take place.

In the communal area, a farming system with alternating cycles of cultivation and fallows is practiced. Characteristic for this farming system is the preservation of some important tree species (e.g. *Adansonia digitata*, *Parkia biglobosa*, *Vitellaria paradoxa*) on croplands. In-between, some savanna sites are not used for agriculture due to their unfavorable soil and habitat conditions (e.g. too dry, wet, or rocky). However, they are strongly affected by other human activities, e.g. extensive livestock grazing, fires, and various harvestings of natural products (including fuel wood, thatching materials, poles for construction, edible, and medicinal plants).

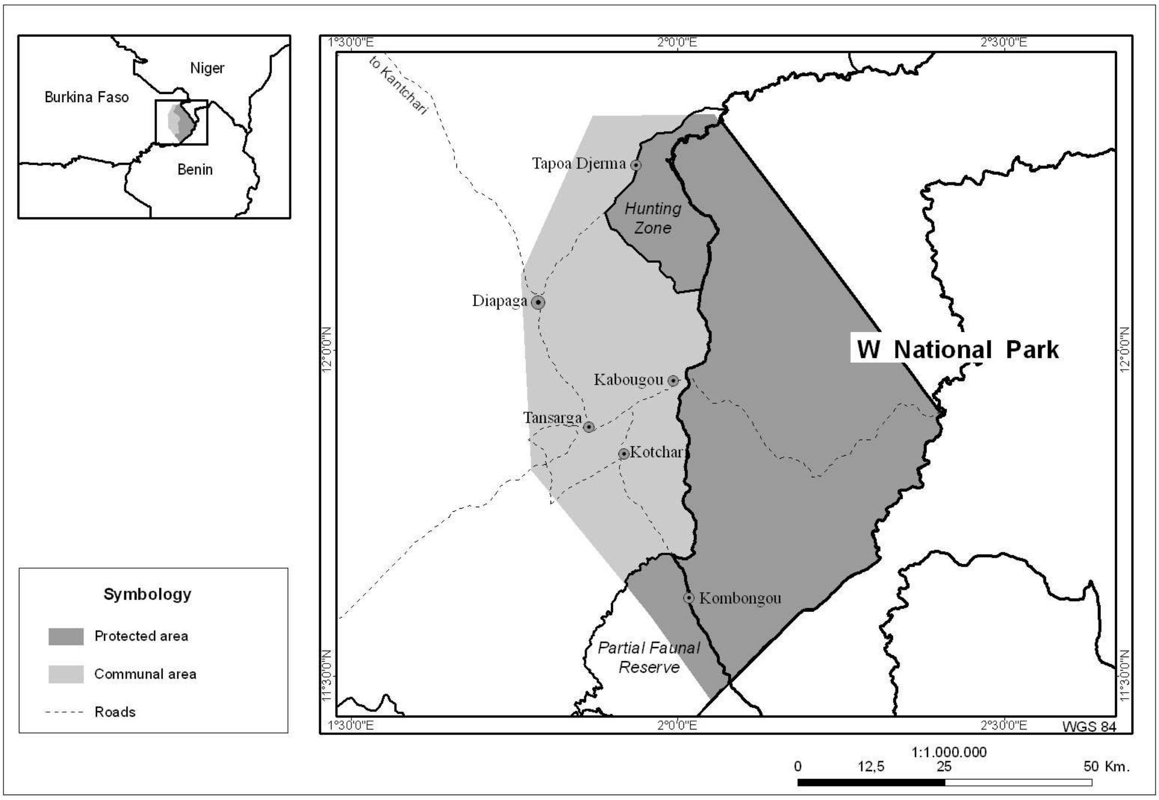

Fig. 1 Study area (UTM zone 31 North, WGS 84).

Vegetation sampling

To characterize the vegetation of the protected (PA) and communal (CA) areas, relevés were performed in both areas. Field work was carried out during the rainy seasons (September-October) 2007 and 2008. This period coincides with the emergence of flower and leaves of most herb species (facilitation of its identification). Relevés were placed following a stratified random design using satellite images and soil maps in order to cover the main occurring habitat types (i.e. dry, medium, wet, and rocky situations).

Vegetation sampling was done separately for the woody and the herb layer. The woody layer was investigated in 900 m² plots (30 m x 30 m) and the herb layer in 100 m² (10 m x 10 m) plots. These plot sizes were shown to be suitable for the characterization of savanna vegetation in the Sudanian zone of Burkina Faso (Hahn-Hadjali, 1998; Ouédraogo, 2006). The herb layer plots were randomly located inside the corresponding woody layer plots. Percentage canopy coverage of all vascular plant species was estimated visually on each plot. Such estimations were done separately for the tree, shrub, and herb layer, using the method proposed by Braun-Blanquet (1932) with the scale suggested by Van der Maarel (1979). In total, 178 vegetation relevés were performed in the protected area and 212 in the communal area.

Nomenclature followed Lebrun and Stork (1991; 1992; 1995; and 1997).

Record of environmental factors

Soil sampling was performed on random selected plots among the vegetation plots to cover all vegetation types. For each vegetation type, at least three samples were taken. Soil profiles were described according to the guidelines for soil description (FAO, 2006) and classified by soil-types according to world reference base classification (WRB, 2006). The following parameters from each soil profile stratified into surface (A) and sub-surface (B) horizons were estimated in the field: soil depth, percentage of coarse fractions (soil particle size >2 mm), and percentage of oximorphic color granularity (gleyic color pattern). Soil texture analysis was determined with the hydrometric method after destruction of soil organic matter with H_2O_2. The particle size distribution includes percentage of clay ($< 2\ \mu m$), silt ($2–50\ \mu m$), and sand ($50-2000\ \mu m$). Other parameters included soil pH measured on a soil water suspension (1/2.5) and total organic carbon (Walkey and Black, 1934).

Based on a digital elevation model (DEM) and the ASTER instrument with a resolution of 30 m x 30 m (http://www.gdem.aster.ersdac.or.jp) and using SAGA GIS, we calculated for each plot solrad (potential increasing of solar radiation), SWI (soil wetness index), and the following topographical parameters: aspect, curvature, elevation, hillshade, and slope. In addition, the distance of each sampled plot to the nearest village was calculated to consider the effect of village distance.

Data analyses

Description of vegetation types

Differences in vegetation composition were analyzed using a Detrended Correspondence Analysis (DCA, with down-weighting of rare species). Relevés located close to each other in the ordination diagram have a comparable vegetation composition; thus, they were assumed to belong to the same vegetation type. To define these, we used a k-means clustering based on the DCA sample scores of the first two axes. The optimal number of clusters was estimated and tested for significance using bootstrapping methods with 100 replications. Prior to analysis, percentage cover values were arcsine square root transformed.

To detect which environmental variables explain the differences in vegetation composition, we calculated Pearson's correlations of the ordination and all environmental factors mentioned above (enhanced by land-use, a binary variable describing the location of a plot as inside the protected area or outside). We correlated environmental data from the 46 soil samples with the DCA-scores of the corresponding vegetation relevés. All environmental factors were standardized prior to the calculation of the correlations to account for different measuring scales.

Each vegetation type found by the DCA with subsequent k-means clustering was characterized by Indicator Species Analysis. This analysis delivers species that are strong indicators for the corresponding vegetation type (Dufrêne and Legendre, 1997). We used two characteristic species (one species of the woody layer and one of the herb layer) following the p-value and the indicator value for each vegetation type (McCune and Grace, 2002).

Influence of land-use on vegetation structure, life form, and diversity

We characterized each plot by two different measures of biodiversity: species richness (number of occurring species at plot level which represents the local alpha diversity and does not represent the diversity of the whole study site) and species evenness. To describe species evenness, the E_{var} index proposed by Smith and Wilson (1996) was used, because it is independent of species richness and sensitive to both rare and common species (Krebs, 1999). Irrespective of vegetation types, the effect of land-use (PA vs. CA) on vegetation structure (cover and height of the tree, shrub, and herb layer) and species richness was tested using t-test for unpaired samples. The mean cover of therophytes per plot in the two areas was tested using t-test, and the mean cover of hemicryptophytes was tested with Wilcoxon rank sum test because the variances were inhomogeneous.

For each vegetation type, we tested for differences in species richness and in species evenness between protected area and communal area using t-test. This was done separately for the herb layer and the woody layer since they may show contrasting reactions to land-use. These tests were done by calculating differences between the communal area and the protected area for plot pairs with minimal differences in dominant species and vegetation composition. Plot pairs were established separately for all vegetation types; based on the DCA scores of the first two axes we chose as pair those plots from the communal and protected areas that were situated as close as possible to each other. Diversity parameters were contrasted by calculating the logarithm of the quotient between CA and PA for species richness (ln(CA/PA)), and the difference (CA-PA) for species evenness.

Influence of land-use on highly valued tree species

In total, 53 tree species are known as highly valued for this region based on local perceptions in the communal area of the W National Park in Burkina Faso, of which 20 are considered as disappearing or threatened (Koadima, 2008). This list was compared to the diversity found in our plots. The occurrence (percentage of occurrence in plots) of these highly valued tree species was compared between the communal and protected area (factor land-use).

Statistical analyses were performed using PASW Statistics 18.0.0 (IBM), PC-ORD (McCune and Mefford, 2006) and R 2.10.1 (R Development Core Team, 2009). The information on life forms was extracted from the vegetation database VegDa 2.7 (Schmidt, 2006). The distance of each plot to the nearest village was calculated using the analysis tool “near” in ArcMap 9.3 (UTM zone 31 North, WGS 84).

Results

Vegetation types

Identification of vegetation types and characteristic species

We detected five vegetation types which were all represented in the protected area and in the communal area (Fig. 2). These vegetation types were named according to their habitat characteristics as follows: dry woodland (abbreviated as woodland), dry forest (abbreviated as forest), upland, grassland, and wetland.

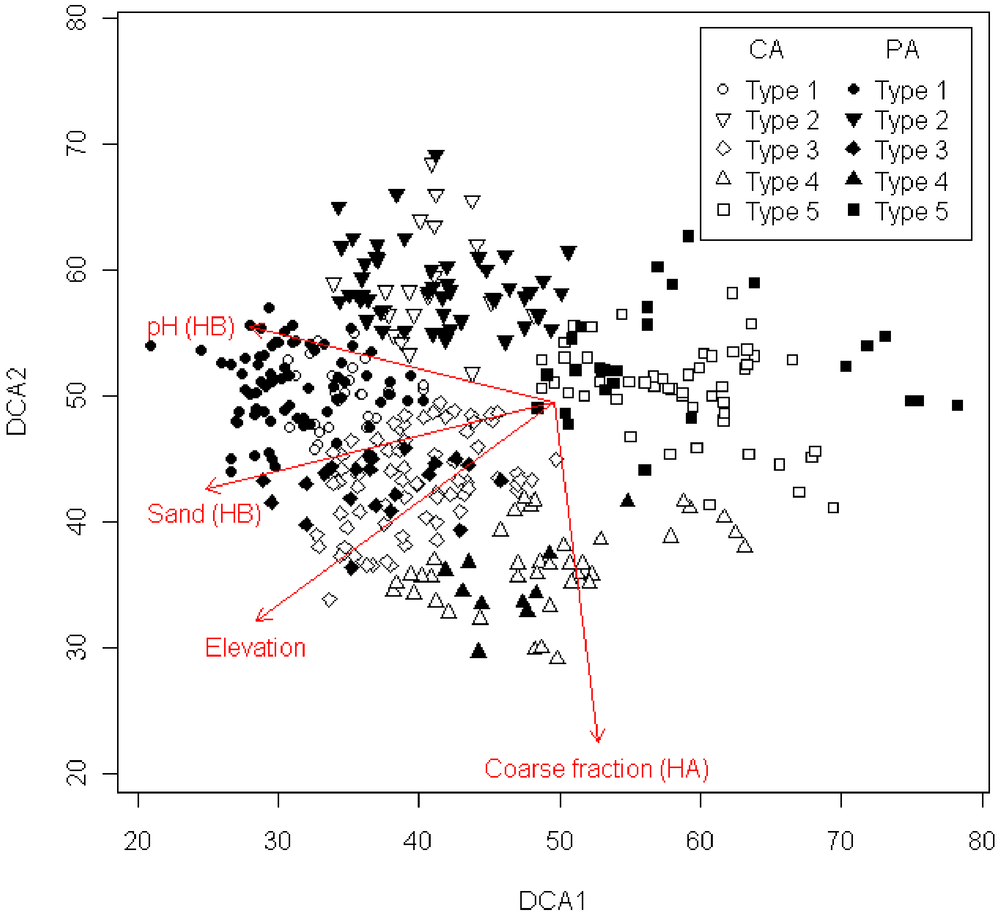

Fig. 2 Ordination-diagram of the vegetation of the communal (CA) and protected area (PA), based on the species cover of the herb and woody layer.
The ordination was based on 612 species in 390 plots (178 in PA, 212 in CA), length of first axis: 4.86, explained variance: 18.4%, second axis: 13.3% explained variance. Correlations with environmental variables are shown for those with r > 0.450; 1.axis: sand (%) of horizon B, r = -0.544; pH water of horizon B, r = -0.465; elevation, r = -0.458, 2.axis: coarse fractions (%) of horizon A, r = -0.585.

Vegetation types: filled symbols = in protected area, blank symbols = in communal area; Types: 1 = woodland, 2 = forest, 3 = upland, 4 = grassland, 5 = wetland.
HA = surface horizon, HB=sub-surface horizon.

The first two characteristic species with the lowest p-value and highest indicator value of these vegetation types were: *Strychnos spinosa* and *Andropogon gayanus* for the woodland, *Anogeissus leiocarpa* and *Wissadula rostrata* for the forest, *Combretum nigricans* and *Brachiaria villosa* for the upland, *Loudetia togoensis* and *Digitaria horizontalis* for the grassland, and *Terminalia macroptera* and *Scleria sphaerocarpa* for the wetland (Appendix 1).

Relating vegetation types to environmental factors

The first axis of the ordination correlated negatively with the percentage of sand, the pH of the soil sub-surface horizon, and with elevation (Fig. 2, Appendix 2). The grassland showed the highest percentage of sand in the sub-surface (mean sand = 54.9%), while the wetland displayed the lowest percentage of sand (mean sand = 15.3%). All other three vegetation types showed intermediate percentages of sand in the sub-surface (mean sand between 34-39%). Soils of all vegetation types displayed moderate acidic conditions. The soil of the forest showed the highest pH-values (mean pH = 6.3) and that of the wetland displayed the lowest values (mean pH = 4.3). The upland and the grassland were found on rocky habitats (mean elevation: 278 a.s.l., 273 a.s.l. respectively), while the wetland was found in temporarily wet depressions (mean elevation: 231 a.s.l.).

The second axis correlated negatively with the percentage of coarse fractions in the soil surface horizon (Fig. 2, Appendix 2). The soil of the grassland contained the highest percentage of coarse fractions (mean = 23.33%), while those of the forest (mean = 2.45%) and of the woodland (mean = 2.88%) contained the lowest percentage of coarse fractions. There were no strong correlations of organic carbon with the DCA axes. The content of organic carbon was low in all cases (about 1%), but slightly higher in the soil surface horizon (A) than in the sub-surface (B). There were also no strong correlations of the DCA axes with soil depth although soil depth differed widely between vegetation types. For instance, the grassland displayed the most shallow soils (mean depth = 13.33 cm), while the woodland exhibited the deepest soils (mean depth = 105.83 cm).

Influence of land-use

Vegetation structure

The vegetation structure (cover and height) differed significantly for all layers (herb, shrub, and tree layer) between the communal area and the protected area (Table 1). The mean cover of the tree and shrub layer was significantly higher in the protected area. In contrast, the mean cover of the herb layer was significantly higher in the communal area. The mean height of all three layers was significantly higher in the protected area than in the communal area.

Table 1 Mean cover and height of the herb, shrub, and tree layer (± standard errors) of the communal (CA) and protected area (PA).

	Communal area	Protected area	t-value	d.f.	p-value
Mean cover (%)					
Tree layer	12.12 ± 1.52	22.13 ± 1.91	4.154	388	0.002
Shrub layer	9.84 ± 0.78	17.59 ± 1.13	5.811	388	0.000
Herb layer	72.03 ± 1.13	61.36 ± 2.22	-4.490	388	0.000
Mean height (m)					
Tree layer	3.24 ± 0.26	6.41 ± 0.33	7.675	388	0.000
Shrub layer	2.03 ± 0.11	3.27 ± 0.12	7.878	388	0.000
Herb layer	0.95 ± 0.03	1.55 ± 0.08	7.621	388	0.000

Life forms

The mean cover of therophytes per plot differed significantly between the two areas ($t = 11.16$, d.f. = 380.95, $p < 0.001$). It was considerably higher in the plots of the communal area (79.6% ± 2.31) than in the protected area (42.3% ± 2.42). The mean cover of hemicryptophytes differed also significantly between the two areas ($W = 10572$, $p < 0.001$). It was lower in the communal area (9.5% ± 1.19) than in the protected area (23.1% ± 2.07).

Species richness and evenness

486 plant species were recorded in the protected area and 376 plant species in the communal area. In general, the mean plant species richness (alpha diversity) was significantly higher in the protected area compared to the communal area (Table 2). Specifically, the species richness of the herb layer was significantly higher in the protected

than in the communal area. In contrast, no significant difference was found for the woody layer between the two areas.

Table 2 Mean species richness (± standard errors) of plots located in the communal (CA) and protected area (PA) separated by herb layer, woody layer, and both layers together.

	Communal area	Protected area	t-value	d.f.	p-value
Herb layer	20.83 ± 0.49	26.71 ± 0.72	6.913	388	0.000
Woody layer	9.21 ± 0.43	10.09 ± 0.45	1.424	388	0.155
Total	30.04 ± 0.70	36.80 ± 0.98	5.737	388	0.000

More differentiated results were found when doing the comparisons separately for the five vegetation types. Species richness and evenness of the five vegetation types differed between the protected area and the communal area. The woody layer of the woodland and of the wetland contained significantly more species in the communal area than in the protected area (Fig. 3a). In all vegetation types outside the protected area a more even distribution of species in the woody layer was detected (Fig. 3b). An opposite trend was observed for the herb layer. The herb layer of the forest and the upland had significantly more species in the protected area than in the communal area (Fig. 3c). Woodland and wetland had a more even distribution of species in the herb layer inside the protected area (Fig. 3d).

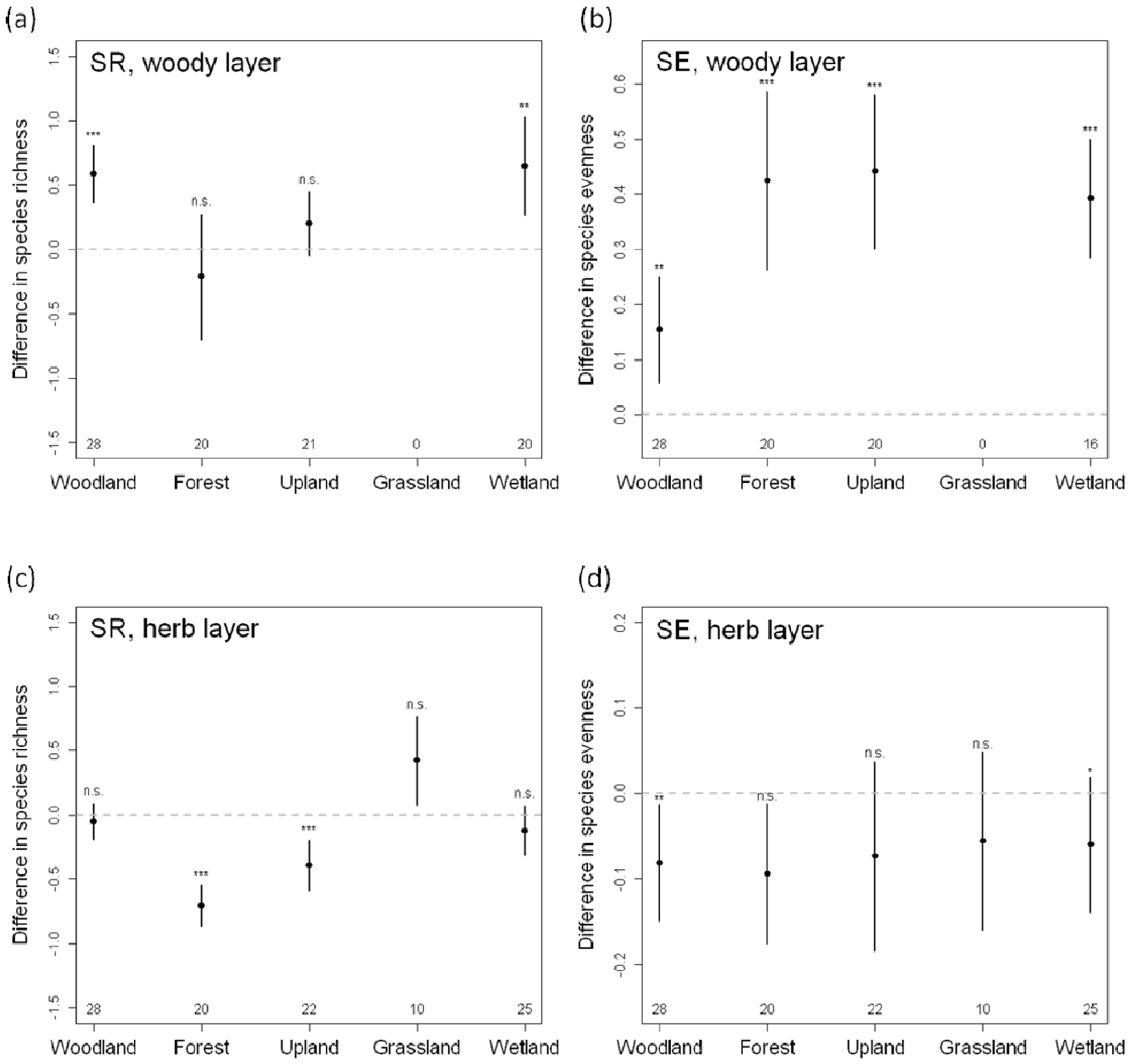

Fig. 3a-d Comparison of species richness (SR) and evenness (SE) of the woody layer (a, b) and the herb layer (c, d) of the different vegetation types of the communal (CA) and protected area (PA). Number of the nearest plot pairs for each vegetation type in the bottom of the graph.

Highly valued tree species

In total, 43 of the 53 tree species cited by Koadima (2008) were found in our plots. The percentages of occurrences of all these 43 highly valued tree species in the plots of the communal and protected area are shown in Table 3.

Table 3 Percentage of occurrence of highly valued tree species in the plots located in the communal (CA) and protected area (PA). Those which did not occur in the plots of the communal area are in bold type.

	Communal area	Protected area
Adansonia digitata	2.83	7.87
Afzelia africana	11.32	11.24
Annona senegalensis	27.36	23.60
Anogeissus leiocarpa	34.43	33.15
Balanites aegyptiaca	14.62	19.66
Bombax costatum	15.57	30.34
Boscia angustifolia	0.47	2.25
Boscia senegalensis	**0.00**	**2.81**
Boswellia dalzielii	**0.00**	**0.56**
Bridelia ferruginea	5.19	7.30
Burkea africana	17.45	35.39
Cadaba farinosa	**0.00**	**3.93**
Cassia sieberiana	5.19	5.62
Detarium microcarpum	36.79	28.65
Diospyros mespiliformis	7.55	7.87
Entada africana	10.38	5.06
Gardenia erubescens	16.04	17.98
Hymenocardia acida	0.47	4.49
Khaya senegalensis	0.47	7.30
Lannea acida	24.53	43.26
Lannea microcarpa	6.60	7.87
Mitragyna inermis	3.30	8.43
Parinari curatellifolia	**0.00**	**2.81**
Parkia biglobosa	4.72	2.81
Pavetta crassipes	**0.00**	**6.18**
Piliostigma reticulatum	18.40	6.74
Piliostigma thonningii	48.11	35.96
Prosopis africana	19.81	24.72
Pseudocedrela kotschyi	**0.00**	**1.69**
Pteleopsis suberosa	15.57	28.65
Pterocarpus erinaceus	0.47	34.83
Sarcocephalus latifolius	0.94	1.12
Sclerocarya birrea	4.25	7.30
Securidaca longepedunculata	3.77	7.30
Sterculia setigera	18.87	16.29
Tamarindus indica	5.66	5.06
Terminalia avicennioides	17.92	21.35
Terminalia macroptera	11.32	4.49
Trichilia emetica	**0.00**	**3.37**
Vitellaria paradoxa	46.70	35.39
Vitex madiensis	2.36	6.18
Xeroderris stuhlmannii	7.55	20.79
Ximenia americana	13.68	9.55

Seven highly valued tree species were completely absent in the plots of the communal area, but were found in the plots of the protected area. Four of them (*Boswellia dalzielii, Parinari curatellifolia, Pavetta crassipes* and *Trichilia emetica*) occurred only in the plots of the woodland. Two species (*Boscia senegalensis, Cadaba farinosa*) were found only in the plots of the forest and one species (*Pseudocedrela kotschyi*) occured in the plots of both the wetland and the forest. Eight species (*Bombax costatum*, *Burkea africana, Hymenocardia acida*, *Khaya senegalensis, Lannea acida, Prosopis africana, Pterocarpus erinaceus,* and *Xeroderris stuhlmannii*) showed a lower abundance in the communal than in the protected area.

Discussion

Occurrence of vegetation types

For the occurrence of the vegetation types in the study area, elevation and the physical properties of the soil sub-surface horizon (percentage of sand and coarse fractions) related to soil moisture played an important role. The soil organic carbon content was not an important environmental factor for the differentiation of the vegetation types. Similarly, Hahn (1996) and Orthmann (2005) found that the physical properties of the soil play a more important role for the occurrence of the vegetation types in West African savannas than the soil nutrient content. Among all parameters of topography (aspect, curvature, elevation, hillshade, and slope), only elevation was found to be an important environmental factor explaining vegetation differentiation. Local hills may affect small scale water run-off rates leading to differences in water availability.

All five vegetation types identified in this study area have been also described for other parts of the West African Sudanian zone (Hahn-Hadjali, 1998; Wittig et al., 2000; Mahamane, 2005; Mbayngone, 2008; Ouédraogo, 2009).

Vegetation type specific influence of land-use on diversity

The influence of land-use on diversity was vegetation type specific. A clear trend was only found for the evenness of the woody layer of all vegetation types (except for the grassland that had no woody layer). In fact, results reveal a more balanced and homogeneous distribution of woody species in the communal area compared to the protected area. The lower evenness of the woody layer in all vegetation types in the protected area indicates that woody species differ widely in abundance. The homogenous distribution of woody species in the communal area may be explained by agricultural impact. In fact, shrub species which are mostly adapted to the alternating cycles of cultivation and fallows (like *Combretum collinum*, *C. glutinosum*, *Gymnosporia senegalensis*, *Piliostigma reticulatum,* and *P. thonningii*) and the highly used tree species which are protected during the cycle (e.g. *Parkia biglobosa*, *Sterculia setigera,* and *Vitellaria paradoxa*) are the dominant woody species of the communal area. Shrubs are well adapted to this agricultural cycle because they can deal with man-made disturbances (e.g. by resprout from stems, fast growth) (Hahn, 1996; Lykke, 1998; Wezel and Boecker, 1998).

The impact of land-use on diversity was most pronounced in the woodland and the wetland. Higher evenness indicates that only few species dominate the herb layer of these vegetation types in the protected area. Indeed, these types are dominated by a dense grass layer in the protected area, composed mainly of tall grasses as *Hyparrhenia involucrata* and the perennial species *Andropogon gayanus, A. schirensis, A. tectorum,* and *Sorghastrum bipennatum* that leave little space for small species (Hahn-Hadjali et al., 2006). In contrast, the herb layer of these two vegetation types was more heterogeneous in the communal area. This is explained by the fact that most grasses in these vegetation types are favored fodder species and therefore, grazing impact is high (Krohmer, 2004). Grazing opens the grass layer of these vegetation types and provides many different microhabitats for annual, pioneer, and forb species (Hahn-Hadjali et al., 2006; Banda et al., 2006). The woody layer of the woodland and that of the wetland were richer in terms of tree species in the communal than in the protected area. This indicates that recruitment of several woody species might be naturally disturbed in the protected area. Low recruitment may be due to the dense grass layer which may have a depressing effect on the survival of woody seedlings by leaving little space and light for recruitment underneath (Hahn-Hadjali et al., 2006; Bond, 2008). In addition, the frequency of burning in the protected areas seems to be a great disadvantage for seedling establishment and seed supply of some woody species. Frequent burning (annually) may be favorable for fire resistant woody species by limiting seedling regeneration of other woody species which are unable to reproduce vegetatively (Hoffmann, 1998; Setterfield, 2002).

For the forest and the upland, there was a different influence of land-use compared to the two vegetation types described above. While the species richness of the woody layer was unaffected, the herb layer was influenced by land-use. The lower species richness in the herb layer of the communal area indicates a higher sensitivity to land-use in comparison to the woodland and the wetland. The upland and the forest are dominated by *Tephrosia pedicellata* and *Achyranthes aspera* in the communal area, which are a disturbance indicator (degradation and over-grazing) (Hahn, 1996; Krohmer, 2004). Given that both vegetation types are rarely used for cultivation due to the unfavorable soil conditions, other human activities, i.e. livestock grazing, should influence the herb species richness. The grassland was the only vegetation type of which the diversity was not influenced by land-use. This might be explained by the fact that this vegetation type is not suitable for cultivation due to its poor soils (lateritic crust). Hence, this vegetation type is not used for agriculture in the communal area and is therefore not involved in the agricultural cycle of cultivation and fallows (Hahn, 1996). In addition, this vegetation type is dominated by the grass *Loudetia togoensis*, which is unfavorable as fodder when full-grown (Krohmer, 2004).

We conclude that the diversity of the woody and herb layer are by trend contrarily influenced by land-use. While the diversity of the woody layer is increased by human disturbances, the diversity of the herb layer is diminished. The different responses of the vegetation types to land-use are mainly due to the different degrees of anthropogenic disturbances to habitat characteristics. Rocky upland habitats are generally less targeted by human activities due to their inaccessibility and therefore, vegetation types of these areas are less influenced by humans than those of equivalent lowland areas (Anderson and Hoffman, 2007). In concordance, in our study area human impact was lowest on rocky habitats with poor soils (shallow soils with a lateritic crust). The impact was highest on the vegetation types with the most favorable soil conditions for cultivation (deep soils with high clay content in the soil sub-surface horizon) and intermediate on those with medium soil conditions (intermediate deep soils with intermediate clay content in the soil sub-surface horizon).

Influence of land-use on vegetation structure and life form

The reduced woody cover in the communal area is a result of human disturbances, such as clearing for agriculture and pole harvesting. The lower herb cover recorded in the protected area compared to those in the communal area is quite likely a result of the higher woody cover in the protected area. A negative relation between woody cover and herb biomass has been described for the West African Sudanian zone as a result of the competition of woody and herb species for resources (e.g. light, nutrients, and soil water) (Scholes and Archer, 1997). Woody cover of about 20-25% strongly reduces the herb biomass production (Orthmann, 2005). Indeed, the woody cover of the communal area was only ca. 20%, while it was twice as high in the protected area (about 40%).

Furthermore, the increase of therophytes (e.g. *Zornia glochidiata, Microchloa indica*) and decrease of hemicryptophytes (e.g. *Andropogon gayanus, A. tectorum*) in the communal area indicate that human disturbances, i.e. livestock grazing and agriculture, lead to a shift from perennial to annual vegetation in the communal area. This is in concordance with previous studies (Olsvig-Wittaker et al., 1993; Shackleton, 2000; Sawadogo et al., 2005; Hahn-Hadjali et al., 2006). The increase of therophytes in the communal area might be explained by the opening of the vegetation through chopping of trees in croplands and extensive livestock grazing in fallows. Therophytes are well adapted to open areas as they survive the unfavorable season in the form of seeds and complete their life-cycle during favorable seasons. In addition, seeds of the majority of therophytes are easily and widely dispersed by cattle (via endo- and exo-zoochorous dispersal). The decrease of hemicryptohytes in the communal area might be explained by the fact that they are often favored as livestock fodder in young stages (beginning of the rainy season) and that constant grazing weakens palatable perennial grasses.

Influence of land-use on the occurrence of highly valued tree species

Ten of the 53 tree species estimated by Koadima (2008) as highly valued were not found in our plots. The reason is that most of them are planted (e.g. *Cussonia arborea*) and these plantation sites (essentially in the villages near the house) were not sampled in our study. All seven species absent in the plots of the communal area are used for medicinal purposes and three species are also used for food (e.g. *Cadaba farinosa*, *Parinari curatellifolia* and *Pavetta crassipes*) and one species for house construction (*Pseudocedrela kotschyi*). The importance of these species for local people was proved by earlier studies (Kristensen and Baslev, 2003; Taita, 2003; Belem et al., 2007), that documented the use of all parts (roots, leaves, barks, wood, etc.) of these species in human daily life. The total absence of these highly used species may be a result of the over-exploitation and the ongoing habitat reduction in the communal area. This suggestion is consistent with findings from Koadima (2008). In this study, most interviewed people stated that *Boscia senegalensis*, *Boswellia dalzielii,* and *Pseudocedrela kotschyi* are absent in the communal area due to human pressure. Another reason for the absence of the seven tree species and also for the lower abundance of other highly used tree species (e.g. *Bombax costatum*, *Burkea africana, Hymenocardia acida*, *Khaya senegalensis, Lannea acida, Prosopis africana, Pterocarpus erinaceus,* and *Xeroderris stuhlmannii*) in the communal area is the fact that farmers control tree species' densities and presence, depending on their preferences and individual species use needs (Gouwakinnou et al., 2009). The preservation of useful plant species on cultivated lands was obvious for woody species with edible fruits but less tangible for timber and service wood (Devineau et al., 2009). While some tree species are protected by farmers during the agricultural cycle of cultivation and fallows, others are removed from cropland when farmers chop the vegetation for agriculture. Thus, other highly used woody species, such as *Parkia biglobosa*, *Sterculia setigera,* and *Vitellaria paradoxa* are protected during the agricultural cycle and are therefore more common in the communal area than in the protected area.

Most of the species which were completely absent in the plots of the communal area occurred in the plots of the woodland and the forest in the protected area. This emphasizes that these two vegetation types are especially important for local people in terms of useful woody species.

Conclusion

Our results show that land-use has an effect on vegetation structure, diversity, and the occurrence of life form types and highly valued tree species. However, these effects were not only negative, as the diversity of the woody layer was even increased under human disturbances. All these findings suggest that human land-use does not automatically lead to a loss of species and to a degradation of savanna habitats and that communal areas are not necessarily characterized by lower biodiversity. These findings are in concordance with other studies from West Africa (Hahn-Hadjali et al., 2006; Paré et al., 2009b) and Southern Africa (Dahlberg, 2000; Shackleton, 2000). Paré et al. (2009b) even demonstrated that tree diversity was higher in communal areas than in protected areas in Burkina Faso. Furthermore, our results agree with findings from Banda et al. (2006), who pointed out that communal areas may be of great importance for conservation of a broad spectrum of biodiversity. In fact, communal areas are characterized by a high heterogeneity, which is the ultimate source of biodiversity (Pickett et al., 2003). Thus, the maintenance of traditional land-use practices resulting in a mosaic-like distribution of various land units is the key to the maintenance of biodiversity in communal areas (Augusseau et al., 2006). However, this counts only when there is enough land for shifting cultivation with long fallow periods. Today with increasing cash-crop cultivation and high demand for land, communal areas are at high risk of degradation and of biodiversity loss. Furthermore, there is a need for more studies that assess the “value” of the biodiversity in the communal area. Despite the importance of communal areas in savanna regions, protected areas play a crucial role in the conservation of rare and highly used species and in protection of “natural” ecological processes (e.g. nutrient and water cycle) by reducing the land-use impact. Furthermore, protected areas are important in protecting vegetation and biodiversity on habitats that are frequently used for agriculture in communal areas. These suggestions are in concordance with Devineau et al. (2009), who stated that maintaining conservation areas in land-use planning is crucial in order to preserve biodiversity.

We conclude that both protected areas as well as communal areas are of great importance for the conservation of savanna vegetation and biodiversity. Overall, our study demonstrates the complexity of the human land-use impact and contributes to the improved understanding of the land-use impact on savanna vegetation and diversity.

Implications for management and conservation

Land-use and climatic changes may more strongly affect savanna vegetation and diversity patterns in future. Therefore, adapted management and conservation strategies in the communal as well as in the protected area are required to ensure the availability of natural resources for local people and to protect ecosystems and biodiversity in the long term. Management must be based on a solid scientific foundation and should be able to adapt to changing conditions (Berkes and Folke, 1998). Our results provide insights on what kind of management activities may be most appropriate. The fact that the influence of land-use on diversity was vegetation type specific highlights the importance of vegetation type specific management recommendations and supports the approach of heterogeneity management proposed by Rogers (2003). This means that different habitats need different management strategies.

Both the wetland and the woodland represent the most endangered vegetation types in the study area as they are frequently used for agriculture due to their favorable soil conditions. On the hydromorphic soils of lowlands (wetland), rice is cultivated, while cotton and cereals are intensively cultivated in the mid-sandy soils of the mid-slopes (woodland). In addition, the grazing impact is high on these two vegetation types because most occurring grasses are favored fodder. Furthermore, most of the highly valued tree species that were completely absent in the communal area occurred in the woodland of the protected area. Thus, these two vegetation types need special attention in management activities. Grazing should be limited in some parts of these vegetation types in the communal area. Furthermore, the intensity of cultivation should be limited and the fallow phase should be extended in some areas to allow vegetation to recover. In addition, fire regime should be adapted for these vegetation types in some areas of the protected area in order to guarantee sufficient recruitment of woody species. Hereby, different fire regimes (different fire frequency, intensity, and seasonality) should be applied and evaluated by monitoring.

The forest and the upland are less endangered because they were less influenced by land-use. However, species richness of the herb layer has decreased in these vegetation types in the communal area due to the grazing impact. Thus, grazing activities should be also reduced in some areas of these vegetation types in the communal areas.

Besides these vegetation type specific management activities, highest priority in management strategies should be given to the highly used tree species, such as *Bombax costatum*, *Burkea africana, Hymenocardia acida*, *Khaya senegalensis, Lannea acida, Prosopis africana, Pterocarpus erinaceus,* and *Xeroderris stuhlmannii*, which are found with lower abundance in the communal area. In addition, appropriate management strategies of the absent highly valued tree species in the communal area should be developed and high priority in restoration programs should be given to them.

All management recommendations given above, based on scientific findings, should be further discussed with all stakeholders (local people, policy makers, managers, and technicians) for jointly developing feasible ways for “putting” them into practice. Hereby, learning from traditional ecological knowledge and management systems of local people will help to produce culturally and ecologically rational conservation and management strategies (Holling et al., 1998). A comprehension of local people gives management strategies a better chance for success as people follow more likely regulations influenced by themselves than those forced on societies from outside (Lykke, 2000; Rogers, 2003).

Long-term studies on permanent plots in the communal area and in the protected area are required to investigate vegetation and diversity changes and to evaluate the conservation success and the effectiveness of management strategies being applied (see e.g. Jürgens et al., 2011). Additionally, more studies investigating the impact of land-use on population structures and dynamics of woody species are highly required. Such studies (e.g. Schumann et al., 2010; Nacoulma et al., 2011) will give evidence of the recruitment and regeneration of woody species in relation to human land-use.

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Appendix

Appendix 1 Synoptic table of 390 plots based on indicator species analysis. Indicator species were arranged by decreasing value of the observed indicator value. Only the indicator species with an indicator value ≥ 20 and $p < 0.05$ are listed.

Vegetation type	woodland	forest	upland	grassland	wetland
Number of relevé plots	100	69	96	48	77
Species richness	375	378	312	268	329
Number of indicator species	92	77	32	58	55
	Stratum	Indicator Value	p-value	Mean cover (%)	
Indicator species of the woodland					
Andropogon gayanus	HL	42.8	0.0002	9.58	
Hyparrhenia involucrata	HL	42.1	0.0002	19.53	
Strychnos spinosa	HL	42.0	0.0002	0.57	
Strychnos spinosa	WL	42.0	0.0002	1.39	
Combretum molle	HL	36.4	0.0002	1.38	
Grewia cissoides	HL	34.2	0.0002	0.89	
Burkea africana	WL	34.0	0.0002	6.22	
Crossopteryx febrifuga	WL	32.0	0.0002	2.47	
Combretum molle	WL	31.8	0.0002	4.33	
Stereospermum kunthianum	HL	31.5	0.0002	0.50	
Vitellaria paradoxa	WL	30.4	0.0002	7.63	
Cochlospermum tinctorium	HL	28.7	0.0002	1.15	
Tephrosia bracteolata	HL	28.3	0.0002	0.52	
Indigofera dendroides	HL	28.2	0.0002	0.41	
Isoberlinia doka	WL	27.5	0.0002	8.02	
Tinnea barteri	HL	27.4	0.0002	0.19	
Lepidagathis anobrya	HL	26.8	0.0002	0.32	
Andropogon chinensis	HL	26.3	0.0002	1.54	
Terminalia avicennioides	HL	25.7	0.0002	0.47	
Vitellaria paradoxa	HL	25.5	0.0002	0.38	
Burkea africana	HL	25.0	0.0002	0.53	
Xeroderris stuhlmannii	WL	24.9	0.0002	0.54	
Afzelia africana	WL	23.1	0.0002	5.29	
Pteleopsis suberosa	HL	22.3	0.0002	0.76	
Crossopteryx febrifuga	HL	21.3	0.0002	0.36	
Cissus cornifolia	HL	21.2	0.0002	0.35	
Combretum glutinosum	WL	21.0	0.0002	1.42	
Melanthera elliptica	HL	20.7	0.0002	2.53	
Lepidagathis collina	HL	20.5	0.0002	0.14	
Cyphostemma flavicans	HL	20.0	0.0002	0.18	
Indicator species of the forest					
Wissadula rostata	HL	37.5	0.0002	6.55	
Anogeissus leiocarpus	WL	34.2	0.0002	13.99	
Achyranthes aspera	HL	28.5	0.0002	1.25	
Feretia apodanthera	WL	28.0	0.0002	3.59	
Cissus quadrangularis	HL	26.1	0.0002	3.34	

Asparagus africanus	HL	25.7	0.0002	0.25
Pennisetum pedicellatum	HL	24.9	0.0002	1.17
Antherotoma naudinii	HL	24.5	0.0002	0.91
Combretum aculeatum	HL	20.4	0.0002	1.20
Indicator species of the upland				
Brachiaria villosa	HL	36.5	0.0002	1.04
Combretum nigricans	WL	35.9	0.0002	9.19
Tephrosia pedicellata	HL	27.8	0.0002	4.40
Spermacoce stachydea	HL	26.9	0.0002	2.97
Microchloa indica	HL	26.0	0.0002	7.14
Acacia macrostachya	WL	24.9	0.0002	3.02
Sporobolus festivus	HL	23.5	0.0002	1.19
Chamaecrista mimosoides	HL	23.4	0.0016	1.66
Combretum collinum	WL	23.4	0.0002	3.55
Hackelochloa granularis	HL	23.4	0.0002	0.63
Detarium microcarpum	WL	23.1	0.0002	6.35
Tripogon minimus	HL	22.7	0.0002	2.12
Pandiaka angustifolia	HL	22.6	0.0004	0.76
Pennisetum polystatichion	HL	20.3	0.0018	3.02
Indicator species of the grassland				
Loudetia togoensis	HL	39.5	0.0002	23.57
Digitaria horizontalis	HL	37.3	0.0002	12.17
Zornia glochidiata	HL	36.4	0.0002	2.53
Dactyloctenium aegyptium	HL	31.8	0.0002	0.71
Setaria pumila	HL	27.7	0.0002	5.15
Waltheria indica	HL	26.4	0.0002	1.26
Chloris pilosa	HL	23.5	0.0002	0.70
Leucas martinicensis	HL	23.3	0.0002	0.72
Striga hermontheca	HL	21.9	0.0002	0.28
Indicator species of the wetland				
Scleria sphaerocarpa	HL	43.5	0.0002	4.25
Sorghastrum bipennatum	HL	41.7	0.0002	15.31
Spermacoce filifolia	HL	37.4	0.0002	2.90
Terminalia macroptera	WL	32.3	0.0002	7.16
Combretum adenogonium	WL	31.4	0.0002	4.34
Cyperus haspan	HL	29.7	0.0002	0.79
Hyptis spicigera	HL	28.9	0.0002	0.88
Bacopa floribunda	HL	26.3	0.0002	0.33
Ludwigia erecta	HL	26.1	0.0002	0.70
Lipocarpha chinensis	HL	25.8	0.0002	0.51
Terminalia macroptera	HL	24.8	0.0002	0.66
Panicum fluviicola	HL	24.7	0.0002	1.40
Hydrolea macrosepala	HL	23.4	0.0002	0.21
Cyperus reduncus	HL	22.5	0.0002	0.51
Melochia corchorifolia	HL	22.5	0.0002	1.09
Combretum adenogonium	HL	21.1	0.0002	0.88
Aristida kerstingii	HL	20.8	0.0002	4.11
Kyllinga pumila	HL	20.6	0.0002	0.45

Appendix 2 Correlation of the first and second axis with environmental factors, those with r > 0.450 are in bold type.

	1.axis				2.axis			
	t- value	d.f.	p-value	r	t- value	d.f.	p-value	r
Aspect	0.449	388	0.653	0.023	-0.101	388	0.920	-0.005
Clay (%), HB	-0.585	44	0.561	-0.088	0.685	44	0.497	0.103
Clay (%), HA	0.051	44	0.960	0.008	0.659	44	0.513	0.099
Coarse fraction (%), HA	0.434	44	0.666	0.065	**-4.783**	**44**	**0.000**	**-0.585**
Coarse fraction (%), HB	-1.374	44	0.176	-0.203	-0.759	44	0.452	-0.114
Curvature	-2.295	388	0.022	-0.116	-0.230	388	0.818	0.000
Depth (cm), HA	0.021	44	0.983	0.003	-0.753	44	0.455	-0.113
Depth (cm), HB	-0.448	44	0.657	-0.067	0.348	44	0.729	0.052
Distance to next village	-7.153	388	0.000	-0.341	2.692	388	0.007	0.135
Elevation	**-10.136**	**388**	**0.000**	**-0.458**	-8.095	388	0.000	- 0.380
Hillshade	0.452	388	0.652	0.023	0.848	388	0.397	0.043
Land-use	5.694	388	0.000	0.278	-7.105	388	0.000	-0.339
Granularity (%), HA	2.590	44	0.013	0.364	0.178	44	0.859	0.027
Granularity (%), HB	0.414	44	0.681	0.062	0.423	44	0.674	0.064
Organic carbon (%), HA	2.374	44	0.022	0.337	-1.775	44	0.083	-0.259
Organic carbon (%), HB	-1.336	44	0.188	-0.197	-1.328	44	0.191	-0.196
pH water, HA	-2.833	44	0.007	-0.393	1.309	44	0.197	0.194
pH water, HB	**-3.484**	**44**	**0.001**	**-0.465**	0.900	44	0.373	0.134
Sand (%), HA	-1.344	44	0.186	-0.199	-2.511	44	0.016	-0.354
Sand (%), HB	**-4.295**	**44**	**0.000**	**-0.544**	-1.004	44	0.321	-0.150
Silt (%), HA	1.221	44	0.229	0.181	1.813	44	0.077	0.264
Silt (%), HB	-2.142	44	0.038	-0.307	1.149	44	0.257	0.171
Slope	-3.389	388	0.001	-0.170	-1.062	388	0.289	-0.054
Soil depth (cm)	-0.761	44	0.451	-0.114	2.056	44	0.046	0.296
SolRad	-2.128	388	0.034	-0.107	-2.45	388	0.015	-0.123
SWI	1.991	388	0.047	0.101	0.699	388	0.485	0.035

HA = surface horizon, HB = sub-surface horizon.

Chapter 3

Impact of Land-Use Type and Bark- and Leaf-Harvesting on Population Structure and Fruit Production of the Baobab Tree (*Adansonia digitata*) in a Semi-Arid Savanna, West Africa

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Abstract

Non-timber forest products (NTFPs) strongly contribute to livelihood security in the semi-arid tropics. There is increasing concern about the population status of NTFP-providing trees and therefore a need for their sustainable use. This study examines the impact of land-use type on the multipurpose baobab tree (*Adansonia digitata* L.) in Burkina Faso, combined with rates and patterns of bark- and leaf-harvesting, and their impact on fruit production. We compared stands in a protected area (W National Park of Burkina Faso) with those of surrounding communal area (fallows, croplands, and villages) to obtain an indication on the status of the baobab population, to assess its harvesting tolerance, and to estimate to what extent their actual use is sustainable. Our results reveal that land-use type has an impact on the population structure of the baobab. The size class distribution curve of park stands was inverse J-shape which indicates good rejuvenation, while the curve of fallows, croplands, and villages stands was bell-shaped, indicating a lack of recruitment. However, a high number of seedlings were recorded in villages. Nearly all baobabs were pruned and debarked in villages, croplands, and fallows while half of the individuals were harvested in the park. Most of the trees were pruned and debarked moderately. Debarking and pruning were slightly size specific. Pruning in interaction with tree-size had a significant impact on fruit production. In contrast, debarking had no effect on fruit production. We conclude that despite the land-use impact and the intense harvesting, baobabs are still well preserved in the communal area due to their longevity, extremely low adult mortality rates, and traditional management practices. However, land-use intensifications may lead to increasing pressure on baobab populations in the future. Therefore, adapted management strategies are needed to guarantee the persistence of this important species and to avoid a shortage of baobab products.

Introduction

Non-timber forest products (NTFPs) have traditionally been used by rural communities in the semi-arid tropics for subsistence and trade (Sinha and Brault, 2005). They are particularly important for livelihood security in cash-poor households by ensuring food security, maintaining the nutritional balance in peoples' diets, meeting medicinal needs, and as a source of income (FAO, 1995; Shackleton et al., 2002; Marshall and Newton, 2003; Emanuel et al., 2005). One major factor determining the populations of NTFPs-providing species is human activities, such as agriculture, livestock grazing, and NTFPs-harvesting (Lykke, 1998). In recent years, there has been concern that populations of NTFP-providing trees are declining due to land-use intensification and over-harvesting and that there is an urgent need for their sustainable use (e.g. Obiri et al., 2002; Djossa et al., 2008). Many authors (Peters, 1994; Ticktin, 2004; Gaoue and Ticktin, 2007) propose that to assess the impact of land-use type on the population status of NTFP-providing trees and to estimate their tolerance to harvesting, knowledge on the population structure (density and size class distribution), combined with rates and patterns of harvesting and their impact on survival, growth and fruit production are required. Tolerance to harvesting varies according to life history, the part of plant that is harvested, in context of environmental conditions over space and time, and by human management practices (Ticktin, 2004). However, according to Condit et al. (1998) and Feeley et al. (2007), the use of population structure as a tool to investigate the demographic health of harvested populations should be interpreted with caution, as other parameters, such as habitat, soil type, and species characteristics (e.g. growth, mortality) affect the population and static information on size class distribution is not necessarily a good predictor for future population trends. In the absence of long-term studies, investigations on population structures, which can be easily achieved from single surveys of size class distributions, are the only way to obtain urgently needed data in a more rapid way (Hall and Bawa, 1993; Lykke, 1998; Cunningham, 2001; Obiri et al., 2002).

One of the most important NTFP-providing trees in West Africa is the multipurpose tree, *Adansonia digitata* L., commonly known as the baobab tree. Baobabs are pruned for their leaves, which are widely used to make sauces. Usually the leaves are dried, powdered, and used for cooking during the dry season. The mealy fruit pulp (monkey bread) is used in cool and hot drinks. The seeds are eaten fresh, dried, or ground and are used in cooking (Sidibé and Williams, 2002; Wickens and Lowe, 2008). The fibre from the inner bark is particularly strong and durable and is commonly used to make ropes, cordages and other items. In addition, baobab leaves and fruits have medicinal properties (Burkill, 1985-2000). Baobabs have the potential to provide additional income to farmers, especially women, and were reported to be one of the tree species with the most valuable food NTFPs by quantity in markets in Burkina Faso (Lamien et al., 1996) and Mali (Gustad et al., 2004). NTFPs of baobab are harvested from different land-use types, e.g. villages, croplands and fallows and to some extent even in protected areas (Dhillion and Gustad, 2004). Leaves are pruned for daily consumption from May to September with a sickle mounted on a long stick or with a regular sickle. Bark can be harvested at any time of the year, usually with a small hoe with a sharp edge (Dhillion and Gustad, 2004).

There are only few studies that have assessed the impact of land-use type (Dhillion and Gustad, 2004; Venter and Witkowski, 2010) and harvesting (Dhillion and Gustad, 2004) on baobab populations. There is virtually no information about the tolerance of baobabs to harvesting and the impact of it on fruit production. In addition, no studies have assessed the impact of harvesting their different parts of the tree and if the response to harvesting varies with tree size and/or with land-use types with different disturbances such as fire, logging, or grazing.

We assess the impact of land-use type and harvesting of bark and leaves on *A. digitata* individuals in south-eastern Burkina Faso in order (i) to obtain an indication on the status of the baobab population, (ii) to assess its harvesting tolerance, (iii) to estimate to what extent their actual use is sustainable, and (iv) which additional management strategies may foster conservation. Specifically, by comparing baobab stands of a National Park with stands in communal land, i.e. fallows, croplands, and villages, we ask the following questions:

(i) Does land-use type affect the population structure (density and size class distribution) of *A. digitata*?

(ii) What are the rates and patterns of bark- and leaf-harvesting of *A. digitata* in different land-use types and size classes?

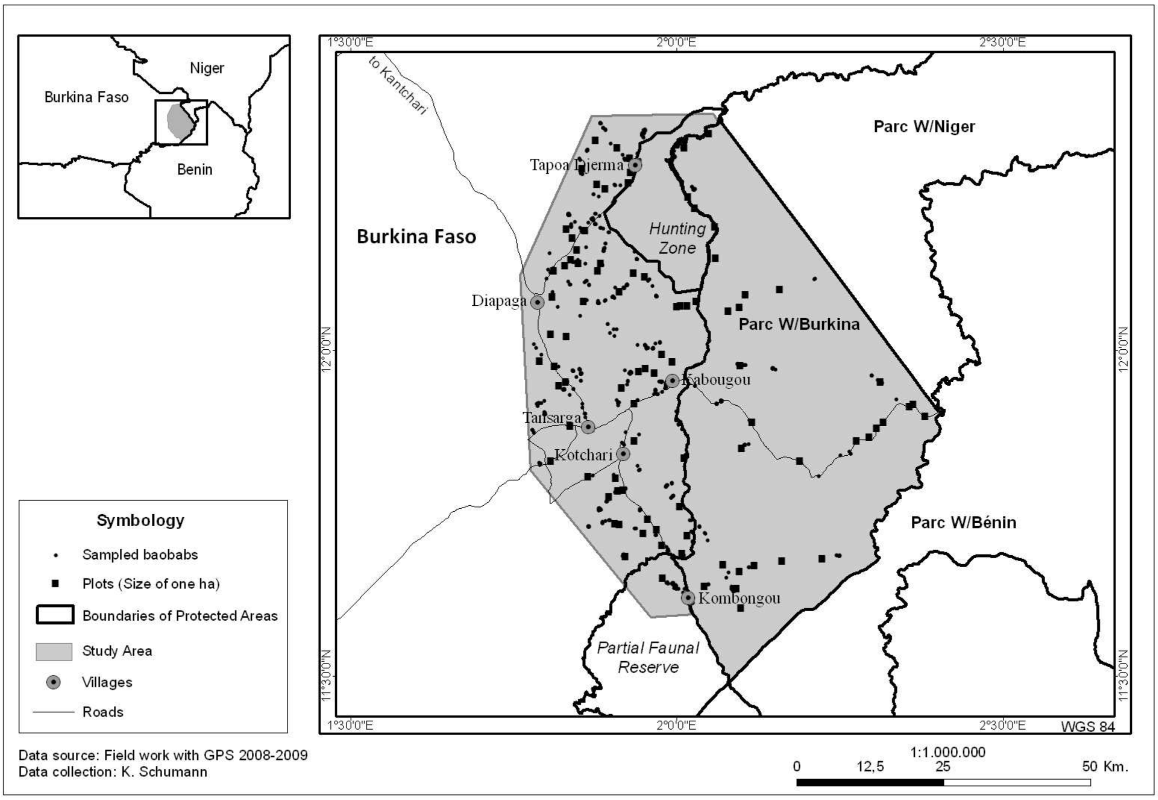
(iii) Do land-use type and bark- and leaf-harvesting affect fruit production of *A. digitata*?

Methods

Study area and species

The study area is located in a semi-arid area in West Africa, Burkina Faso (11°30'-12°22' N and 1°46'-2°23' E) and comprises fallows, croplands, villages, and the western part of the W National Park (Fig. 1). The W National Park is a trans-boundary (Benin, Burkina Faso, and Niger) biosphere reserve of UNESCO-MAB (Man and the Biosphere Programme, November 2002). The study area belongs to the North Sudanian vegetation zone (average rainfall of 750-1000 mm) and is characterised by the presence of a rainy (May-October) and a dry season (November-April). Vegetation of the region is characterised by shrub, tree, and woodland savannas. The dominant ethnic group in the surrounding area of the W National Park in Burkina Faso is the Gulimanceba, who live mainly from agriculture (cotton, maize, millet, and sorghum). The farming system consists of alternating cycles of cultivation and fallows. Highly valued trees, such as the baobab, are preserved when land is cleared for agricultural production. Grazing activities by cattle, sheep, and goat herds are extensive. Animal husbandry is traditionally the domain of the Fulani.

A. digitata belongs to the Malvaceae family (subfamily Bombacoideae) and is known to be extremely long-lived. Age estimates vary between 1000 and 2000 years (Wickens, 1982). It is a large, deciduous tree that can reach 23 m in height. The trunk is abruptly bottle-shaped or short and thick, up to 10 m in diameter (Wickens, 1982). Many animals (monkeys, elephants, birds) and humans disperse the seeds (Wickens and Lowe, 2008). Germination rate of baobab is generally low due to physical dormancy of the seeds (Muthane et al., 1980; Baskin and Baskin, 2001). Typically, *A. digitata* is scattered relatively irregular and patchily in the savanna, and is often associated with human settlements. It usually grows at low altitudes (450-700 m), at mean annual rainfall of 150-1500 mm (Wickens, 1982). *A. digitata* occurs on well-drained soils, from clay to sand and is often spared when land is cleared for cultivation (Wickens and Lowe, 2008).



Data source: Field work with GPS 2008-2009
Data collection: K. Schumann

Fig. 1 Map of the study area, with the position of sampled baobab individuals and plots (size of one-hectare) (UTM zone 31 North, WGS 84).

Data collection

Data were collected in four different land-use types: park, fallows, croplands, and villages. These land-use types differ in the kind and level of human pressure. The park was assumed to be without or with only slight human disturbances, i.e. NTFPs-harvesting. Fallows, croplands, and villages are all disturbed by human, i.e. NTFPs-harvesting, livestock browsing, preservation of highly valued tree species and agriculture, but they differ in the extent of human disturbance. Villages are most disturbed due to various human activities. Croplands are second most disturbed and fallows are intermediate between villages and croplands, as regeneration of savanna vegetation takes place.

To assess the impact of land-use type, to quantify harvesting rates and patterns, and to estimate the impact of land-use type and bark- and leaf-harvesting on fruit production, we considered 837 baobab individuals > 1 cm diameter at breast height (dbh) in the entire study area (Fig. 1). All baobab individuals were randomly selected and were equally distributed in all land-use types (park = 256, fallow = 176, cropland = 200, and village = 205). We measured the following variables on each individual: dbh, tree height, percentage of crown pruned and percentage of trunk debarked by humans and/or elephants. Dbh was measured using a forest tape and tree height using a clinometer. The following pruning categories were used: no-pruning (0% of crown pruned), low-pruning (1-25% of crown pruned), medium-pruning (25-50% of crown pruned), and heavy-pruning (>50% of crown pruned). Percentage of trunk debarked was estimated using the scale of Cunningham (2001): 0% of trunk debarked, 1-10% of trunk debarked, 10-25% of trunk debarked, 25-50% of trunk debarked, 50-75% of trunk debarked. It was possible to distinguish between elephant and human bark damage, because elephants strip the bark from the trunk with their tusks, while humans strip the bark without damaging the trunk.

Fruit production was estimated by counting the number of fruits per tree. The number of fruits was counted for a representative subset of trees, i.e. for 316 individuals, with approximately equal numbers of trees counted for the different land-use types and different harvesting intensities.

One-hectare plots were installed to assess the impact of land-use types on the absolute density of baobabs. A total of 120 one-hectare plots were selected in a stratified random way (30 plots per land-use type, i.e. park, fallow, cropland, and village, Fig. 1). In each plot, the number of seedlings (dbh 0-1 cm), sub-adults (dbh 1-150 cm), and adults (dbh > 150 cm) was counted.

We sampled baobab individuals from May to July 2008 and 2009. This period coincided with the start of the rainy season, when leaves start to develop. Two years of field work were required to assess a sufficient number of individuals. The number of sampled baobab individuals was equal for the two years (418 individuals in 2008 and 419 individuals in 2009). The one-hectare plots were sampled during the rainy season in the year 2009. Fruit production was estimated before the start of the fruit-harvesting period, from November to December 2008.

Data analysis

All tests were conducted at individual level and the implications considered at population level. We assumed that all studied baobab individuals belong to one population because gene flow is possible between all individuals, due to the fact that baobabs are under the constant influence of human activities in the study area, i.e. farmers and traders enable gene flow between geographically distant populations by facilitating village-to-village transport of fruits (Assogbadjo et al., 2006).

We used dbh as a measure of tree size of *A. digitata*, because dbh was highly correlated with height (spearman's rho = 0.805, $p < 0.001$). Each sampled baobab was assigned to one of the nine 50 cm wide dbh size classes, ranging from 1–50 cm to 401-450 cm. Size class distribution was calculated for each land-use type. Fischer's exact test was used to test if dbh size class distribution differed between land-use types. Absolute density of seedlings (dbh 0-1 cm), sub-adults (dbh 1-150 cm), and adult trees (dbh > 150 cm) was calculated for each land-use type on the basis of the one-hectare plots. The ratio of seedlings (dbh < 1 cm) to sub-adults/adults (dbh > 1 cm) was calculated for each land-use type. Species which are successfully recruiting are expected to have recruitment/adult-ratios of > 1, while ratios of < 1 would indicate species with low recruitment (West et al., 2000; Mwavu and Witkowski, 2009). A general linear model (GLM) was performed to test the impact of land-use type, distance to the nearest road and village on the absolute density of seedlings, sub-adults and adults, and the ratio of seedlings to sub-adults/adults. Distance to the nearest road and village were used as covariates to adjust for the effect of location of the sampled baobab individual within the study site and land-use types were used as a fixed factor.

Proportion of trees pruned and debarked was calculated for the different land-use types. The extent of the different pruning and debarking intensities was assessed for the different land-use types and different size classes to examine harvester preferences for particular size classes. Analysis of variance (ANOVA) was used to compare mean pruning and debarking percentage between land-use types and between dbh size classes.

The effect of distance to the nearest road and village, land-use-type, dbh, pruning, and debarking on the number of fruits was tested using a GLM. Debarking, pruning, distance to nearest road, and village were used as covariates while land-use type was used as a fixed factor. Dbh was used as covariate to adjust the effect for tree size. Using GLM allowed testing of the different effects separately and for several combined effects, i.e. 'land-use type*pruning', 'land-use type*debarking' and 'debarking*pruning'. We also tested the effect of the interaction 'pruning*dbh' on fruit production to assess if the response to pruning varied with tree size.

Density of seedlings, sub-adults, and adults, number of fruits per tree, and distance to nearest road and village were log-transformed (log(x+1)) prior to analysis to obtain normally distributed residuals for each response variable.

The statistical package SPSS 16.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analysis. The distance of each sampled tree and the plots to the nearest village and road was calculated using the analysis tool "near" in ArcMap 9.3 (UTM zone 31 North, WGS 84).

Results

Size class distribution and density in different land-use types

Dbh size class distribution was significantly different between land-use types (Fig. 2). An inverse J-shaped curve was observed for baobab stands in the park (Fig. 2a). In total, 65% of the individuals in the park had a dbh between 1 and 150 cm, 32% had a dbh between 151 and 300 cm, and only 3% had a dbh > 301 cm. In contrast, the size class distribution curves of the stands in the three land-use types of the communal area were bell-shaped (Fig. 2b-2d), with 35-40% of the individuals in the dbh class 1-150 cm, 50-60% in the medium dbh classes (151-300 cm), and around 10% in the large size classes (> 301 cm). The stands of the three land-use types in the communal area differed mainly in the smallest dbh class (1-50 cm), where croplands and villages had twice as many individuals (10%) as fallows (5%).

With regard to the density of the baobab tree, we found that the mean density of sub-adults and adult trees (dbh > 1 cm) differed between the land-use units. The same number was found in the park (1.45 ± 0.41 individuals/ha) and villages (1.45 ± 0.28 individuals/ha). They were nearly three time as high in the latter (park and villages) as in croplands (0.58 ± 0.19 individuals/ha) and even four times higher than in fallows (0.35 ± 0.13 individuals/ha). To go into detail, we analysed the density for sub-adult baobab trees (dbh 1-150 cm) and adult baobab trees (dbh > 150 cm) separately. The mean density of sub-adult baobab trees differed significantly between the land-use types (Table 1). Post hoc tests showed that the density of sub-adults was significantly higher in the park (1.03 ± 0.34 individuals/ha) than in croplands (0.26 ± 0.11 individuals/ha) and fallows (0.14 ± 0.18 individuals/ha) but not than in villages (0.74 ± 0.20 individuals/ha)

(Fig. 3). Densities of sub-adults did not differ significantly between croplands and villages. The density of sub-adults was lowest in fallows. The mean density of adult baobab trees differed only slightly between the land-use types (Table 1). Equal numbers were found for the park (0.52 ± 0.15 individuals/ha) and villages (0.52 ± 0.15 individuals/ha) (Fig. 3). They were twice as high in park and villages than in croplands (0.36 ± 0.12 individuals/ha) and four times higher than in fallows (0.19 ± 0.08 individuals/ha). The density of adult trees increased with increasing distance to villages.

The mean density of seedlings (dbh 0-1 cm) differed also significantly between the land-use types (Table 1). Villages had the highest density of seedlings (8.84 ± 5.63 individuals/ha), while densities in the park (0.29 ± 0.21 individuals/ha) and fallows (0.05 ± 0.03 individuals/ha) were significantly lower (Fig. 3). Croplands did not contain any seedlings. Density was also significantly related to the distance to village (Table 1). The mean density of seedlings was highest at distances of 0-0.5 km from villages (7.75 ± 6.03 individuals/ha) and decreased with increasing distance to villages or was zero.

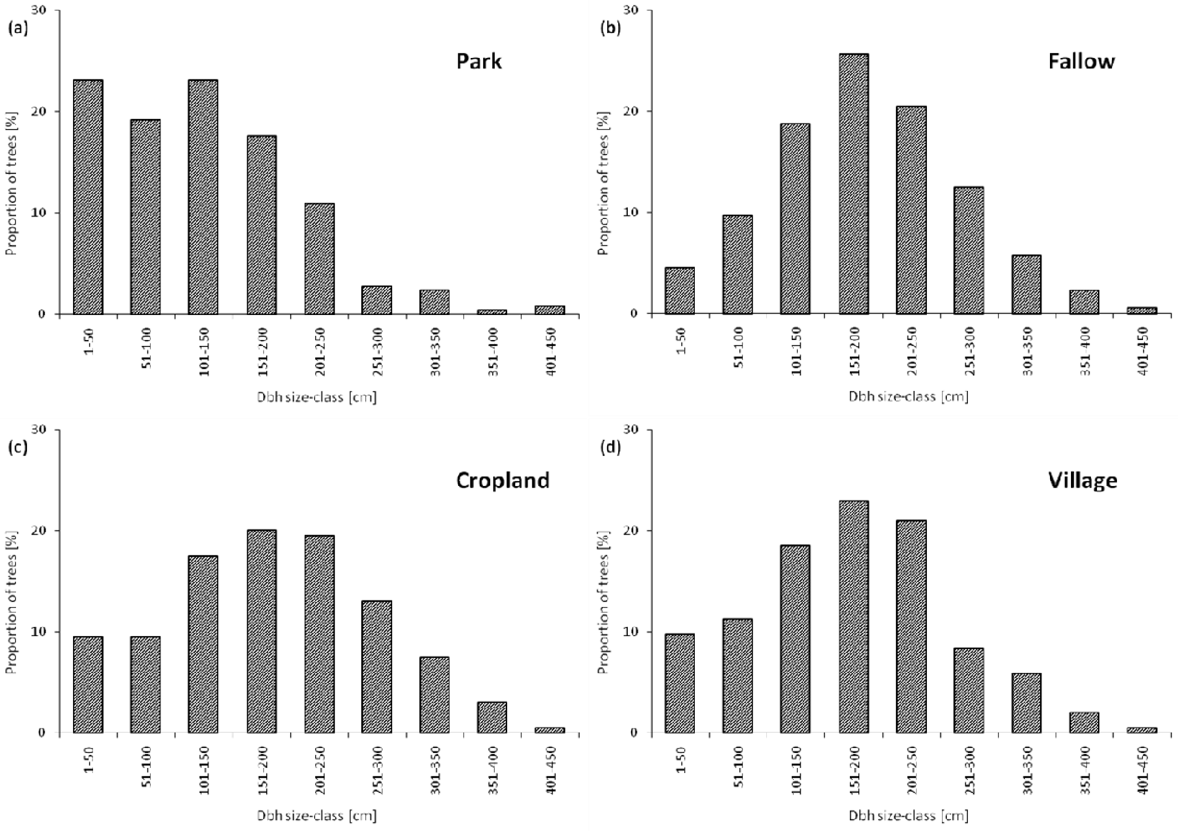


Fig. 2a-d Stem diameter (dbh) class distributions of *A. digitata* in different land-use types ($p < 0.001$, Fisher's exact test).

Table 1 Results of general linear model to test for the effect of land-use type and distance to nearest village and road on the density of seedlings, sub-adults, and adult trees and mean ratio of seedlings to sub-adults, and adults of *A. digitata*.

	Density of seedlings (dbh 0-1 cm)				Density of sub-adults: (dbh 1-150 cm)				Density of adults: (dbh > 150 cm)				Ratio seedlings to sub-adults/adults			
Factor tested	SS	d.f.	MS	F-value	SS	d.f.	MS	F-value	SS	d.f.	MS	F-value	SS	d.f.	MS	F-value
Corrected Model	23.44	5	4.69	15.42 ***	1.58	5	0.32	4.92 ***	0.74	5	0.15	3.69 **	103.23	5	20.65	5.30 ***
Distance to nearest road	0.48	1	0.48	1.58	0.19	1	0.19	2.99	0.12	1	0.12	2.92	11.68	1	11.68	3.00
Distance to nearest village	2.39	1	2.39	7.87 **	0.14	1	0.14	2.24	0.38	1	0.38	9.57 **	4.26	1	4.26	1.09
Land-use type	8.35	3	2.79	9.16 ***	1.27	3	0.42	6.59 ***	0.48	3	0.16	3.97 *	61.05	3	20.35	5.22 ***
Error	34.65	114	0.30		7.31	114	0.06		4.54	114	0.04		233.93	60	3.90	
Total	67.55	120			12.61	120			7.74	120			403.39	66		

Model type II, density of seedlings: $R_2 = 0.403$, density of sub-adults: $R_2 = 0.178$, density of adults: $R_2 = 0.139$, ratio seedlings/sub-adults and adults: $R_2 = 0.306$, covariate: distance to nearest village and road; fixed factor: land-use type, log-transformed: density of seedlings, sub-adults, and adult trees, distance to nearest road and village, SS = sum of squares, MS = mean square.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

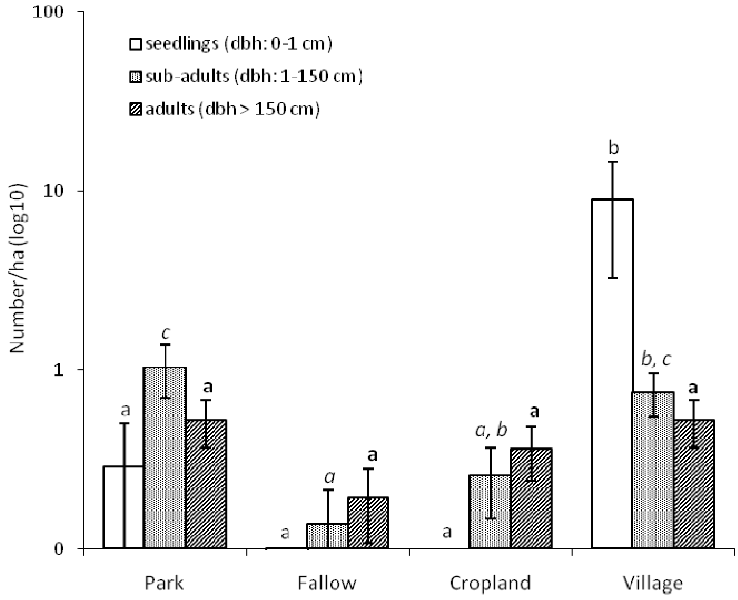


Fig. 3 Mean density (number of individuals/ha, ± S.E.) of seedlings, sub-adults, and adults of *A. digitata* in different land-use types, bars marked with different letters (a, b, and c) are significantly different ($p < 0.05$).

The mean ratio of seedlings (dbh 0-1 cm) to sub-adults/adults (dbh > 1cm) differed significantly (Table 1) between the different land-use types. It was significantly higher in villages than in the park, fallows, and croplands (Fig. 4). The ratio was > 1 in villages, indicating successfully recruiting. In contrast, the ratios of park, fallows, and croplands stands were < 1, which indicates low recruitment.

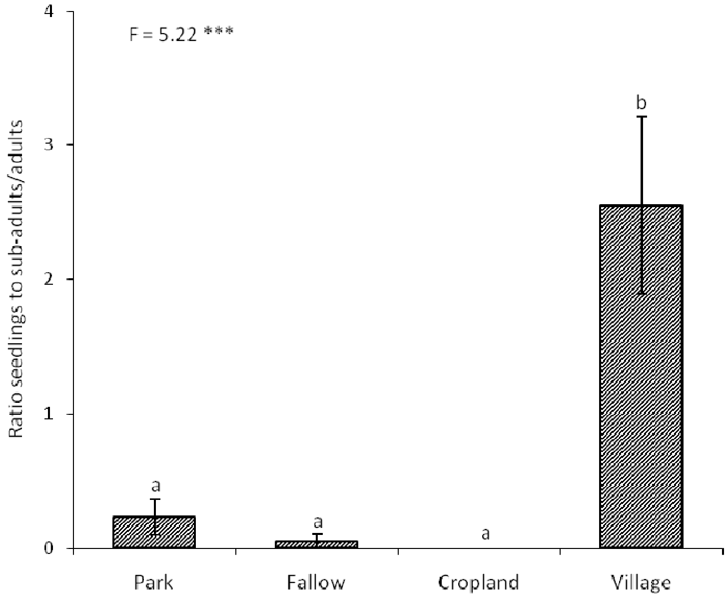


Fig. 4 Mean ratio of seedlings (dbh 0-1 cm) to sub-adults/adults (dbh > 1cm) of *A. digitata* (± S.E.) in different land-use types, bars marked with different letters (a and b) are significantly different ($p < 0.05$).

Harvesting rates and patterns

Nearly all individuals (97-100%) of the sampled baobabs in the communal area (fallows, croplands, villages) were harvested by humans (Table 2). Most of the trees were both pruned and debarked. There was a considerably lower proportion of harvested baobab trees by humans in the park. However, this proportion was still high for a protected area (58%).

Table 2 Percentage of *A. digitata* trees not harvested, pruned, debarked, or both by humans in different land-use types.

	Trees not harvested (%)	Trees pruned only (%)	Trees debarked only (%)	Trees pruned and debarked (%)
Park	41.80 ± 1.77	26.17 ± 2.75	8.59 ± 1.75	23.44 ± 2.65
Fallow	2.27 ± 2.14	2.28 ± 1.12	1.13 ± 0.80	94.32 ± 1.75
Cropland	0.50 ± 0.20	8.00 ± 1.92	0.00 ± 0.00	91.50 ± 1.98
Village	0.00 ± 0.00	6.34 ± 1.70	0.00 ± 0.00	93.66 ± 1.71

Mean ± S.E.

The mean pruning percentage differed significantly between the land-use types ($F = 68.94$, $p < 0.001$). Post hoc tests showed that the mean pruning percentage was significantly lower in the park than in the three land-use types of the communal area (i.e. fallows, croplands, and villages). Within the communal area, the mean pruning differed not significantly between croplands and villages but was significantly higher for the latter than for fallows. In the communal area, 80-90% of the sampled baobab trees displayed low or medium intensity pruning, whereas 40% in the park represented low or medium intensity pruning.

The mean debarking percentage differed also significantly between the land-use types ($F = 135.21$, $p < 0.001$). Post hoc tests showed that the mean debarking percentage was significantly lower in the park than in the three land-use types in the communal area (i.e. fallows, croplands, and villages) but differed not significantly within the three land-use types in the communal area. The majority of the debarked trees of all land-use types were debarked at rates of 1 to 50% of total bark.

Baobab trees were pruned and debarked by humans over all dbh size classes in all land-use types, but the extent of pruning and debarking differed between the size classes (Fig. 5). Pruning differed significantly between size classes (Fig. 5a). Most trees (ca. 60%) of smaller size classes (dbh 1-100 cm) were pruned to a medium or high intensity, but also many trees (ca. 20%) in these size classes were not pruned at all. In contrast, most of the trees (60-100%) of the medium and larger size classes (dbh > 150 cm) were pruned to a low or medium intensity.

Debarking differed significantly between the size classes (Fig. 5b). Debarking was lower in the smallest (25% of trees debarked) and largest (60% of trees debarked) size classes than in all other medium size classes (70-95% of trees debarked). We found for these medium size classes that the proportion of trees debarked increased with increasing dbh. Most of the trees were debarked at rates of 1 to 50% of total bark.

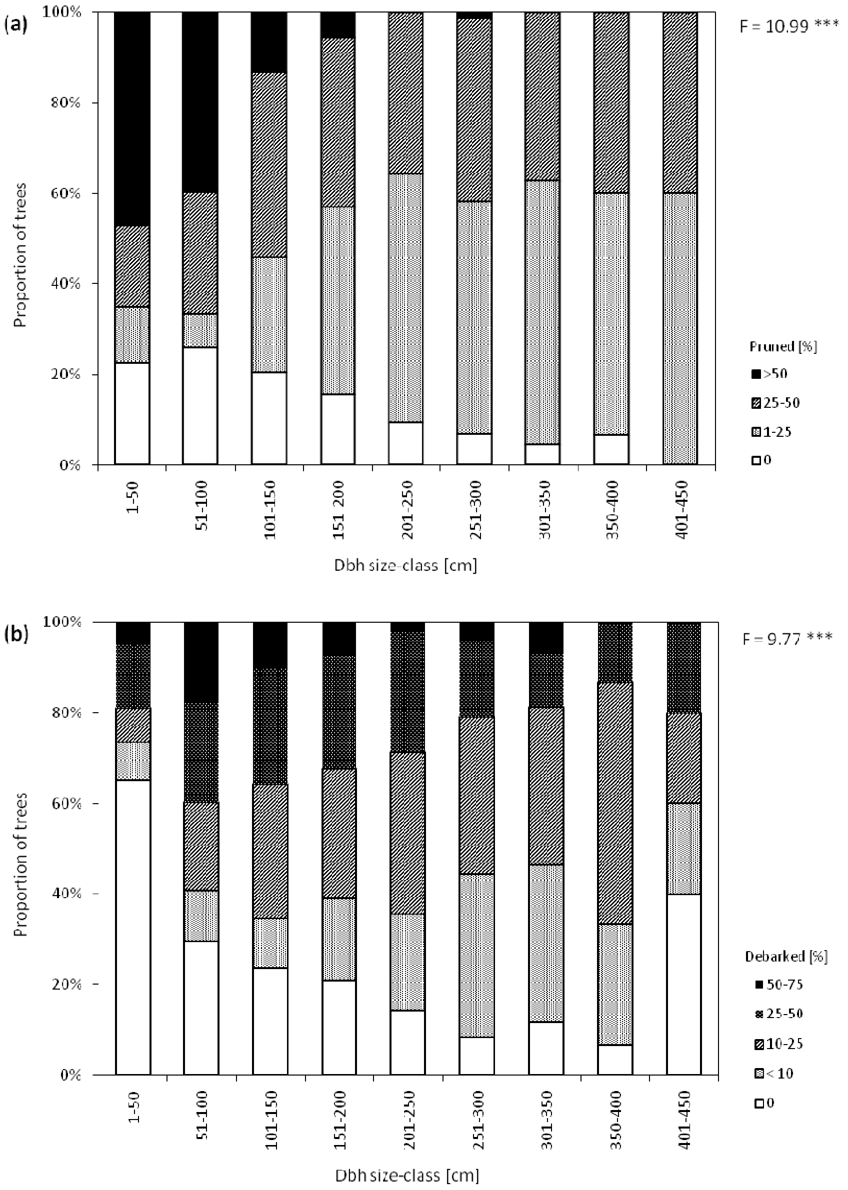


Fig. 5a-b Proportion of *A. digitata* individuals within different stem diameter (dbh) classes according to (a) percentage of crown pruned and (b) percentage of trunk debarked.
***$p < 0.001$.

In addition, 34% of the individuals in the park were debarked by elephants (not presented in Table 2 and Fig. 5b). The proportion of trees debarked by elephants increased with increasing dbh, 20-30% of the small baobabs and 40-100% of the medium to large baobabs. Sampled baobab trees of the communal land were not damaged by elephants. Thus, we did not include debarking by elephants in any further analyses.

Impact of bark- and leaf-harvesting and land-use-type on fruit production

Fruit production was significantly influenced by the dbh, the interaction ‘pruning*dbh’, and the distance to nearest village (Table 3). Debarking had no significant impact on fruit production and there was no significant impact of the interaction between ‘pruning*debarking’, ‘debarking*land-use type’, or ‘pruning *land-use type’. Trees fruited with a minimum dbh of 51 cm. Fruit production increased with increasing dbh and decreased with increasing pruning except for trees without pruning, which had less fruit production than slightly-pruned trees. Heavily-pruned trees produced nearly no fruits. There were significant differences in the impact of pruning on the fruit production between the dbh size classes (Fig. 6, interaction ‘dbh*pruning’ in Table 3). In most of the smaller size classes (dbh < 150 cm), trees without pruning produced almost four times as much fruit (e.g. dbh 100-150 cm = 59.68 fruits ± 32.96) as slightly-pruned trees (dbh 100-150 cm = 15.75 fruits ± 7.64). The opposite is true for most of the trees in the medium and large size classes (dbh > 150 cm), where slightly-pruned trees (e.g. dbh 250-300 cm = 264.39 fruits ± 172.60) bear more than three times as much fruit as trees without pruning (e.g. dbh 250-300 cm = 90.44 fruits ± 126.33). In addition, no- and slightly-pruned trees began fruiting at smaller sizes (minimum fruiting dbh 57 cm and 51 cm respectively) than medium and heavily-pruned trees (minimum fruiting dbh 84 cm and 133 cm respectively). The number of fruits was also significantly related to the distance to village (Table 3). The fruit production increased with increasing distance to village.

Table 3 Results of general linear model to test for the effect of land-use type, distance to nearest road and village, percentage of pruning and debarking, (dbh), and several interactions of these parameters on the number of fruits of *A. digitata.*

	Number of fruits				
Factor tested	SS	d.f.	MS	F-value	
Corrected Model	11.05	16	0.69	32.04	***
Distance to nearest road	0.02	1	0.02	0.72	
Distance to nearest village	0.19	1	0.19	8.65	**
Dbh	2.89	1	2.89	133.99	***
Pruning	0.04	1	0.04	1.68	
Debarking	0.04	1	0.04	2.06	
Land-use type	0.16	3	0.05	2.48	
Debarking*pruning	0.08	1	0.08	3.47	
Land-use type*debarking	0.09	3	0.03	1.32	
Land-use type*pruning	0.06	3	0.02	0.92	
dbh*pruning	0.49	1	0.49	22.55	***
Error	6.45	299	0.02		
Total	37.85	316			

Model type II, $R_2 = 0.632$, covariate: distance to nearest road and village, dbh, pruning, debarking; fixed factor: land-use type, log-transformed: distance to nearest road and village, debarking, and number of fruits, SS = sum of squares, MS = mean square, **p < 0.01, ***p < 0.001.

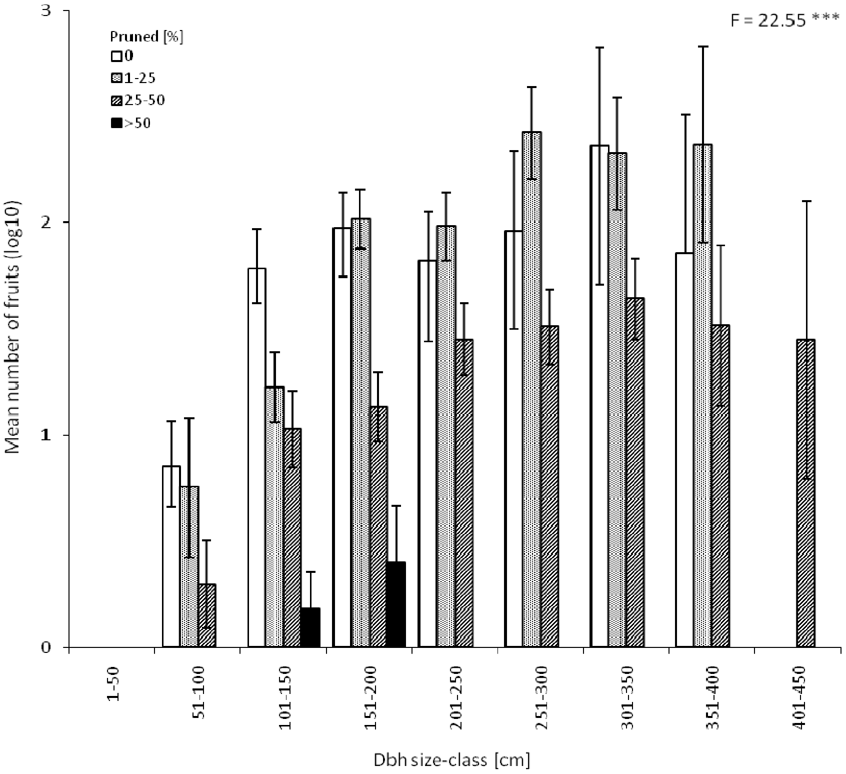


Fig. 6 Relationship between fruit production (± S.E.) of *A. digitata* and percentage of crown pruned in different stem diameter (dbh) classes (interaction 'dbh*pruning' in Table 3).
***p < 0.001.

Discussion

Impact of land-use type on population structure

Our results reveal that land-use type has an impact on the population structure of the baobab. The differences in size class distributions between the park and the three land-use types of the communal area indicate that human activities affect the population structure of baobab stands. This assumption is also supported by the differences of the number of seedlings between the land-use types. Some human activities are beneficial to the baobab, either intentionally (e.g. full-grown baobabs are traditionally left untouched when land is cleared for agricultural production) or unintentionally (e.g. dispersal of seeds in garbage), while others are detrimental (e.g. livestock browsing) (Dhillion and Gustad, 2004). Dispersal of seeds with garbage may explain the high number of seedlings in villages in our study area. The lack of smaller size classes (dbh 1-100 cm) indicates a high mortality of seedlings in villages. This high mortality is mainly due to livestock browsing and trampling and also due to clearing for agriculture around the yards. The low number of seedlings and the low ratio of seedlings to sub-adults/adults in fallows and croplands may be also explained by livestock browsing and trampling, clearing for agriculture, and fire. Farmers cut recruiting baobabs when chopping the vegetation for agriculture while they preserve mainly the mature baobab trees as they are of higher immediate value. The low number of baobabs of the smaller size classes in fallows, croplands, and villages compared to the park may give evidence of an ageing population. In contrast, the inverse J-shaped distribution curve and the high density of sub-adults and adults suggest that the baobab stand is healthy in the park. This suggests that baobabs in the park were not strongly affected by elephants as for example in South Africa (Edkins et al., 2007). However, the relative low ratio of seedlings to adults indicates that recruitment might be disturbed in the park. This may be due to competition from grass species and intensive fires due to high grass biomass. Indeed, wild fire affects seed survival and leads to a negative effect on woody plant density (Zida et al., 2007).

Other studies in West Africa showed also that baobab density and good recruitment is associated with human activities (Dhillion and Gustad, 2004; Assogbadjo et al., 2005; Duvall, 2007). In contrast, Venter and Witkowski (2010) found a more stable baobab population (a better recruitment) in South African fallows than villages. The reason for the difference between West Africa and South Africa may be explained by the higher human population densities and infrequent domestic use of baobab fruit in South Africa (Venter and Witkowski, 2010).

Rates and patterns of bark-and leaf-harvesting

The fact that nearly all baobabs were harvested in villages, croplands, and fallows indicates a high pressure on baobabs in this region - even in the protected area - and suggests that villagers highly appreciate baobab NTFPs. In addition to the human pressure, baobab trees in the park, especially the larger ones, were also considerably damaged by elephants. Most of the trees in all land-use types were harvested to a moderate level. These findings contradicted the results of Dhillion and Gustad (2004) in Mali, who found that pruning practices were more intense in villages and croplands than in fallows. Dhillion and Gustad (2004) attribute this to the greater walking distance to reach the fallow stand. Despite the long walking distance to reach the fallow and park stand, a high proportion of baobabs are harvested in these land-use types. This underlines the high use-pressure on baobab of the region. This assumption is also supported by the fact that harvesting baobab trees in the park means additional expenditure for villagers, as they need to obtain permission for harvesting baobabs in the park.

Most of the trees were subject to both bark- and leaf-harvesting. This emphasizes the role of the baobab as a multipurpose species. Across all size classes, most of the trees were moderately-pruned, with the exception of the smallest size classes. For this class, we found on the one hand the highest proportion of trees without pruning in the park and on the other hand severely-pruned individuals in the communal area. The latter might be due to the facilitated accessibility to the leaves because the trees are smaller and the taste of the leaves. The moderate pruning intensity across all size classes could be explained by the findings of Dhillion and Gustad (2004). Baobab trees with good-tasting leaves based on local preferences were cut regularly to prevent the development of branches and to improve the food-quality of the leaves. Assogbadjo et al. (2008) found that the people of four West African countries used 21 criteria to differentiate baobab individuals and used preferred combinations of traits as a guide for harvesting (e.g. the easier the bark-harvesting, the tastier the pulp and leaves; or the slimier the pulp, the less tasty it is). Debarking was lowest in the smallest and largest size classes than in all other medium size classes.

Overall, our findings on harvesting patterns suggest that pruning and debarking are slightly size specific. This has important implications for the baobab populations because tolerance to harvesting varies with size classes. Larger baobab trees can withstand higher rates of pruning than smaller ones because smaller trees have relatively fewer photosynthetically active parts after pruning than larger ones. Therefore, the fact that the smallest size classes are mostly severe pruned is alarming because they are less tolerant to pruning. In contrast, there is less concern about debarking because it was lowest in the smallest size classes. In addition, the extent of debarking was moderate in all size classes.

Which factors have an impact on fruit production?

The most direct ecological consequence of NTFP-harvesting is alteration of the rates of survival, growth, and fruit production of harvested individuals (Ticktin, 2004). Our study shows that pruning in interaction with dbh had a significant impact on fruit production of the baobab, while debarking had no significant effect. In addition, no- and slightly-pruned trees began fruiting at smaller sizes than medium and heavily-pruned trees. These findings suggest that baobabs are likely resilient to debarking but not fully resilient to pruning and show that the type of plant part harvested affects the potential for species to tolerate harvest. These different effects of debarking and pruning might be explained by the fact that pruning leads to the removal of plant parts that are photosynthetically active or nutrient-rich, which decreases the photosynthetic capacity. In contrast, debarking does not lead to the removal of photosynthetically active plant parts. In addition, the parenchyma cells of the old wood of baobabs are able to form a callus-like tissue that seals off wounds (Fischer, 1981). These results are partially consistent with findings from Dhillion and Gustad (2004) which have shown that pruning of baobab causes reductions in the number of fruits of the baobab. However, we found that the response to pruning varied with tree size. Smaller baobab trees are more vulnerable to pruning due to their generally lower amount of photosynthetically active parts and it seems that fruit production of adult baobab trees benefits from slight-pruning. This benefit may be caused by the reallocation of resources or stored reserves from re-growth to fruit production. Some studies show that NTFP-harvesting negatively affects fruit production (e.g. Rijkers et al., 2006; Gaoue and Ticktin, 2008), whereas others show that harvest may not affect fruit production at all (e.g. Emanuel et al., 2005). This suggests a species-specific response to harvesting because the tolerance of plant species to harvesting depends on many factors, including the harvested plant's life history, parts harvested, environmental conditions, and management practices (Ticktin, 2004).

Furthermore, our results reveal that there were no combined effects of the interaction 'pruning*debarking' on fruit production of the baobab. This suggests that the baobab as a multipurpose species is not at a higher risk to over-harvesting than single-purpose species. However, fruits of baobab are also harvested. Further studies should focus on the combined effects of debarking, pruning, and fruit-harvesting. Furthermore, our results show that neither land-use type nor the interactions 'pruning*land-use type', and 'debarking*land-use type' had a significant impact on fruit production. This suggests that the response to harvesting of the baobab did not vary between land-use types with different kinds and levels of disturbances such as fire, logging, or grazing.

Conclusion and implication for conservation and sustainable management

The results of the impact of land-use type on the population structure and of the harvesting rates and patterns and its impact on fruit production allow us to determine the current status of the baobab populations and to assess their harvesting tolerance.

The inverse J-shaped size class distribution curve of the park indicates that the baobab stands are in a healthy state, while the lower recruitment in the three land-use types of the communal area indicates a decline of the baobab in these land-use types. Current debarking rates and patterns do not strongly affect the population and may actually permit population persistence of the baobab over the long-term. In contrast, the tolerance of the baobab to pruning is much lower, especially in the smaller size classes. Current pruning rates and patterns may therefore lead to changes in the vital rates of individuals (reduced reproductive performances) and may in turn affect the structure and dynamics of the population over the long-term. However, it has to be considered that other parameters, such as habitat, soil type, management activities, and species characteristics (growth, mortality, light tolerance, and life form) affect the population of woody species as well (Condit et al., 1998; Lykke, 1998; Schwartz et al., 2002; Ticktin, 2004; Feeley et al., 2007). In fact, baobabs are highly influenced by management practices. Traditional management practices were developed by people who have been harvesting this species for hundreds of years (Ticktin et al., 2002). The fact that baobab trees are left untouched in croplands especially permits the maintenance of these stands in croplands and fallows and allows their resilience in the agricultural cycle. In addition, longer-lived species - such as the baobab - can sustain population levels with low or episodic recruitment (Condit et al., 1998). This is also supported by the fact that baobab recruitment is often underestimated as young baobabs grow faster than older trees, suggesting that recruitment is not as poor as it appears (Dhillion and Gustad, 2004). Additionally, trees which grow rapidly in small size classes and trees that have a high rate of survival are able to sustain population levels with low or episodic recruitment (Condit et al., 1998).

Therefore, we conclude that despite the land-use type impact and the intense harvesting, baobabs are still well preserved in the communal area due to their longevity, extremely low adult mortality rates (Wickens and Lowe, 2008), and due to traditional management practices. However, current land-use intensifications due to strongly increasing cash-crop cultivation may lead to an increasing pressure on baobab in the future and display a conservation concern over the long-term. Therefore, adopted management strategies are needed to guarantee the persistence of this economically important plant species and to avoid a shortage of baobab products. These conclusions agree with findings of Dhillion and Gustad (2004) for Mali and Venter and Witkowski (2010) for South Africa, who pointed out that baobab populations are not declining but in need of management that secures the maintenance of a genetically diverse population in the long term.

Other studies have shown that the impact of land-use type and harvesting on population of woody species varies according to the characteristics of the species, the part of plant that is harvested, in context of environmental conditions, and by human management practices (e.g. Gaoue and Ticktin, 2007; Djossa et al., 2008; Gaoue and Ticktin, 2009; Gouwakinnou et al., 2009; Fandohan et al., 2010). This emphasizes the importance of region- and species-specific population studies. This is especially true for highly-valued tree species because these studies provide important implications for conservation and sustainable management for over-used tree species. These implications may have little meaning outside the specific conditions in which they were determined (Ticktin, 2004). The observed rates and patterns of harvesting of this study as well as its impact on fruit production provide insights on what kind of management may be most appropriate. Current moderate pruning practices of medium and large trees in the study area seem appropriate and should be maintained, as fruit production is secured and even enhanced by low pruning. By contrast, small trees (dbh 1-150 cm), which were found to be especially vulnerable to pruning (lower fruit production) and which were particularly heavily pruned should be spared from pruning or should only be pruned to a low intensity to maintain fruit production. People living in villages adjacent to the W National Park do not have a tradition of planting and protecting baobab seedlings (personal observation). However, a high number of seedlings occurred in villages. These seedlings could be protected against livestock browsing and trampling and could be transplanted to croplands and fallows.

To summarize, this study provides an assessment of the current population status of a highly used species, its harvesting tolerance, to what extent their actual use is sustainable, and which management strategies may foster conservation. It also illustrates that the impacts of NTFP-harvesting must be assessed in the context of multi-uses and different land-use types with different disturbances such as fire, logging, or grazing. The presented population structure is a static representation of the population at a certain moment in time. However, the population structure provides valuable information, given that it was combined with rates and patterns of harvesting and its impact on fruit production, on the population status, and its tolerance to harvesting. In time of rapid intensification of land-use, there is an urgent need for rapid approaches that can be the basis for strong management decisions (Hall and Bawa, 1993; Cunningham, 2001; Obiri et al., 2002). However, long-term studies from data collected on permanent plots are required to investigate population dynamics.

Acknowledgments

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Chapter 4

Impact of Land-Use Type and Harvesting on Population Structure of a Non-Timber Forest Product-Providing Tree (*Anogeissus leiocapa*) in a Semi-Arid Savanna, West Africa

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Abstract

Non-timber forest products (NTFPs) strongly contribute to livelihood security in the semi-arid tropics. Main factors determining the populations of NTFP-providing species are human activities. This study examined the impact of land-use, combined with rates and patterns of debarking and chopping on a NTFP-providing tree (*Anogeissus leiocarpa*) in Burkina Faso. We compared stands in a protected area (W National Park) with those of its surrounding communal area (fallows, croplands) in order to (i) obtain an indication on the status of the population, (ii) assess its harvesting tolerance, (iii) estimate the sustainability of present management, and (iv) derive which additional management strategies may foster its conservation. Our results reveal that the stands of *A. leiocarpa* are in healthy states in fallows and in the park. In croplands, the absence of saplings gives evidence of a declining population. Nearly all individuals of *A. leiocarpa* were harvested in croplands and fallows, while the number of harvested individuals in the park was negligible. Intensity of debarking and chopping was tree size-specific. The sprouting ability significantly increased with higher chopping intensity. We conclude that despite the land-use impact and the intense harvesting, stands of *A. leiocarpa* are still well preserved due to the species life history (fast growing and high sprouting) and due to indirect positive influences of human activities by providing better environmental conditions for its recruitment. Thus, the population of *A. leiocarpa* is not at risk to over-harvesting and land-use even though it is not protected.

Introduction

Many cash-poor households in the semi-arid tropics strongly depend on non-timber forest products (NTFPs) for livelihood. Besides being a source of income, the harvesting of NTFPs ensures food security and the meeting of medicinal needs (FAO, 1995; Shackleton et al., 2002). Main factors determining the populations of NTFP-providing species are human activities, such as agriculture, fire, livestock grazing, and NTFP-harvesting (Lykke, 1998). In recent years, there has been growing concern that populations of NTFP-providing trees are declining due to land-use intensification and over-harvesting. Therefore, the need for research on their sustainable use is becoming more and more pressing (e.g. Obiri et al., 2002; Ndangalasi et al., 2007; Djossa et al., 2008). Tolerance to harvesting varies according to life history (e.g. growth, mortality), the part of the plant that is harvested, in combination with environmental conditions over space and time, and by human management practices (Ticktin, 2004). Many authors (Peters, 1994; Ticktin, 2004; Gaoue and Ticktin, 2007) propose that to assess the impact of land-use and harvesting on the population status of NTFP-providing trees, knowledge on the population structure, combined with rates and patterns of harvesting is required. However, according to Condit et al. (1998) and Feeley et al. (2007), the use of the population structure as a tool to investigate the viability of harvested populations should be interpreted with caution, as static information on size class distribution are not necessarily a good predictor for future population trends. Nevertheless, in the absence of long-term studies, investigations on population structures are the only way to rapidly obtain urgently needed data (Hall and Bawa, 1993; Lykke, 1998; Cunningham, 2001).

The population status of NTFP-providing trees in land-use areas depends amongst other things on their level of protection. In West Africa, farmers control tree species’ densities and presence, depending on their preferences and individual species use needs (Gouwakinnou et al., 2009). In fact, some NTFP-providing trees, such as the baobab (*Adansonia digitata*) and the shea tree (*Vitellaria paradoxa*), are protected by farmers during the agricultural cycle of cultivation and fallows and are therefore still well preserved (Djossa et al., 2008; Schumann et al., 2010). In contrast, other NTFP-providing trees are not or only partly preserved during the agricultural cycle and may therefore be at higher risk of being over-harvested.

One of the latter is *Anogeissus leiocarpa* (DC.) Guill. & Perr. This important NTFP-providing tree is harvested for multi-purposes. The wood of *A. leiocarpa* is highly appreciated for construction and as firewood (Sobey, 1978; Sacande and Sanogo, 2007) and its barks, fruits, leaves, and roots are used in traditional medicine (Burkill, 1985-2000; Andary et al., 2005; Thiombiano, 2005; Sacande and Sanogo, 2007). Moreover, bark and leaves of *A. leiocarpa* are used for dyeing and tanning (Andary et al., 2005). Presumably due to its very intensive use, *A. leiocarpa* is an endangered woody species in West Africa (Hahn-Hadjali and Thiombiano, 2000; Lykke et al., 2004) and is even listed as 'vulnerable' on Burkina Faso's national biological diversity monograph (Sacande and Sanogo, 2007). However, there are only few studies assessing the impact of land-use (Assogbadjo et al., 2009b; Paré et al., 2009a) and there is virtually no information about effects of harvesting on populations of *A. leiocarpa*. We assumed that the adverse impact of harvesting and land-use on the population of *A. leiocarpa* may be compensated by its life history. In fact, *A. leiocarpa* is rather common and is considered a pioneer species (i.e. high seed production and asexual regeneration) (Sacande and Sanogo, 2007).

We studied the impact of land-use type, combined with rates and patterns of debarking and chopping, on *A. leiocarpa* individuals in south-eastern Burkina Faso in order to (i) obtain an indication on the status of the population, (ii) assess its harvesting tolerance, (iii) estimate the sustainability of present management, and (iv) derive which additional management strategies may foster its conservation. Specifically, by comparing stands of a National Park with those of its surrounding communal area, i.e. fallows and croplands, we sought to answer the following questions:

(i) Does land-use type affect the population structure of *A. leiocarpa*?

(ii) What are the rates and patterns of debarking and chopping of *A. leiocarpa* in different land-use types and size classes?

(iii) How strong is the sprouting ability of *A. leiocarpa* in response to chopping and does this vary with tree size and land-use type?

Methods

Study area and species

The study area was located in a semi-arid area in Burkina Faso, West Africa (11°30’-12°22’ N and 1°46’-2°23’ E) and comprised fallows, croplands, and the western part of the trans-boundary W National Park (Fig. 1). It belongs to the North Sudanian vegetation zone (Guinko, 1984) with an average rainfall of 750-1000 mm and a rainy season from May to October followed by a dry season from November to April. The vegetation is characterized by shrub, tree, and woodland savannas. Human population density is relatively low and the dominant ethnic group is represented by the Gulimanceba, who mainly live from agriculture (cotton, maize, millet, and sorghum). The farming system consists of alternating cycles of cultivation and fallows. Highly valued trees are preserved on croplands. Grazing activities by cattle, sheep, and goat herds are extensive.

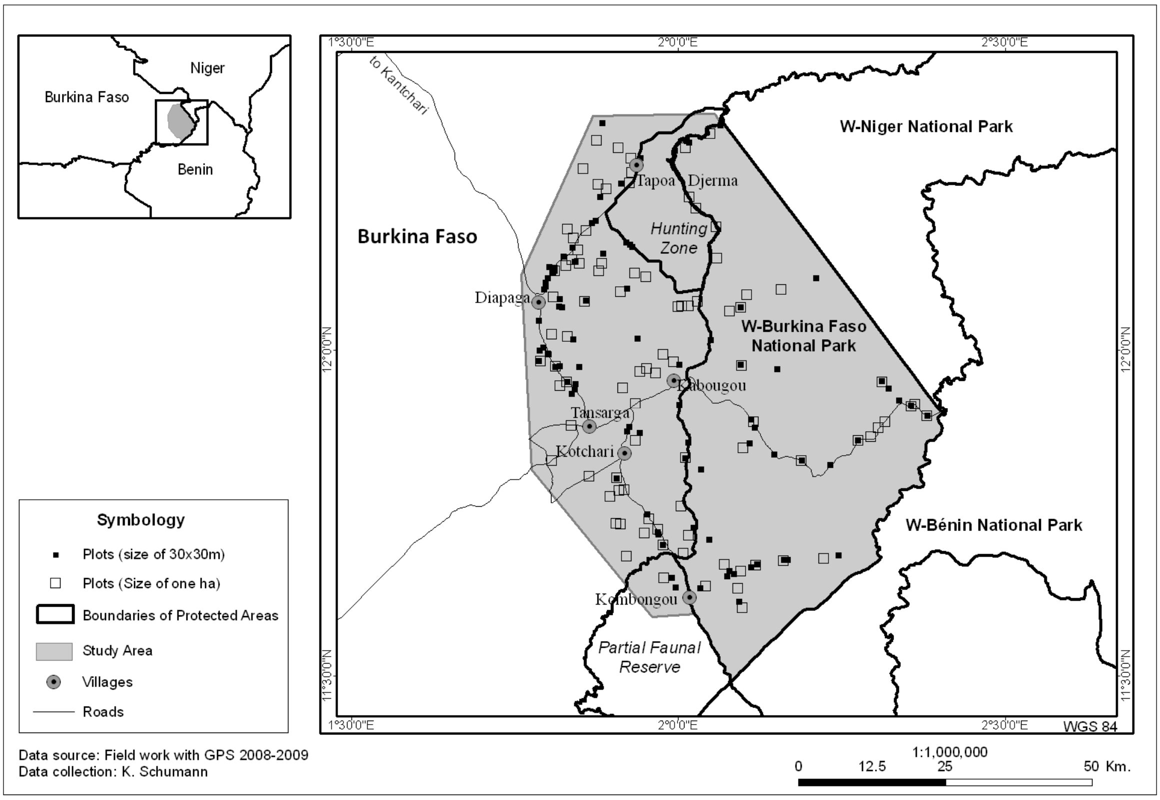

Fig. 1 Study area, with the position of plots (UTM zone 31 North, WGS 84).

A. leiocarpa belongs to the Combretaceae family. The deciduous tree can grow up to a height of 15–18(–30) m (Arbonnier, 2002), has a slightly grooved bole, and an open crown with drooping, pubescent branches. There is no information about its age or size in regard to the first reproduction. However, trees larger than 30 cm in diameter show a significantly higher seed production than smaller tree individuals (Hennenberg et al., 2005). Fruits of *A. leiocarpa* contain about 40 seeds of 10 mg each. Seeds are mainly dispersed by wind (Hovestadt et al., 1999), but also by mammals, e.g. baboons (Kunz and Linsenmair, 2008). A seed bank is absent (Hennenberg et al., 2005). Seedling and stump sprouting are the most important regeneration mechanisms of *A. leiocarpa* (Bognounou et al., 2010b). Germination capacity of seeds is generally low (2-4%) due to a large proportion of infertile ovules (Thiombiano, 2005; Ouédraogo, 2006; Bognounou et al., 2010a). Infertility could be due to a lack of pollination or inbreeding (Sacande and Sanogo, 2007). These adverse factors are compensated by advantageous seed dissemination (winged seeds) and a high fruit production (Thiombiano, 2005; Ouédraogo, 2006).

A. leiocarpa has a wide geographical distribution ranging from the borders of the Sahara down to the humid tropical forests. Depending on the vegetation zone, it can be found in savannas, dry forests, and gallery forests (Couteron and Kokou, 1997; Müller and Wittig, 2002; Thiombiano, 2006). It is typically found at altitudes of 450 to 1900 m and can grow on a range of different soil types (Thiombiano, 2006).

Data collection

Plant performance of *A. leiocarpa* was measured in 89 randomly selected plots (30 m x 30 m) (Fig. 1) in sites that were assigned to three different land-use types (park = 32 plots, fallows = 29 plots, croplands = 28 plots). These land-use types differed in the kind and level of human pressure. Human disturbance was lowest in the park (i.e. NTFP-harvesting of some species, fire) and highest in croplands (i.e. NTFP-harvesting, fire, livestock grazing, preservation of highly valued tree species, and agriculture).

Within each plot, we measured the following variables of all individuals of *A. leiocarpa* with a diameter at breast height (dbh) > 10 cm: Basal diameter (bd), dbh, height, damage by fire (yes or no), percentage of trunk debarked, percentage of branches/trunk chopped, and the number of sprouts (= plantlets arising from stumps or branches in response to disturbances). Percentage of trunk debarked was estimated using the categories (0%, 1-10%, 10-25%, 25-50%, and 50-75% of trunk debarked) of Cunningham (2001). The estimated percentage of branches chopped was grouped into following categories: no-chopping (0%), low to medium branch-chopping (1-50% of branches chopped), strong branch-chopping (> 50% of branches chopped), and trunk-chopping (whole trunk chopped = stump). The number of sprouts per individual was estimated using the following categories: no sprouting (0 sprouts), weak sprouting (1-5 sprouts), medium sprouting (5-10 sprouts), and strong sprouting (> 10 sprouts). Within each plot, one subplot of 5 m x 5 m were installed to measure the dbh and height of individuals < 10 cm dbh. The basal diameter was measured for individuals < 130 cm height.

One-hectare plots (100 m x 100 m) were installed to assess the impact of land-use types on the density of *A. leiocarpa*. A total of 90 one-hectare plots were selected in a stratified random way (30 plots per land-use type, Fig. 1). In each plot, the number of adults (dbh > 5 cm) was recorded. The number of seedlings/saplings (dbh < 5 cm) was counted in one nested plot (10 m x 10 m) within each one-hectare plots.

Plots with a size of 30 m x 30 m were sampled in 2008 and 2009 from May to July at the beginning of the rainy season, when leaves start to develop and seeds germinate. All one-hectare plots were sampled in 2009 from May to July.

Data analysis

Population structure

We used dbh as a measure of tree size of *A. leiocarpa*, because dbh was correlated with height (Pearson, r = 0.608, t = 19.44, d.f. = 643, p < 0.001). Size class distributions (SCD) of *A. leiocarpa* were calculated for each land-use type using the following dbh size classes: 0-1, 1-5, 5-15, 15-25, 25-40, 40-55, > 55 cm. To test whether the land-use type influenced the size class distribution, we used a generalized linear model (GLM) with a gamma error distribution and a log link function. The size class midpoint, the land-use type, and the year were used as independent variables and the mean number of individuals per hectare as the dependent variable. Year was included in the model to consider the effect of year, as *A. leiocarpa* is a pioneer species. GLM was run with a maximum fitted model. The non-significant explanatory variables (including interactions) were removed until a reduced final model was achieved. Thus, year was removed as it had no significant effect. Land-use type was included as factors in the GLM. The factor ‘park’ and ‘fallows’ were joined together, as they did not significantly differ from each other.

Seedlings referred to individuals with a dbh of 0-1 cm, saplings with a dbh of 1-5 cm, and adult trees with a dbh > 5 cm. The ratio of seedlings/saplings (dbh < 5 cm) to adults (dbh > 5 cm) was calculated for each land-use type according to Mwavu and Witkowski (2009).

Density of seedlings/saplings and of adult trees was calculated on the basis of the one-hectare plots. The Kruskal-Wallis-Test was used to test if density differed between the three land-use types.

Harvesting rates and patterns

Proportion of individuals chopped and debarked was calculated for the different land-use types. The proportion of individuals in the different chopping and debarking intensities was computed for the different land-use types. To examine harvester preferences, the proportion of individuals chopped (branches/whole trunk) and debarked was calculated for different size classes. The relationship between bd and dbh was tested with linear regression since only bd was measured for stumps.

Response to chopping by sprouting

A GLM with a poisson error distribution and a log link function was performed to test the impact of chopping, dbh, land-use type, and year on the sprouting ability (mean number of sprouts per individual) of *A. leiocarpa*. The sprouting ability was used as the dependent variable and dbh, chopping, land-use type, and year as independent variables. GLM was run with a maximum fitted model, where all non-significant explanatory variables were removed. Consequently, dbh, land-use type, and year were removed from the GLM.

Statistical analyses were performed using PASW Statistics 18.0.0 (SPSS Inc., Chicago, IL, USA) and R 2.10.1 (R Development Core Team, 2009).

Results

Population structure in different land-use types

Land-use type significantly influenced the SCD of *A. leiocarpa* (Appendix 1, Fig. 2a-c).

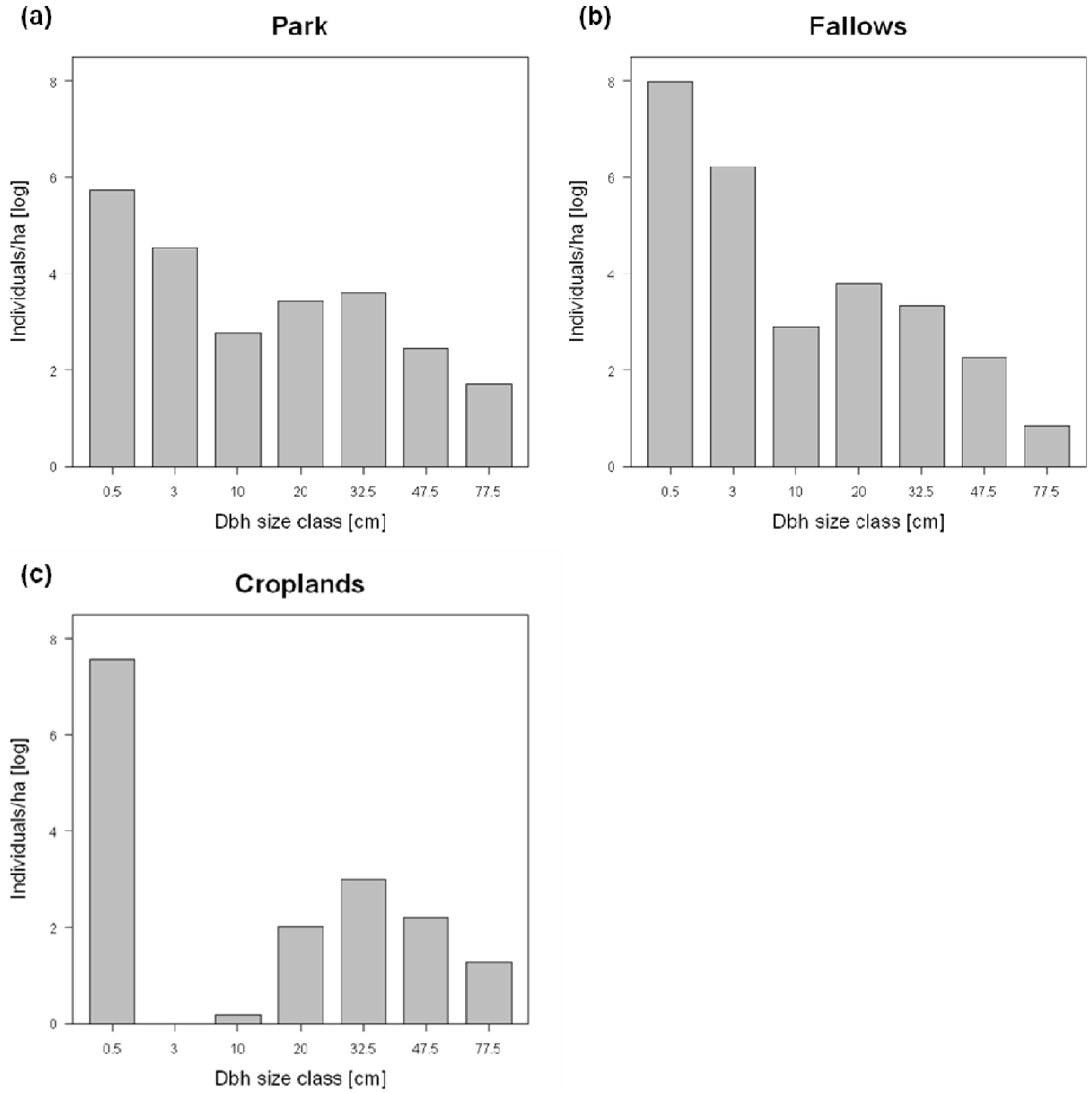

Fig. 2a-c Stem diameter (dbh) class distribution of *A. leiocarpa* in (a) the park, (b) fallows, and (c) croplands.

The SCD curve of croplands was significantly different to those in the park and fallows. In contrast, SCD curves differed not significantly between the park and fallows. A roughly inverse J-shaped curve was observed for the stands in the park (Fig. 2a). The SCD curve of fallow stands was inverse-J shaped (Fig. 2b). There were high numbers of individuals in the lowest diameter classes and a gradual decline – besides the dbh size class 5-15 cm –

down to the largest diameter class. SCD of cropland stands showed almost a bimodal curve (Fig. 2c) due to the high number of seedlings and the lack of saplings and of the dbh size class 5-15 cm.

The mean ratio of seedlings/saplings to adult trees was > 1 for all three land-use types, indicating successful recruiting. However, it was higher in fallows (ratio = 4.68) and croplands (ratio = 5.29) than in the park (ratio = 2.38).

Density of seedlings/saplings (dbh 0-5 cm) significantly differed between the land-use types (H = 20.53, d.f. = 2, $p < 0.001$). The highest number of seedlings/saplings was found in fallows (10.03 ± 2.40 individuals/ha), while the number was lower in croplands (4.57 ± 2.55 individuals/ha) and lowest in the park (1.03 ± 0.43 individuals/ha). The density of adult trees (dbh > 5 cm) differed also significantly between the land-use types (H = 26.74, d.f. = 2, $p < 0.001$). The number of adult trees was considerably higher in fallows (16.10 ± 2.71 individuals/ha) and in the park (11.50 ± 2.31 individuals/ha) than in croplands (1.73 ± 0.63 individuals/ha).

Harvesting rates and patterns

In croplands, almost all sampled individuals of *A. leiocarpa* were harvested (99.4%) (Table 1). Many individuals were both chopped and debarked but most individuals were only chopped. Also in fallows, a high proportion of individuals were harvested (79.1%). Most of them were chopped. The intensity of bark harvesting was considerably lower. In contrast, in the park, only a small proportion of individuals were chopped (4.9%) and none of the individuals were debarked. However, 62.2% of the individuals in the park were damaged by fire, whereas fire damaged only 20.2% in croplands and 4.3% in fallows (not presented in Table 1).

Table 1 Percentage of *A. leiocarpa* individuals not harvested, chopped, debarked, or both in different land-use types.

	Trees not harvested (%)	Trees chopped only (%)	Trees debarked only (%)	Trees chopped and debarked (%)
Park	95.09 ± 1.29	4.91 ± 1.28	0.00 ± 0.00	0.00 ± 0.00
Fallows	20.88 ± 2.46	60.44 ± 2.96	1.83 ± 0.08	16.85 ± 2.27
Croplands	0.59 ± 0.06	68.60 ± 3.55	0.00 ± 0.00	30.81 ± 3.53

Mean ± S.E.

In croplands, 59.9% of all sampled individuals displayed branch-chopping, whereas the whole trunk was chopped in 39.5% of cases. In contrast, in fallows, the trunk was chopped from only 4% of individuals and 73.3% were branch-chopped. All chopped individuals of the park displayed only low branch-chopping intensity. The majority of the debarked individuals in croplands and fallows were debarked at rates of 1 to 25% of total bark.

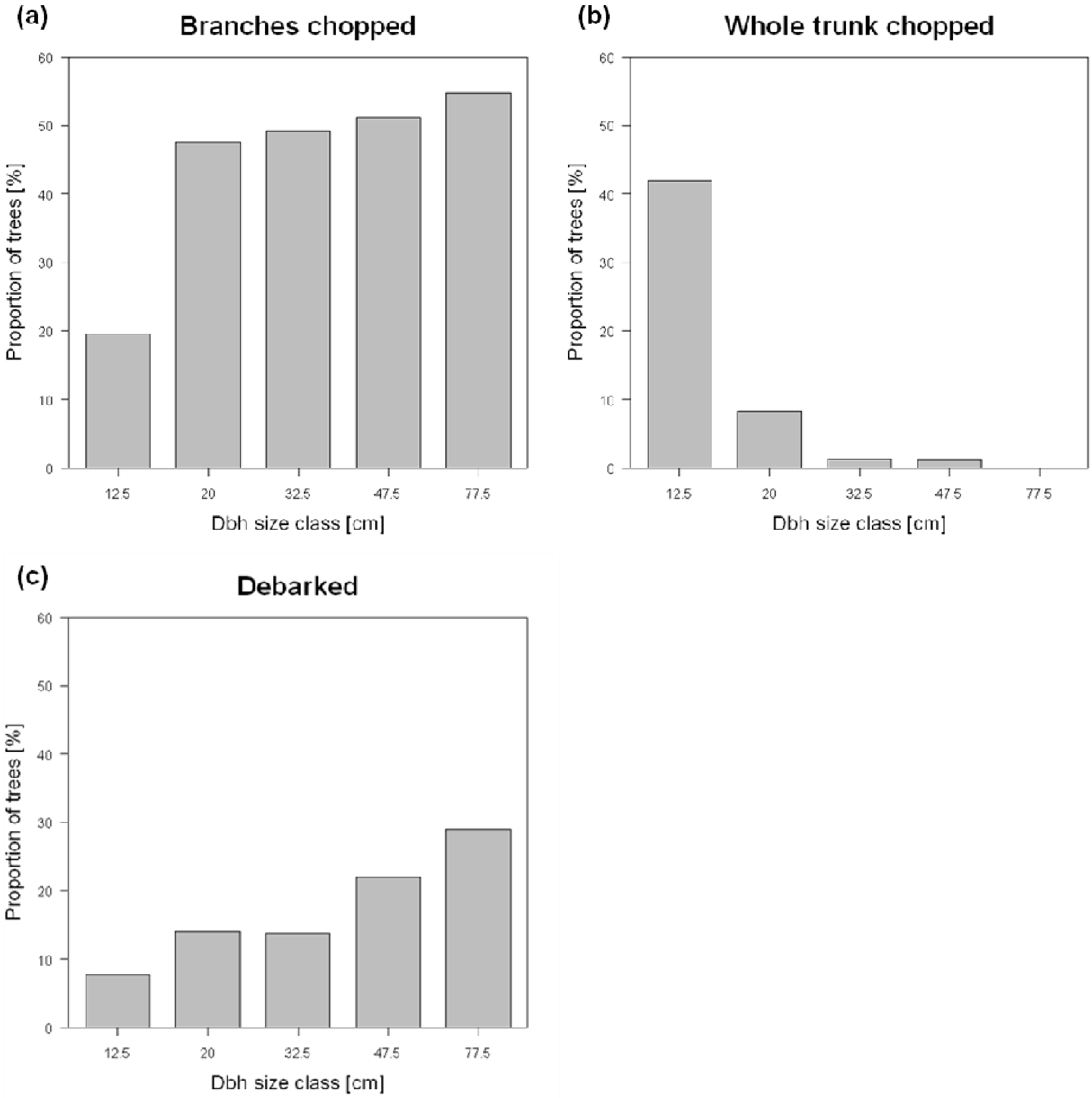

Fig. 3a-c Proportion of *A. leiocarpa* individuals within different stem diameter (dbh) classes according to (a) branches and (b) whole trunk chopped and (c) trunk debarked.

With regard to dbh size classes, chopping of branches (Fig. 3a) and of the whole trunk were clearly tree size-specific (Fig. 3b). While the proportion of branch-chopped individuals increased with increasing size class, the opposite was true for trunk-chopped individuals. Harvester clearly favored trunks of trees with a dbh of 10-15 cm. Similarly, debarking was tree size-specific. The proportion of individuals debarked increased with increasing size class (Fig. 3c).

Response to chopping by sprouting

The sprouting ability differed significantly between the chopping intensities (z-value = 22.24, d.f. = 54, p < 0.001). It increased with higher chopping intensity and was considerably higher for strong branch-chopped and trunk-chopped individuals than for individuals without chopping and low to medium branch-chopped individuals (Fig. 4).

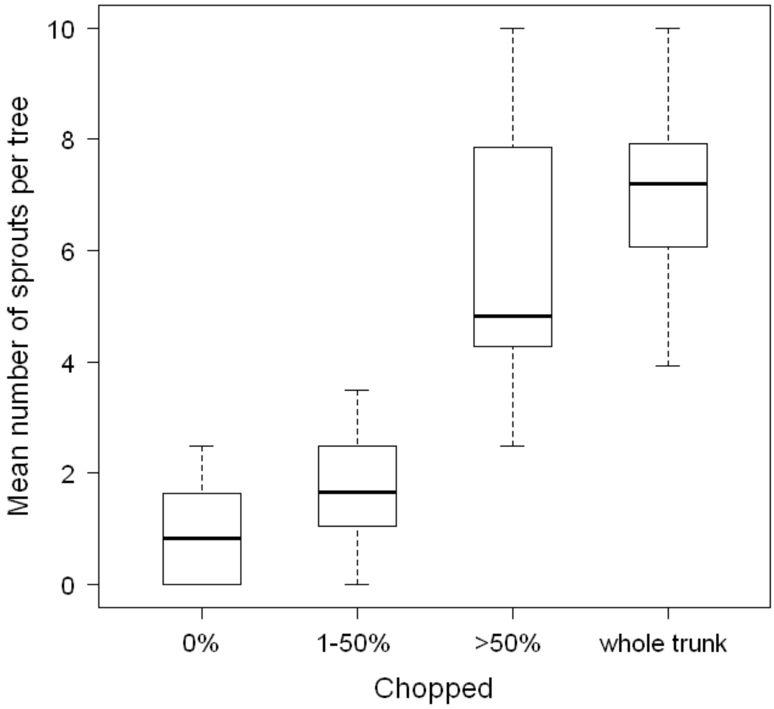

Fig. 4 Mean number of sprouts per *A. leiocarpa* individual according to the different chopping intensities.

Discussion

Impact of land-use type on population structure

In croplands, the strong peak in the seedling size class followed by an absence of saplings indicates a high mortality of *A. leiocarpa* seedlings. This is mainly due to clearing for agriculture. Farmers cut recruiting individuals of *A. leiocarpa* when chopping the vegetation for agriculture, while they only partly preserve adult trees in order to have shade for taking a break and to have facilitated accessibility to NTFPs (Lykke et al., 2004). However, most of the adult trees on croplands were removed. Both stands in the park and in fallows showed healthy recruitment patterns. Nevertheless, stands of fallows displayed a more successful recruitment than stands in the park. This indicates that human activities can have a positive influence on seedlings/saplings of *A. leiocarpa*. This positive human influence can be explained by the fact that chopping of trees in croplands and extensive livestock grazing in fallows lead to an opening of the vegetation (Shackleton, 1993). This opening of the vegetation cover reduces biomass and therefore fire intensity and shade. These two factors are beneficial for the germination and growth of seedlings/saplings, as *A. leiocarpa* is a fire-sensitive and shade intolerant pioneer species (Sobey, 1978; Hennenberg et al., 2005). Seedlings of *A. leiocarpa* are more vulnerable to fire than saplings and adults (Hennenberg et al., 2005) and they are disliked by livestock (personal observations). In addition, the opening of the vegetation reduces the competitive effects for light and nutrients on seedlings of *A. leiocarpa* during the establishment phase. Similarly, Bognounou et al. (2010a) found that the survival and the growth of seedlings of *A. leiocarpa* are favored on open areas.

The lower recruiting of *A. leiocarpa* in the park compared to fallows and croplands might be explained by the higher grass biomass in the park. In fact, the vegetation of the protected area is dominated by a two to three meters tall and very dense grass layer, which may have a marked effect on germination rate and seedling survival by leaving little space and light for recruitment of *A. leiocarpa* underneath (Hahn-Hadjali et al., 2006; Bond, 2008) and by providing high amounts of fuel for fire. Grégoire and Simonetti (2010) revealed that fire intensity is more than five times higher in the park than in the surrounding communal area. In concordance with this finding, our results reveal that fire damages on individuals of *A. leiocarpa* were severe in the park, but negligible in fallows and croplands. Overall, high recruitment of *A. leiocarpa* is associated with moderate human disturbances. This is in concordance with a study in southern Burkina Faso (Paré et al., 2009a).

Rates and patterns of debarking and chopping

The high chopping rates of *A. leiocarpa* in fallows and croplands show that villagers highly appreciate its wood and also indicate a high pressure on its stands. In general, chopping of the whole trunk of *A. leiocarpa* was more common in croplands, while chopping of branches was more common in fallows. The small proportion of chopped *A. leiocarpa* individuals in the park is in concordance with the protection status.

Harvester preferably chopped the trunk of pole sized trees (dbh size class 10-15 cm), because they are suitable for construction. This is also supported by the lower number of individuals in the size class dbh 5-15 cm. Similarly, other studies have reported that these small sized stems are the most frequently chopped due to the ease of their transport and to the value for construction (Lykke, 1998; Obiri et al., 2002; Luoga et al., 2004; Neke et al., 2006). The branches of most individuals of the medium and large size classes (> 15 cm) were chopped for fuel wood and to gain pole for construction purposes.

Overall, our findings suggest that chopping and debarking are size-specific. This has important implications for the population of *A. leiocarpa* because the impact of harvesting on populations depends on which size class is mostly harvested (Ticktin, 2004). In regard to debarking, Delvaux et al. (2010) found for 12 savanna species that the bark recovery rate after bark harvesting is size-dependent. Thus, bark recovery after debarking should be investigated for the different size classes of *A. leiocarpa* to evaluate the sustainability of this debarking pattern. Individuals in larger size classes show a significantly higher seed production than individuals in smaller size classes (Hennenberg et al., 2005). Fortunately, the whole trunk was rarely chopped in larger size classes (dbh > 25 cm). Thus, a decline in available seeds for recruitment is avoided and hence, the sexual reproductive potential of *A. leiocarpa* is guaranteed. Nevertheless, the strong debarking of these larger size classes may display a conservation concern over the long-term, as debarking may negatively influence fruit production. More studies are needed that investigate the impact of harvesting on the fruit production of *A. leiocarpa*.

Response to chopping by sprouting

Our results show that *A. leiocarpa* has a great ability to respond to chopping by sprouting. This suggests that *A. leiocarpa* is fairly resilient to chopping by producing sprouts and thus, secondary trunks. Our findings agree with several studies that show the importance of sprouting for the resilience and productivity of woody species in tropical areas in response to various disturbances (Higgins et al., 2000; Luoga et al., 2004; Mwavu and Witkowski, 2008). Our assumption is supported by the fact that the sprout mortality of *A. leiocarpa* is relatively low (18%) (Sawadogo et al., 2002). The low sprouting mortality may be related to the high wood density of *A. leiocarpa* (720–1200 kg/m^3, Andary et al., 2005) and the low moisture content (15%), possibly because a high wood density enables plants to resist fungi and pathogens.

The fact that tree size did not determine sprouting response shows that larger individuals of *A. leiocarpa* do not lose the ability to sprout after chopping as shown for other savanna and forest species (Neke et al., 2006; Mwavu and Witkowski, 2008). Adult sprouting behavior in response to chopping is the most useful stage to estimate the potential persistence of a tree species (Bond and Midgley, 2001). Overall, we conclude that the high sprouting ability of *A. leiocarpa* – even of larger individuals – allows current high chopping levels.

Conclusion and implication for conservation and sustainable management

SCD curves indicate that the stands of *A. leiocarpa* are in healthy states in fallows and in the park. The absence of saplings in croplands gives evidence of a declining population in this land-use type. However, it seems that until now *A. leiocarpa* has the ability to recruit successfully during the fallow period. Current debarking and chopping rates and patterns in our study area did not strongly affect the population and may actually permit population persistence of *A. leiocarpa* over the long-term.

Although *A. leiocarpa* is not protected by farmers during the agricultural cycle, such as the baobab (Schumann et al., 2010), human activities have an indirect positive effect on its population by providing better environmental conditions for its recruitment. Therefore, we conclude that despite the intense harvesting, the population of *A. leiocarpa* is still well preserved due to its species ability of fast growing and high sprouting and due to indirect positive influences of human activities. These conclusions are in agreement with findings of Sokpon and Biaou (2002) and Ouédraogo (2006), who pointed out that populations of *A. leiocarpa* are stable in some parts of Benin and Burkina Faso. Similarly, Schwartz and Caro (2003) and Zida et al. (2009) found that chopping did not reduce recruitment density of other tree species. However, the disturbed population of *A. leiocarpa* in croplands may indicate, in the light of current extension of croplands and shortening of fallow periods due to strongly increasing cash-crop cultivation, an increasing pressure on *A. leiocarpa* in the future and displays a conservation concern over the long-term. The shortening of fallow periods may hamper a successful establishment of *A. leiocarpa* as the species will have not enough time to regenerate successfully during the fallow period. However, more information about the life history (e.g. size of its first reproduction) of *A. leiocarpa* is required to precisely evaluate the influence of the shortened fallow period on the persistence of this species in the future.

Adopted management strategies should be already initiated to guarantee the persistence of this economically important species and to avoid a shortage of its products. Current high chopping levels seem appropriate and could be maintained, as *A. leiocarpa* exhibits a high sprouting ability over all size classes, as it produces a large supply of under story pole sized trees, and as chopping per se has a negligible impact on recruitment. Due to the high sprouting ability, chopping of branches can even exceed 50% of total branches per individual. However, individuals with a dbh > 30 cm that have significantly higher seed production should be spared from chopping or should only be chopped to a low degree. This would secure sufficient seed production and thus, the maintenance of a genetically diverse population of *A. leiocarpa* in the long term.

It is generally predicted that densely sprouted stumps will be slower at producing stems than sparsely sprouting ones (Mwavu and Witkowski, 2008). Therefore, manual thinning could be important to reduce the number of sprouts on the stump and encourage faster development of stems. In regard to debarking, it seems that the effect of debarking on the population of *A. leiocarpa* is negligible because debarking rates are relatively low. Thus, current debarking rates seem to be appropriate for sustainable use. However, further studies are necessary to estimate the long-term effect of harvesting stress on the viability of this multi-purpose tree.

To summarize, although *A. leiocarpa* is not or only slightly protected by people, this species is not at higher risk to over-harvesting and land-use than protected species like *A. digitata* and *V. paradoxa* (Djossa et al., 2008, Schumann et al., 2010). This is mainly due to the life history of this pioneer species. In fact, *A. leiocarpa* is able to withstand high human pressure by its fast growing, high recruitment, and asexual regeneration. In contrast, other studies in West Africa have shown that none protected and harvested trees (e.g. *Afzelia africana*, *Khaya senegalenis*) are declining due to land-use and harvesting impacts (Sinsin et al., 2004; Gaoue and Ticktin, 2007). This is presumably due to the fact that the adverse impact of harvesting and land-use on their population is not compensated by their life histories. Thus, region- and species-specific population studies are highly required in order to detect these species-specific responses to harvesting and land-use and to develop adapted management strategies. Overall, this study shows the importance of considering the land-use and harvesting impact, the protection status, and the life history together, when assessing a population status of a tree species.

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Appendix

Appendix 1 Effect of land-use type on the SCD of *A. leiocarpa* using GLM.

	Estimate	Standard Error	t-value	p-value	
Intercept	-2.36E-04	5.61E-05	-4.20	0.000	***
Size class midpoint	1.03E-03	6.22E-05	16.62	0.000	***
Croplands	-2.51E-04	1.09E-04	-2.31	0.022	*
Size class midpoint*as.factor(croplands)	3.43E-04	1.67E-04	2.06	0.040	*

Null deviance: 1485.12 on 304 degrees of freedom, Residual deviance: 210.71 on 301 degrees of freedom.
*p < 0.05, ***p < 0.001.

Chapter 5

Uses and Management Strategies of the Baobab Tree (*Adansonia digitata*) in Eastern Burkina Faso

with R. Wittig, A. Thiombiano, U. Becker, K. Hahn

Abstract

Many cash-poor households in the semi-arid tropics strongly depend on non-timber forest products (NTFPs) for livelihood. Increasing threats on NTFP-providing tree species, due to land-use intensification and over-harvesting, require ecological studies as well as additional information provided by local people. Our study identifies uses, perceptions to population development, and management strategies of the NTFP-providing baobab tree (*Adansonia digitata* L.) among the Gulimanceba people in eastern Burkina Faso. We conducted a quantitative ethnobotanical survey and investigated distribution of ethnobotanical knowledge related to this species on a small-scale, i.e. difference in knowledge between villages, genders, and generations. Interviews reveal that the baobab is harvested by local people for 25 different uses and emphasize its high importance - especially for nutritional and medicinal purposes - for local people. Local knowledge and perceptions of baobab were mostly evenly spread between genders and generations, while it slightly differed between people from different villages. Current local harvesting modes and management strategies resulted in sustainable use. However, ongoing land-use intensifications require adapted harvesting and management techniques to guarantee the persistence of this economically important species. Our results provide, in combination with ecological results of our previous study, appropriate management recommendations. It emphasizes the importance of ethnobotanical studies on a small-scale level in order to develop management strategies that are reliable in the specific area under the specific circumstances. Furthermore, our study shows that local knowledge and perceptions of the baobab tree correspond to ecological findings and highlight the awareness of local people to their environment.

Introduction

Many cash-poor households in the semi-arid tropics strongly depend on non-timber forest products (NTFPs) for livelihood (FAO, 1995). In recent years, there has been growing concern that populations of NTFP-providing trees are declining due to land-use intensification and over-harvesting. Consequently, several studies assessed the impact of land-use and harvesting on the population status (e.g. size class distribution, fruit production) of important NTFP-providing tree species (e.g. Gaoue and Ticktin, 2007; Djossa et al., 2008; Schumann et al., 2010). However, these studies on their own may not adequately justify the conservation assessment of the status of species (Dovie et al., 2008). Important additional information to these studies can be provided by local people. Their profound knowledge and opinions on use-preferences, management strategies, and their impact on the resource are crucial elements for producing culturally and ecologically rational conservation and management strategies (Lykke et al., 2004; Gaoue and Ticktin, 2009). The specific harvesting modes by which the target plant parts are extracted from individual plants (e.g. harvesting area and tools) and local management practices (e.g. sparing, fertilization, and planting) can influence the harvesting and land-use tolerance of species (Ticktin, 2004).

In West Africa, the knowledge and perceptions of the local people living in natural environments are based on experience gathered over generations (Lykke, 2000; Paré et al., 2010). Local management practices were developed by people who have been harvesting these species for hundreds of years (Ticktin et al., 2002) and are usually based on both ecological and cultural/socio-economic considerations. Age, ethnicity, gender, and several other socioeconomic factors shape knowledge of plant use and management. Moreover, knowledge can even vary within one ethnic group on a small-scale level. Lykke et al. (2004) found significant differences from village to village when it came to the knowledge of uses and dynamics of woody species in Burkina Faso as a consequence of different natural and cultural conditions. Therefore, knowledge should not emanate only from and for larger-scales but also from the finest micro level (i.e. local contexts) (Dovie et al., 2008). Proposals for changes in management on a larger-scale may be impractical or impossible to apply for local harvesters. Thus, management recommendations should focus on adaptation of management strategies currently practiced locally (Ticktin, 2004).

One of the most important NTFP-providing trees in West Africa is the multipurpose tree, *Adansonia digitata* L., commonly known as the baobab tree. NTFPs of the baobab tree are widely used for household, medicinal, and nutritional purposes and provide additional income to farmers (Sidibé and Williams, 2002; Gustad et al., 2004; Wickens and Lowe, 2008).

Ethnobotanical studies of the baobab tree in West Africa (De Caluwé et al., 2009; Buchmann et al., 2010) described mainly uses and management strategies on a larger-scale level (e.g. differences between ethnic groups). Very little information, however, is available on a small-scale. Therefore, we conducted a quantitative ethnobotanical survey among the Gulimanceba people in eastern Burkina Faso in order to identify uses, perceptions to population development, and management strategies of *A. digitata* on a small-scale level. The specific objectives of the study were to (i) document uses of the different plant parts, (ii) describe harvesting modes of the local communities, (iii) reflect local perceptions about the population status, and (iv) assess the local conservation status of *A. digitata*.

In this context, we aimed to investigate knowledge distribution on a small-scale, i.e. differences in knowledge between gender, generations, and villages. In a previous study, we had documented the impact of harvesting and land-use on the population structure and fruit production of *A. digitata* in the same area (Schumann et al., 2010). By combining these results with the findings of our ethnobotanical study, we aimed, as an overarching result, to achieve a coherent synergy between ethnobotanical knowledge and ecological findings on *A. digitata* in order to provide appropriate management recommendations that are reliable under currently practiced management strategies.

Methods

Study area and species

The study area is located in a semi-arid area in the province Tapoa in Burkina Faso, West Africa (Fig. 1) in the vicinity of the trans-boundary W National Park. The study area belongs to the North Sudanian vegetation zone with an average rainfall of 750-950 mm and a rainy season from May to October followed by a dry season from November to April (Guinko, 1984). The vegetation is characterized by shrub, tree, and woodland savannas. The dominant ethnic group is represented by the Gulimanceba (85% of the total population in the Tapoa province), who are autochthon and mainly live from agriculture (cotton, maize, millet, and sorghum). The farming system consists of alternating cycles of cultivation and fallows. Highly valued trees are preserved on croplands. Grazing activities by cattle, sheep, and goat are extensive. Human population density is relatively low with 16 inhabitants per km² (Tapoa province, INSD, 2007).

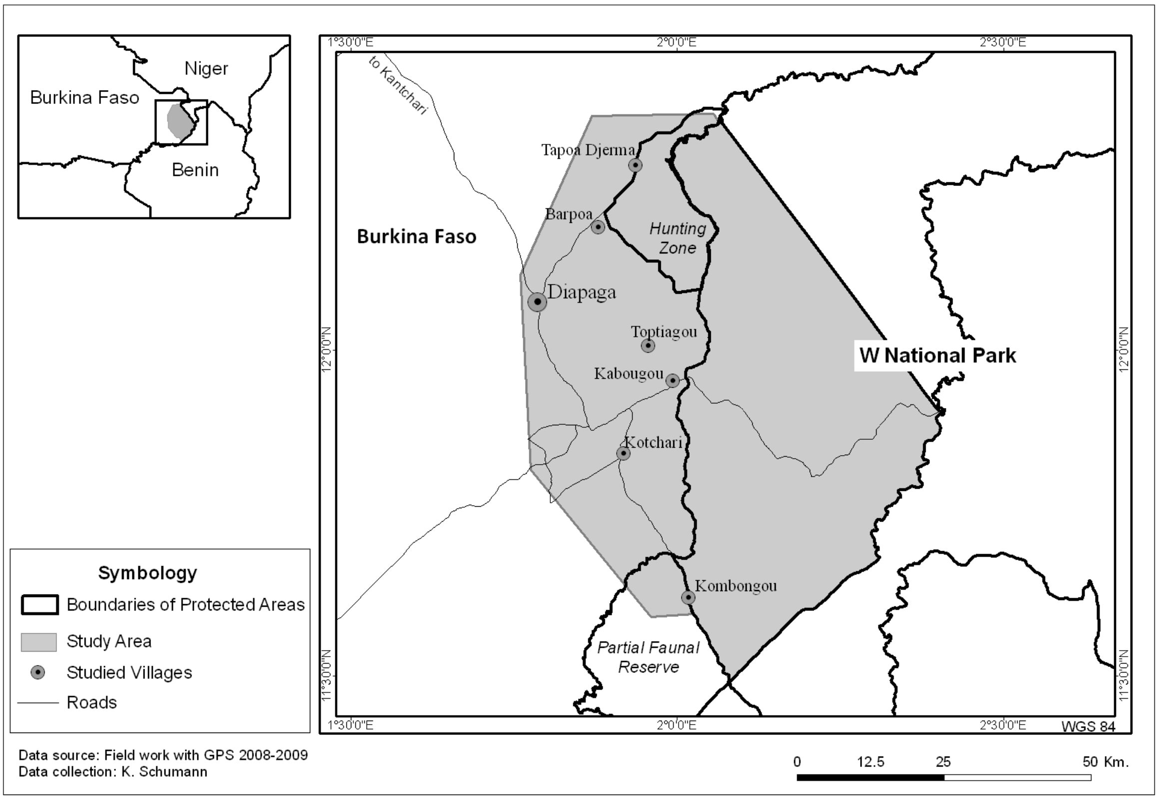

Fig. 1 Study area (UTM zone 31 North, WGS 84).

The baobab tree (*Adansonia digitata* L.) belongs to the Malvaceae family (subfamily Bombacoideae) and is known to be an extremely long-lived deciduous tree that can reach 23 m in height. The trunk is abruptly bottle-shaped or short and thick, up to 10 m in diameter (Wickens, 1982). Leaves are present throughout the rainy season and are shed at the start of the dry season (Wickens and Lowe, 2008). Flowering primarily occurs before the beginning of the rainy season (Sacande et al., 2006). Fruits develop 5-6 months after flowering (Sidibé and Williams, 2002) and are ripe by the end of the dry season (Wickens and Lowe, 2008).

A. digitata is scattered relatively irregularly and patchily in the savanna and is often associated with human settlements. It usually grows at low altitudes (450–700 m) with mean annual rainfall between 150 and 1500 mm (Wickens, 1982). It occurs on well-drained, clayey to sandy soils and is often spared when land is cleared for cultivation (Wickens and Lowe, 2008).

Data collection

For the structured interviews, six villages adjacent to the W National Park were chosen (Tapoa Djerma, Barpoa, Toptiagou, Kabougou, Kotchari, and Kombongou, Fig. 1). All villages show similar cultural and social structure (e.g. nearly all people work as farmers). Interviews were conducted between September and October 2008. In total, 49 Gulimanceba people (28 men and 21 women) were interviewed individually. Men and women and different age-classes (< 30 years, 31-50 years, and > 50 years) were equally represented within the villages. Informants were asked to describe:

- the uses of each baobab plant part for food, household, and medicine as well as their preparations and applications
- the harvesting modes of baobab (area, season, used tools, and preferences for special trees)
- the population development of baobab (decreasing, increasing, or stable and reasons for this)
- applied conservation practices for baobab

Data analysis

To detect similarities and discrepancies among informants, answers were coded as binary variables and were merged by means of a Principal Component Analysis (PCA) for each category. To detect the explaining variables of the first two PCA-axes for each category, we calculated correlations between PCA-scores of the first two axes and each answer. For each category, we examined the ordination diagrams for patterns and we used linear models (LM) to test whether knowledge and perception differed between age-classes, between men and women, and between people from the six different villages. Thus, age-classes, gender, and villages were used as independent variables and the PCA-scores of the first two axes were used as the dependent variable. LMs were run with a maximum fitted model. The non-significant explanatory variables (including interactions) were removed until a reduced final model was achieved, containing only significant explanatory variables.

Statistical analyses were performed using PC-ORD (McCune and Mefford, 2006), PASW Statistics 18.0.0 (SPSS Inc., Chicago, IL, USA), and R 2.10.1 (R Development Core Team, 2009).

Results

Uses of A. digitata

Interviews reveal that the baobab, called *bu tuobu* in Gulimancema, is harvested by local people for 25 different uses. The different plant parts are used for 17 medicinal uses, 7 food uses, and 1 household use (Table 1). The preparations and applications of all medicinal, household, and food uses are presented in Appendix 1.

The mean number of mentioned baobab uses per respondent was 4.88 (± 0.20). Even though a higher total number of medicinal uses was recorded, the mean number of mentioned food uses (2.90 ± 0.11) was higher than the mean number of medicinal uses (1.67 ± 0.19) per respondent.

The bark was the plant part with the highest number of medicinal uses, e.g. the bark was mainly used as “vitamins” to strengthen babies and to heal wounds. The leaves were mainly used to treat diarrhea and the fruits to heal cough and diarrhea. However, different parts were used against the same diseases. Regarding household uses of baobab products, one third of the respondents mentioned the use of the bark to make ropes, cordages, and other items. Fibers of the inner bark are twisted into ropes etc., while fibers of the outer bark are less suitable for these purposes.

All respondents reported the use of the leaves to prepare sauce (called *ti tuofari kpindi* in Gulimancema) (Fig. 2a). The various uses of baobab fruit included the pulp and the seeds (Fig. 2b). The mealy fruit pulp was added to the local drink *l’eau blanche* (*mi ñimpiema*) and to the local porridge *bouillie* (*li kanbiali*). Furthermore, the pulp was used to prepare the juice of *pain de singe* (*mi tuokua ñima*). Respondents reported the use of the seeds as spice in sauces and as an additive in *soumbala*, which is a fermented paste made of seeds of *Parkia biglobosa*. In addition, 5% of respondents declared the value of the baobab for spiritual uses, such as sacrifices (not presented in Table 1).

Table 1 Uses of *A. digitata* NTFPs for traditional medicine, for household, and for food.

	% of respondent				
	Bark	Fruits	Leaves	Roots	Seeds
Medicinal uses					
Diarrhea	8.2	10.2	22.4		
Vomiting	2.0	6.1	2.0		
Cough	8.2	14.3			
Cold	2.0	6.1			
Hemorrhoids	4.1		6.1		
Stomach ache	4.1		2.0		
Wounds	34.7			4.1	
Vitamins for newborns and babies	34.7				
Cardialgia	10.2				
Appendicitis	2.0				
Snake bite	2.0				
Tooth ache	2.0				
Lactation for women		4.1			
Cholera		2.0			
Itching		2.0			
Parasites			4.1		
Leprosy				2.0	
Household uses					
Rope, cordage	30.6				
Food uses					
Additive in *l'eau blanche*		53.1			
Additive in *bouillie*		38.8			
Juice of *pain de singe*		28.6			
Sauce			100.0		
Spice (to prepare couscous)					40.8
Additive in *soumbala*					22.4
Additive in *galette*					6.1

In regard to knowledge distribution, the use of the baobab did not clearly differ between respondents. In the ordination plot (Appendix 2), only the respondents of the northernmost village Tapoa Djerma were separated along the first axis from the respondents of the five other villages. The first axis of the ordination correlated mostly with three fruit food uses. For these uses (= 1.axis), we found significant differences between villages (Table 2).

Table 2 Results of LM, testing whether knowledge of baobab uses differs between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					2.axis				
	Juice of *pain de singe*, additive in *l'eau blanche*, additive in *bouillie* (all fruits)					Additive in *soumbala* (fruits), vitamins for babies (bark)				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	61.58	7.92	7.78	<0.001	***	51.02	3.47	14.71	<0.001	***
Village	-4.36	1.98	-2.20	0.033	*					

*$p < 0.05$, ***$p < 0.001$, S.E. = Standard error.

Eigenvalue of first axis: 2.98 and of second axis: 2.24, explained variance of first axis: 9.9% and of second axis: 7.5%.

Correlations of axes with variables: Juice of *pain de singe* (fruits): $r = 0.803$, $p < 0.001$; additive in *l'eau blanche* (fruits): $r = -0.614$, $p < 0.001$; additive in *bouillie* (fruits): $r = -0.618$, $p < 0.001$; additive in *soumbala* (fruits): $r = -0.596$, $p < 0.001$; vitamins for babies (bark): $r = 0.662$, $p < 0.001$.

Differences between villages were mainly explained in different fruit food uses in Tapoa Djerma in comparison to all other villages. The juice of *pain de singe* was a well-known fruit use in Tapoa Djerma, while it was less important in all other villages, where the use of the fruit pulp in *l'eau blanche* and in *bouillie* was more important. For the second axis, we found no significant differences (Table 2).

Harvesting modes of A. digitata

Bark and roots were harvested at any time of the year (71% of respondents). Fresh leaves were collected during the rainy season from May to August (100% of respondents). Fruits were collected during the dry season from December to June (98% of respondents), when fruits are mature and field harvesting is done. Bark was mainly harvested with a hoe, an axe (84% and 37% of respondents, respectively), or a machete (locally called *coupe-coupe* or in Gulimancema *gu handagu*) (10% of respondents). Roots were also harvested with a hoe (2% of respondents). For leaves harvesting, three-fourth of the respondents reported that people have to climb up the tree and harvest the leaves by hand (Fig. 2c), sticks or with a *coupe-coupe*. In addition, leaves were collected from the ground with a knife mounted on a long stick or by throwing sticks (20% and 12% of respondents, respectively). For collecting fruits, nearly all respondents (92%) attested that people have to climb up the tree and use their hands or sticks. Additionally, sticks were thrown into the tree and the fallen fruits were collected from the ground (86% of respondents). A high proportion of the respondents (78%) reported that they do not harvest all baobab trees, but prefer certain trees due to their food quality, i.e. glabrous leaves and sweet fruits. According to harvesting areas, most respondents (67%) stated fallows as the main area of harvesting. Villages, croplands and the park were less often mentioned as harvesting area (35%, 8%, and 2% of respondents, respectively).

Harvesting modes of the baobab did not clearly differ between respondents. In the ordination plot (Appendix 3), only the respondents of the northernmost village Tapoa Djerma were separated along the first axis from the respondents of the five other villages. The first axis of the ordination correlated mostly with harvesting tools for the bark and fruits. For these harvesting modes (= 1.axis), we found significant differences between villages (Table 3). People from the two northernmost villages (Barpoa and Tapoa Djerma) used a machete to harvest the bark, while people from the other villages used mainly a hoe for bark harvesting. The second axis of the PCA ordination correlated mostly with preferences for certain trees. For this (= 2.axis), we found significant differences between men and women (Table 3). Men mentioned more often than women that they prefer certain trees for harvesting.

Table 3 Results of LM, testing whether harvesting modes of baobab differ between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					**2.axis**				
	Hoe (bark), climb (fruits), stick (fruits)					Preferences for certain trees				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	43.41	7.52	5.78	<0.001	***	32.28	6.70	4.82	<0.001	***
Village	-6.19	1.91	-3.23	0.001	**					
Gender						9.23	4.40	2.10	0.042	*

*p < 0.05, **p < 0.01, ***p < 0.001, S.E. = Standard error.

Eigenvalue of first axis: 3.00 and of second axis: 2.05, explained variance of first axis: 18.8% and of second axis: 12.8%.

Correlations of axes with variables: Hoe (bark): r = - 0.843, p < 0.001; climb (fruits): r = - 0.655, p < 0.001; stick (fruits): r = - 0.698, p < 0.001; preference for certain trees: r = - 0.674, p < 0.001.

Population development of A. digitata

Half of the informants (52%) claimed that the number of baobab trees decreased in the area, while 41% stated that the population is stable. Only 7% of respondents announced that the number of baobab trees increased. Respondents attributed the decline to poor rainfall (17% of respondents), destructive harvesting modes (13% of respondents), and elephants (4% of respondents).

There was no differentiation pattern in the ordination diagram (not presented). The first axis of the ordination correlated mostly with the perception that the population was decreasing or stable. For these perceptions (= 1.axis), we found significant differences between villages (Table 4). People from the southernmost village Kombongou did not see a decline of baobab but thought that the baobab population is stable. In contrast, respondents from the other five villages reported a decline of the baobab population. The second axis of the ordination correlated mostly with the perception that the population was decreasing due to elephants and destructive harvesting modes. For this perception (= 2.axis), we found significant differences between villages and gender (Table 4). Only people from the northernmost villages (Barpoa and Tapoa Djerma) and only women attributed the decline of baobabs to elephants. Destructive harvesting modes as a reason for the decline of baobabs were mentioned in all villages, except in Kabougou and Kombongou.

Table 4 Results of LM, testing whether perception to population development of baobab differs between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					**2.axis**				
	Population development (decrease), population development (stable), regression (due to lower rainfall)					Regression (due to elephants and due to destructive harvesting modes)				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	62.65	11.73	5.34	<0.001	***	146.53	18.29	8.01	<0.001	***
Village	-6.92	2.88	-2.40	0.021	*	-17.17	4.49	-3.82	<0.001	***
Gender						-49.45	12.00	-4.12	<0.001	***
Village*gender						10.27	2.94	3.49	0.001	**

*p < 0.05, **p < 0.01, ***p < 0.001, S.E. = Standard error.

Eigenvalue of first axis: 2.39 and of second axis: 1.16, explained variance of first axis: 39.8% and of second axis: 19.4%.

Correlations of axes with variables: Population development (decrease): r = 0.951, p < 0.001; population development (stable): r = -0.892, p < 0.001; regression (due to lower rainfall): r = 0.601, p < 0.001; regression (due to elephants): r = - 0.619, p < 0.001; regression (due to destructive harvesting modes): r = 0.591, p < 0.001.

Conservation practices for A. digitata

Three-fourth of the informants declared that they spare baobab trees in croplands (Fig. 2d), whereas 30% of the informants declared that they do not protect baobab trees. Only a small proportion of respondents (3%) stated that they actively protect baobab seedlings and sapling, e.g. with small fences. Planting, sowing, or transplanting of baobab were never mentioned.

There was no differentiation pattern in the ordination diagram (not presented). The first axis of the ordination correlated strongest with none protection and protection of trees in croplands. For these statements (= 1.axis), we found significant differences between villages (Table 5).

Table 5 Results of LM, testing whether conservation strategies for baobab differ between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					**2.axis**				
	None protection, protection of trees in croplands					Protection of seedlings and saplings				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	81.38	12.59	6.47	<0.001	***	81.38	12.59	6.47	<0.001	***
Village	-11.25	3.162	-3.56	0.001	***	-11.25	3.16	-3.56	0.001	***

***p < 0.001, S.E. = Standard error.

Eigenvalue of first axis: 1.91 and of second axis: 1.01, explained variance of first axis: 63.9% and of second axis: 33.9%.

Correlations of axes with variables: None protection: r = 0.982, p < 0.001; protection of trees in croplands: r = - 0.972, p < 0.001; Protection of seedlings and saplings: r = 0.995, p < 0.001.

A high proportion of people in Barpoa and Tapoa Djerma stated that they do not protect the baobab tree and only a minority of them conserves baobab trees in the fields. In contrast, the majority of the respondents in the four other villages declared that they spare baobab trees in fields. The second axis of the ordination correlated most strongly with the protection of seedlings and saplings. For this conservation practice (= 2.axis), we found significant differences between villages (Table 5). The active protection of baobab seedlings and saplings was only mentioned in Barpoa and Tapoa Djerma. However, this active protection was mentioned by very few people.

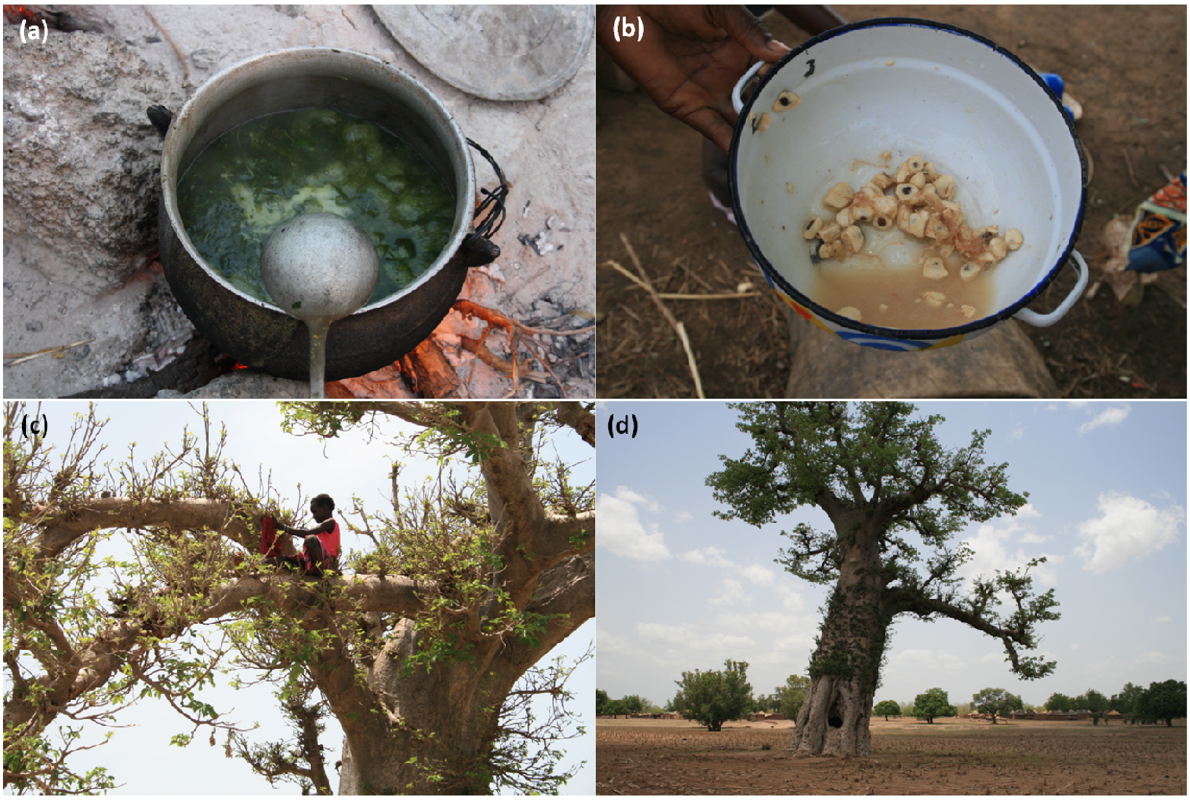

Fig. 2a-d Sauce made of fresh baobab leaves (a), dissolved pulp of baobab fruits (b), harvesting of baobab leaves (c), and spared baobab tree in cropland (d).
(Fig. 2a by Katja Heubach; Fig. 2b-d by Katharina Schumann).

Discussion

Uses of A. digitata

Interviews emphasize the high importance of the baobab tree - especially for nutritional and medicinal purposes - for local people. This is consistent with other studies in West Africa, which have shown that the baobab is one of the most important species for rural communities in West Africa (e.g. Kristensen and Lykke, 2003; Gustad et al., 2004; Assogbadjo et al., 2008; De Caluwé et al., 2009; Buchmann et al., 2010). In our study, the high number of mentioned uses indicates that local people have a deep knowledge about baobab uses. Especially the use of fresh and dried baobab leaves for sauce seems to be very important for the Gulimanceba people. The sauce accompanies millet gruel for daily consumption. Baobab leaves are a significant protein and mineral source, especially of calcium, iron, and magnesium (Yazzie et al., 1994). Likewise, baobab fruits are also highly appreciated for food purposes by the Gulimanceba people. The fruit pulp has very high vitamin C content, almost ten times that of oranges (Gebauer et al., 2002), and the roasted seeds are rich in proteins and fats (Sidibé and Williams, 2002). Overall, baobab leaves and fruits add valuable minerals and vitamins to the otherwise micronutrient-“poor” staple crops of the Gulimanceba people. Similar food uses have been described for several other West African countries (e.g. De Caluwé et al., 2009; Buchmann et al., 2010).

Among the interviewed Gulimanceba people, the variety of medicinal uses was higher than that of the food uses. The fact that most medicinal uses were mentioned by a low proportion shows that medicinal knowledge differs widely between people. In contrast, knowledge of baobab food uses was more uniform. Some medicinal uses of the baobab that have been reported in literature - e.g. treatment of fever and malaria (Sidibé and Williams, 2002; Wickens and Lowe, 2008; De Caluwé et al., 2009) - were not of importance for villagers in this area.

The number of spiritual and religious uses can be assumed to be much higher in reality. However, it is difficult to collect this kind of information with structured interviews.

Harvesting modes of A. digitata

Leaves and fruits were collected during the entire foliage and fruiting periods, respectively. This emphasizes the high demand on baobab leaves and fruits in this area. Similar harvesting periods were reported in Mali (Dhillion and Gustad, 2004).

According to harvesting tools, leaf and fruit harvesting techniques seem to be sustainable in this area as most people climb up the tree for harvesting and rarely harvest from the ground. Leaf harvesting at close range causes less damages than from a certain distance (Dhillion and Gustad, 2004). Harvesting with a knife mounted on a long stick is less specific and often removes complete shoots. This results in a reduction of the number of flower buds, as these are either damaged or removed entirely together with the shoots (Buchmann et al., 2010).

In regard to preferences of tree individuals, our interviews clearly reveal that certain trees are preferably harvested due to their food quality. These preferences were also reported for other African countries (Assogbadjo et al., 2008; Buchmann et al., 2010; Cuni Sanchez et al., 2010). Assogbadjo et al. (2008) even showed that people use several criteria to differentiate baobab individuals and used preferred combinations of traits as a guide for harvesting (e.g. the easier the bark-harvesting, the tastier the pulp and leaves). Hereby, the locally-recognized morphotypes seem to include a substantial amount of genetic variation. This means that the traditional selection of morphotypes with desired traits do not directly alter the natural population genetic structure (Assogbadjo et al., 2009a). According to harvesting areas, respondents stated fallows, villages and croplands as the areas of harvesting. This corresponds with results from Schumann et al. (2010) that showed that nearly all baobab individuals were harvested in these land-use types. The same harvesting areas were reported for Mali (Dhillion and Gustad, 2004).

Population development of A. digitata

The informants' perception to population development was not uniform as half of the interviewed people see a decline of baobab in this area, whereas the other part thinks that the baobab population is stable. Results of Schumann et al. (2010) support the view of the latter respondents. Despite the high land-use and harvesting impact, baobabs are still well preserved in this area due to their longevity, extremely low adult mortality rates, and due to traditional management practices. These conclusions agree with findings of Dhillion and Gustad (2004) for Mali and of Venter and Witkowski (2010) for South Africa, who pointed out that baobab populations are not declining. However, increasing pressure on baobab due to current land-use intensifications may lead to a decline of baobab population in the future.

Conservation practices for A. digitata

Most of the interviewed people stated that they spare baobab trees as prescribed by law, when chopping the vegetation for agriculture. However, farmers preserve only adult baobab trees as they are of high immediate value, while they mostly cut recruiting baobabs. In fact, Schumann et al. (2010) demonstrated that baobab seedlings were completely absent on croplands. The fact that adult baobab trees are left untouched in croplands permits a current maintenance of this important species in the agricultural cycle of cultivation and fallows. Lykke (2000) and Fifanou et al. (2011) also pointed out that the traditional agroforestry system protects and maintains the population of useful tree species in West Africa through the choice of tree species in the farming systems. However, the absence of baobab seedlings on croplands displays, in the light of current land-use intensification, a conservation concern over the long-term. In fact, shortening or absence of fallow periods may prevent successful recruiting of the baobab tree during the fallow period.

Overall, Gulimanceba people have a more passive attitude concerning the conservation of trees as they did not see the sparing of baobab individuals on croplands as an active management and that sowing or planting of baobab were never mentioned. Several studies across West Africa (e.g. Kristensen and Lykke, 2003; Buchmann et al., 2009) also showed that local people have no tradition for planting of indigenous trees, as they are considered as “wild”. This is not explained by the lack of technical knowledge, but rather by local belief systems, referring amongst other things to tree spirits and taboos (Buchmann et al., 2009).

Distribution of knowledge

The local knowledge and perceptions of baobab were mostly evenly spread between men and women as well as between young and old people. Although women are mainly involved in harvesting and processing of baobab products, their knowledge and perceptions were similar to those of men. However, Buchmann et al. (2010) stated that the exact knowledge on the preparation is partly linked to gender. The lack of age differences suggests that the traditional knowledge about the baobab is not disappearing and that knowledge is passed on from one generation to another. Nevertheless, it has to be considered that the questions were relatively broad, whereas more detailed questions on medicinal uses, for instance, could probably have revealed age differences (Lykke et al., 2004). Our findings are consistent with those from De Caluwé et al. (2009) and Buchmann et al. (2010) in several West African countries, which have shown that knowledge distribution of baobab uses was not related to gender and age.

Even though knowledge and perceptions did not differ substantially between people from different villages, some differences were found. People from the northernmost village Tapoa Djerma had slightly different knowledge and perceptions of the baobab in comparison to people from the other villages. These differences might be explained by the fact that this village, being close to the neighboring country Niger, has a high proportion of people from the ethnic group Zerma. In contrast, all other villages are mostly dominated by the Gulimanceba people. Consequently, people from Tapoa Djerma are differently influenced than people from the other studied villages, which may lead to differences in uses and management strategies. The fact that people do not or scarcely protect baobab trees in Tapoa Djerma might have led to a lower density of baobab trees, and thus lower seedling density, in comparison to the other villages (personal observation). Furthermore, the perception of people from the southernmost village Kombongou in regard to population development differed in comparison to all other villages. People from Kombongou did not see a decline of baobab. This is in concordance with our field observations that individuals of *A. digitata*, and especially recruiting individuals, are very common around this village.

Implication for conservation and sustainable management of A. digitata

Our results provide, in combination with the results of our previous study (Schumann et al., 2010) and other literature, appropriate management recommendations that are reliable under currently practiced management strategies in this area. Current local harvesting modes and management strategies seem to be sustainable so far. However, ongoing land-use intensifications require adapted harvesting and management techniques to guarantee the persistence of this economically important species and to secure the harvesting for future generations. Leaf harvesting of the baobab trees should be moderate to ensure fruit production (Schumann et al., 2010) and to avoid infections of the tree (CUC, 2010). Smaller baobab trees should be only harvested by hand and only to a low degree, as they are especially vulnerable to leaf harvesting (Schumann et al., 2010). The bark was mainly harvested with a hoe. This tool seems appropriate as far as only small pieces are removed and if regeneration time is long enough (3-5 years). This avoids infections of the tree. CUC (2010) declared that the best period to harvest the bark is at the end of the rainy season. Bark regeneration depends on humidity as the moisture content of the exposed wound is the most important factor allowing the start of the bark recovery process (Delvaux et al., 2010).

Furthermore, some baobab seedlings and saplings should be spared and protected by local people on croplands. This protection could include similar measures as it has been demonstrated for Mali (Dhillion and Gustad, 2004): physical barriers to prevent browsing, irrigation, installing of a basin-shaped bed for water collection and cutting of surrounding vegetation. In addition, as there is a high number of seedlings in villages due to the dispersal of seeds in garbage, seedlings from villages could be transplanted to croplands.

Practical details for transplanting of baobab seedlings were demonstrated by CUC (2010). For instance, transplanting should preferably be carried out in the beginning of the rainy season and when individuals have reached a height of 30 cm.

Conclusion

Our study firstly describes uses and management strategies of the baobab tree among the Gulimanceba people in Burkina Faso. Our results show that local knowledge and perceptions of the baobab tree correspond to ecological findings of our previous study and highlight the awareness of local people to their environment. Furthermore, our study demonstrates how local knowledge and perceptions combined with ecological background information can help to design appropriate management recommendations for a highly used tree species. Hereby, our study emphasizes the importance of ethnobotanical studies on a small-scale level in order to develop management strategies that are reliable in the specific area under the specific circumstances.

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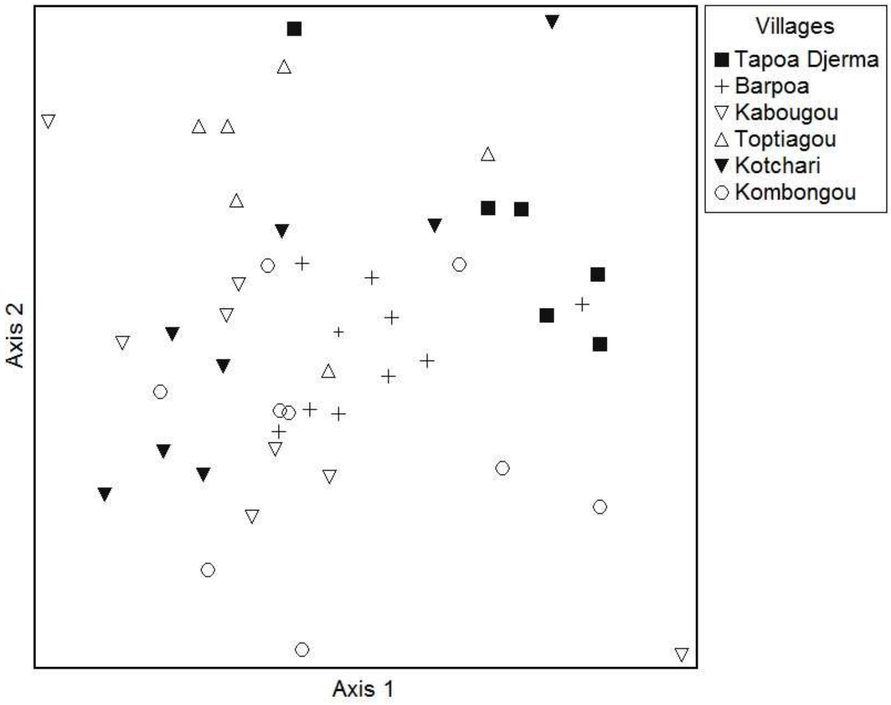
Appendix

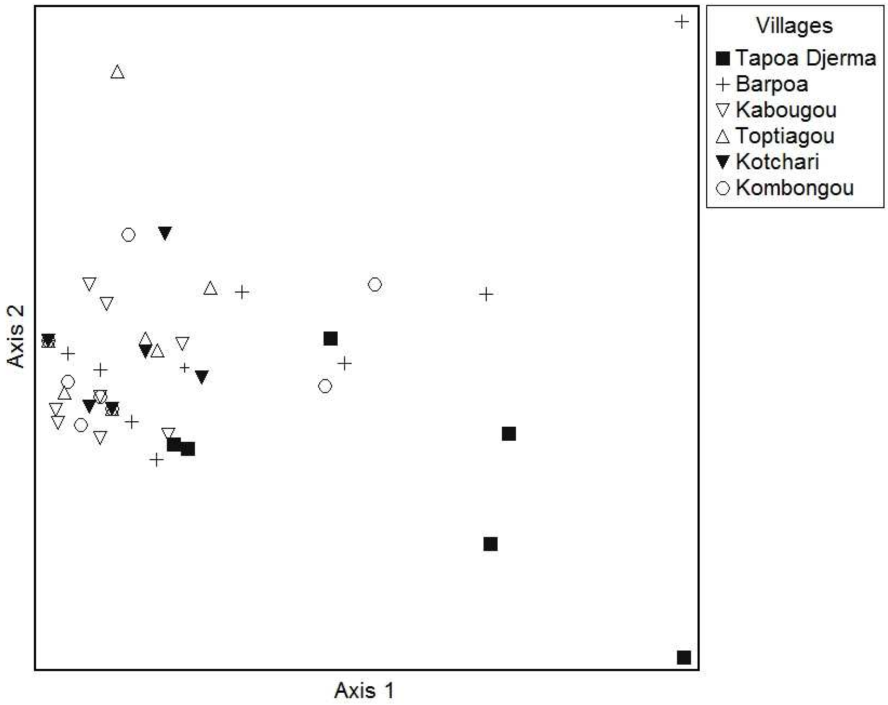
Appendix 1 Preparation and application of the different medicinal, household and food uses.

	Preparation and application
Medicinal uses	
Appendicitis	The decoction of the bark (mixed with *Dichrostachys cinerea*) is served as drink.
Cardialgia	The decoction of the bark is served as drink.
Cholera	The fruit pulp is pounded, boiled, and served as drink.
Cold	Bark: The decoction (mixed with the leaves of *Piliostigma thonningii*) is served as drink. Fruits: The pulp is pounded, mixed with vinegar, boiled, and served as drink.
Cough	Bark: The decoction is served as drink. Fruits: The pulp is pounded, boiled, and served as drink.
Diarrhea	Bark: The decoction is served as drink (often mixed with the bark of other trees). Fruits: The fruit pulp is pounded, boiled (mixed with sorghum or *Combretum collinum*), and served as drink. Leaves: The dry leaves are crushed (mixed with water or *bouillie*), boiled, and served as drink.
Hemorrhoids	Bark: The decoction is served as drink. Leaves: The dry leaves are crushed, boiled, and served as drink.
Itching	The fruit shell is roasted, mixed with the leaves and the skin is washed.
Lactation for women	The fruit pulp is pounded, boiled, and served as drink.
Leprosy	The decoction of the roots (mixed with roots of other plants) is served as drink.
Parasites	The dry leaves are crushed, boiled, and served as drink.
Snake bite	The decoction of the bark is served as drink.
Stomach ache	Bark: The decoction is served as drink. Leaves: The dry leaves are crushed, boiled, and served as drink.
Tooth ache	The decoction of the bark is served as drink.
"Vitamins" for newborns and babies	The decoction of the bark is served as drink and the babies are washed with the decoction.
Vomiting	Bark: The decoction is served as drink. Fruits: The pulp is pounded, boiled, and served as drink. Leaves: The dry leaves are crushed, boiled, and served as drink.
Wounds	The bark or roots are dried or boiled, pounded, and applied (mixed with sheabutter) on the wound. Furthermore, the decoction of the bark or roots is used to wash the wound.
Household uses	
Rope, cordage	The fiber of the inner bark are used and processed.
Food uses	
Additive in *l'eau blanche*	The fruit pulp is dissolved and added to *l'eau blanche* (a drink based on millet or sorghum and cold water).
Additive in *bouillie*	The fruit pulp is dissolved and added to *bouillie* (a porridge based on millet or sorghum and boiled water), to make them more acidic.

Additive in *galette*	The seeds are roasted, pounded and mixed with flour.
Additive in *soumbala*	The boiled seeds are crushed into powder and dried. This powder is used as an additive in *soumbala*, which is a fermented paste made of seeds of *Parkia biglobosa*.
Juice of *pain de singe*	The fruit pulp is crushed and mixed with water.
Sauce	During the rainy season, the fresh leaves are crushed and prepared as a sauce for daily consumption. In addition, the leaves are dried and crushed to powder. This powder can be stored for a long time, which allows its use during the dry season.
Spice	The seeds are roasted, crushed into powder, and used as spice in sauces (mainly to prepare couscous).



Appendix 2 PCA-scores along the first two axes of PCA analysis of baobab uses. Each dot represents one informant (n = 46). Eigenvalue of first axis: 2.98 and of second axis: 2.24, explained variance of first axis: 9.9% and of second axis: 7.5%. Informants are indicated with symbols marking the village (correlation of village with first axis: t = -2.200, d.f. = 44, $p < 0.05$, r = -0.315).



Appendix 3 PCA-scores along the first two axes of PCA analysis of harvesting modes. Each dot represents one informant (n = 48). Eigenvalue of first axis: 3.00 and of second axis: 2.05, explained variance of first axis: 18.8% and of second axis: 12.8%. Informants are indicated with symbols marking the village (correlation of village with first axis: t = -3.232, d.f. = 46, $p < 0.01$, r = -0.430).

Chapter 6

Uses and Management Strategies of the Multipurpose Tree *Anogeissus leiocarpa* in Eastern Burkina Faso

with R. Wittig, A. Thiombiano, U. Becker, K. Hahn

Abstract

Many people in the semi-arid tropics strongly depend on non-timber forest products (NTFPs) for livelihood. Increasing threats on NTFP-providing tree species, due to land-use intensification and over-harvesting, require ecological studies as well as additional information provided by local people. One important NTFP-providing tree in West Africa is *Anogeissus leiocarpa*. Even though this species is highly used, ethnobotanical studies on *A. leiocarpa* are scarce and address mainly qualitative aspects. Our study investigates uses, perceptions of the population development, and management strategies of *A. leiocarpa* among the Gulimanceba people in eastern Burkina Faso. We conducted a quantitative ethnobotanical survey and investigated distribution of ethnobotanical knowledge related to the species on a small-scale, i.e. difference in knowledge between villages, genders, and generations. Interviews reveal that *A. leiocarpa* is harvested by local people for 18 different uses and emphasize its high importance for local people. Ethnobotanical knowledge of *A. leiocarpa* was mostly evenly spread between genders and generations, while it slightly differed between people from different villages. Although local people did not actively protect *A. leiocarpa*, current local harvesting modes and management resulted in sustainable use. However, ongoing land-use intensifications require adapted management strategies to guarantee the persistence of this important species. Our results provide, in combination with ecological results of our previous study, appropriate management recommendations. The study emphasizes the importance of ethnobotanical studies on a small-scale level in order to develop management strategies that are reliable in the specific area under the specific circumstances.

Introduction

Many people in the semi-arid tropics strongly depend on non-timber forest products (NTFPs) for livelihood (FAO, 1995). In recent years, there has been growing concern that populations of NTFP-providing trees are declining due to land-use intensification and over-harvesting. Therefore, several studies assessed the impact of land-use and harvesting on the population status of important NTFP-providing tree species (e.g. Gaoue and Ticktin, 2007; Schumann et al., 2010). However, these studies on their own may not adequately justify the conservation assessment of the status of species (Dovie et al., 2008). Important additional information to these studies can be provided by local people. Their profound knowledge and opinions on use-preferences, management strategies, and their impact on the natural resource are crucial elements for producing rational conservation and management strategies (Lykke et al., 2004; Gaoue and Ticktin, 2009).

In West Africa, knowledge and perceptions of local people living in natural environments are based on experience gathered over generations (Lykke, 2000; Paré et al., 2010). Local management practices were developed by people who have been harvesting these species for hundreds of years (Ticktin et al., 2002) and are usually based on both ecological and cultural/socio-economic considerations. Age, ethnicity, gender, and several other socioeconomic factors shape knowledge of plant use and management. Moreover, knowledge can even vary within one ethnic group on a small-scale level. Lykke et al. (2004) found significant differences from village to village when it came to the knowledge on uses and dynamics of woody species in Burkina Faso as a consequence of different natural and cultural conditions. Therefore, knowledge should not emanate only from and for large-scale but also from the finest micro level (i.e. local contexts) (Dovie et al., 2008). Proposals for changes in management on a larger-scale may be impractical or impossible to apply for local harvesters. Thus, management recommendations should focus on adaptation of management strategies currently practiced locally (Ticktin, 2004).

One important NTFP-providing tree in West Africa is *Anogeissus leiocarpa* (DC.) Guill. & Perr. NTFPs of this tree are widely used for household and medicinal purposes (Burkill, 1985-2000; Andary et al., 2005; Sacande and Sanogo, 2007). Even though this species is highly used, ethnobotanical studies on *A. leiocarpa* are scarce and address mainly qualitative aspects (Lykke et al., 2004; Belem et al., 2007; Paré et al., 2010). There is virtually no detailed quantitative analysis of the utilization, harvesting modes, and conservation strategies of this important species. Therefore, we conducted a quantitative ethnobotanical survey among the Gulimanceba people in eastern Burkina Faso in order to identify uses, perceptions of population development, and management strategies of *A. leiocarpa* on a small-scale level. The specific objectives of the study were to (i) document uses of the different plant parts, (ii) describe harvesting modes of the local communities, (iii) reflect local perceptions about the population status, and (iv) assess the local conservation status of *A. leiocarpa*. In this context, we also aimed to investigate ethnobotanical knowledge distribution on a small-scale, i.e. differences in knowledge between gender, generations, and people from different villages.

In a previous study, we had documented the impact of harvesting and land-use on the population structure of *A. leiocarpa* in the same area (Schumann et al., 2011). By combining these results with the findings of our ethnobotanical study, we aimed, as an overarching result, to achieve a coherent synergy between ethnobotanical knowledge and ecological findings on *A. leiocarpa* in order to provide appropriate management recommendations that are reliable under currently practiced management strategies.

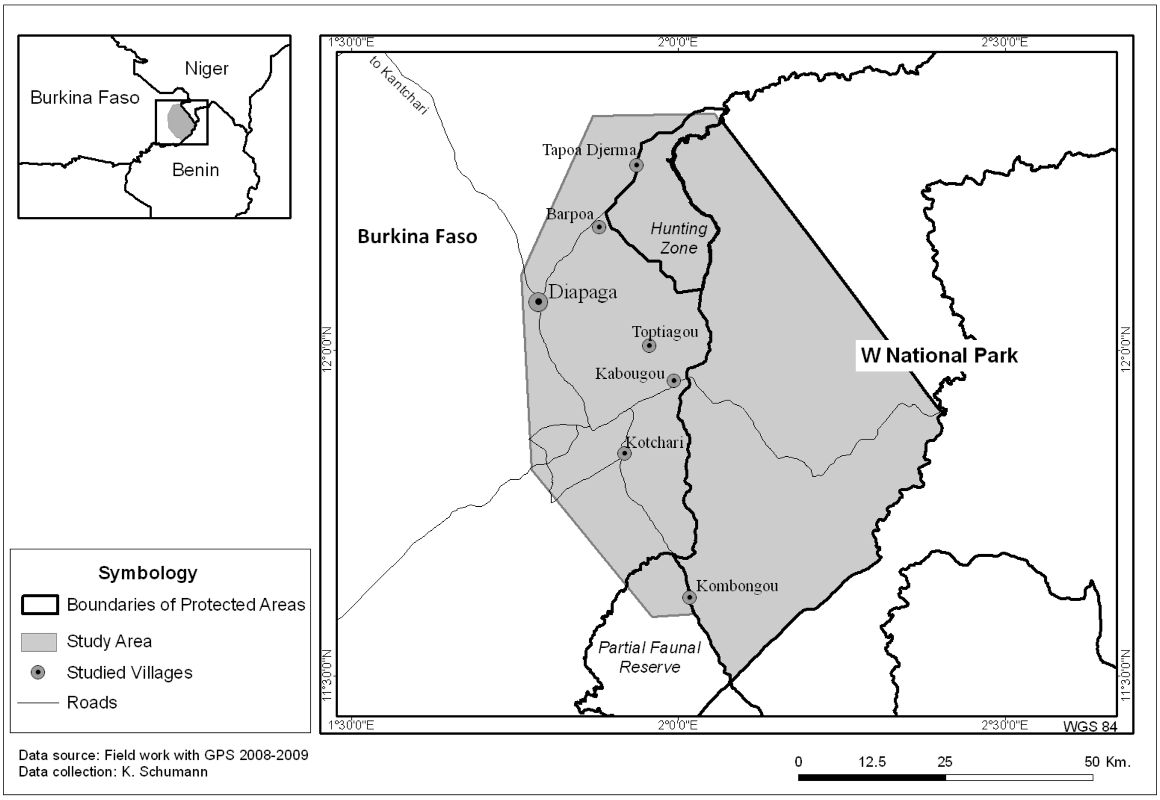
Methods

Study area and species

The study area is located in a semi-arid area in the province Tapoa in Burkina Faso, West Africa (Fig. 1) in the vicinity of the trans-boundary W National Park. The study area belongs to the North Sudanian vegetation zone, with an average rainfall of 750-950 mm and a rainy season from May to October followed by a dry season from November to April (Guinko, 1984). The vegetation is characterized by shrub, tree, and woodland savannas. The dominant ethnic group is represented by the Gulimanceba (85% of the total population in the Tapoa province), who are autochthon and mainly live from agriculture (cotton, maize, millet, and sorghum). The farming system consists of alternating cycles of cultivation and fallows. Human population density is relatively low with 16 inhabitants per km² (Tapoa province, INSD, 2007).

Anogeissus leiocarpa (DC.) Guill. & Perr. belongs to the Combretaceae family. The deciduous tree can grow up to a height of 15–18(–30) m (Arbonnier, 2002), has a slightly grooved bole, and an open crown with drooping, pubescent branches. Flowering occurs at the end of the dry season, or the beginning of the rainy season, just after leaf flushing (Sacande and Sanogo, 2007). Seeds ripen during the dry season and germinate mainly at the beginning of the rainy season.

It has a wide geographical distribution ranging from the borders of the Sahara down to the humid tropical forests. Depending on the vegetation zone, it can be found in savannas, dry forests, and gallery forests (Couteron and Kokou, 1997; Müller and Wittig, 2002; Thiombiano et al., 2006). It is typically found at altitudes between 450 and 1900 m and can grow on a range of different soil types (Thiombiano et al., 2006).



Data source: Field work with GPS 2008-2009
Data collection: K. Schumann

Fig. 1 Study area (UTM zone 31 North, WGS 84).

Data collection

For the structured interviews, six villages adjacent to the W National Park were chosen (Tapoa Djerma, Barpoa, Toptiagou, Kabougou, Kotchari, and Kombongou, Fig. 1). All villages show similar cultural and social structure (e.g. nearly all people work as farmers). Interviews were conducted between September and October 2008. In total, 49 Gulimanceba people (28 men and 21 women) were interviewed individually. Men and women and different age-classes (< 30 years, 31-50 years, and > 50 years) were equally represented within the villages. Informants were asked to describe:

- the uses of each plant part of *A. leiocarpa* for food, household, and medicine as well as their preparations and applications
- the harvesting modes of *A. leiocarpa* (area, season, used tools, and preferences for special trees)
- the population development of *A. leiocarpa* (decreasing, increasing, or stable and reasons for this)
- applied conservation practices for *A. leiocarpa*

Data analysis

To detect similarities and discrepancies among informants, answers were coded as binary variables and were merged by means of a Principal Component Analysis (PCA) for each category. To detect the explaining variables of the first two PCA-axes for each category, we calculated correlations between PCA-scores of the first two axes and each answer. For each category, we examined the ordination diagrams for patterns and we used linear models (LM) to test whether knowledge and perception differed between age-classes, between men and women, and between people from the six different villages. Thus, age-classes, gender, and villages were used as independent variables and the PCA-scores of the first two axes were used as the dependent variable. LMs were run with a maximum fitted model. The non-significant explanatory variables (including interactions) were removed until a reduced final model was achieved, containing only significant explanatory variables.

Statistical analyses were performed using PC-ORD (McCune and Mefford, 2006), PASW Statistics 18.0.0 (SPSS Inc., Chicago, IL, USA), and R 2.10.1 (R Development Core Team, 2009).

Results

Uses of A. leiocarpa

Interviews reveal that *A. leiocarpa,* called *bu siebu* in Gulimancema, is harvested by local people for 18 different uses. The different plant parts are used for 13 medicinal uses and for 5 household uses (Table 1). The preparations and applications of all medicinal and household uses are presented in Appendix 1. The mean number of mentioned uses of *A. leiocarpa* per respondent was 4.89 (± 0.31).

Table 1 Uses of *A. leiocarpa* NTFPs for traditional medicine and for household.

	% of respondent				
	Bark	Fruits	Leaves	Roots	Wood
Medicinal uses					
Stomach ache	61.2	4.1	26.5	38.8	
Diarrhea	24.5	2.0	14.3	6.1	
Yellow fever	14.3	4.1	20.4	4.1	
Hemorrhoids	28.6		12.2	6.1	
Parasites		16.3	4.1		
Wounds		2.0		2.0	
Cough	2.0				
Eye disease	6.1				
Fatigue	4.1				
Tooth ache	2.0				
Vomiting			2.0		
Vitamins for newborns and babies			4.1		
Dysentery			2.0		
Household uses					
Firewood					95.9
Construction wood					61.2
Soap					10.2
Surrogate for potash	6.1				
Dyeing of clothes	2.0				

The bark (Fig. 2a) and the leaves (Fig. 2b) were the plant parts with the highest number of medicinal uses, e.g. they were used to heal diarrhea, hemorrhoids, stomach ache, and yellow fever. The fruits (Fig. 2c) were mainly applied against parasites. Different parts were used against the same diseases. The wood (Fig. 2d) and the bark of *A. leiocarpa* were the most important plant parts for household uses. Nearly all respondents reported that the wood was used as fuel and three-fourths mentioned its use for construction, e.g. for huts, roofs, and sheds. Furthermore, the ash of the wood was used to prepare soap and the bark was used as surrogate for potash and for dyeing of clothes.

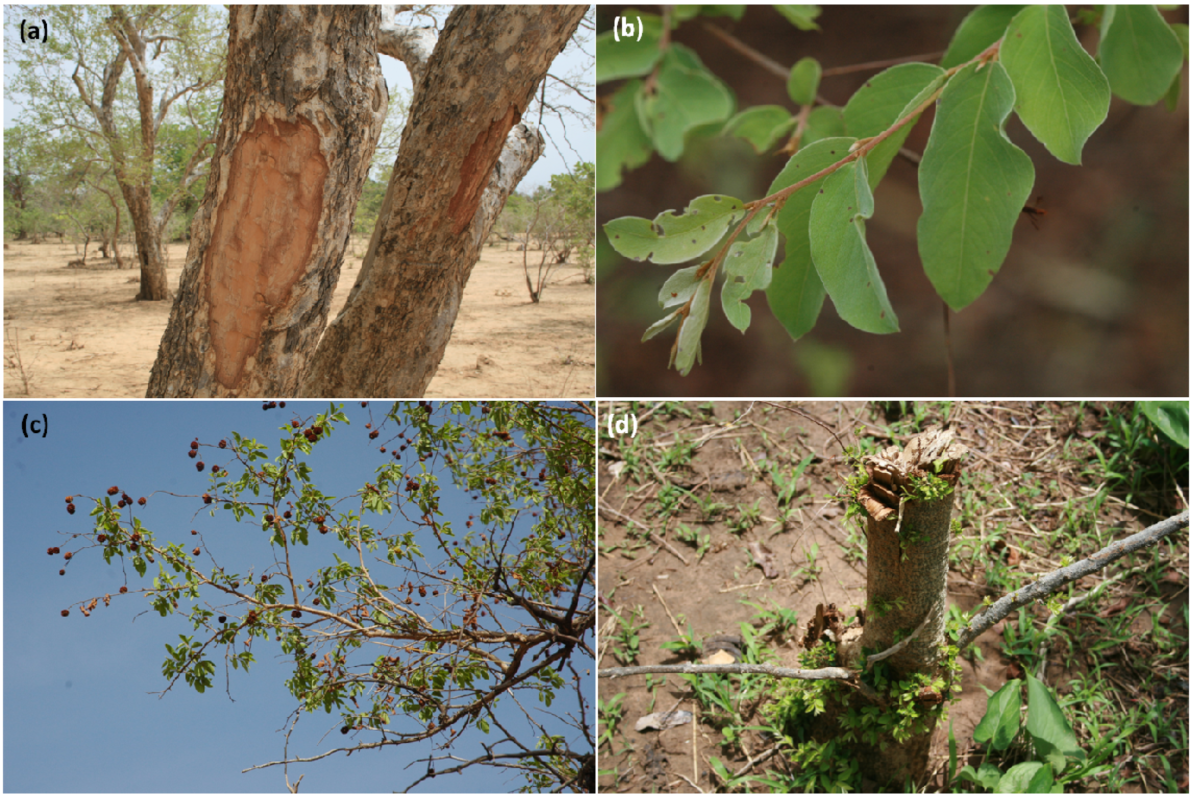


Fig. 2a-d Bark (a), leaves (b), fruits (c), and wood of (d) *A. leiocarpa.*
(Fig. 2a and 2d by Katharina Schuman; Fig. 2b and 2c by Arne Erpenbach).

In regard to knowledge distribution, there was no distinct pattern in the ordination diagram (Appendix 2). This indicates that the use of *A. leiocarpa* did not clearly differ between respondents. The first axis of the ordination correlated mostly with three medicinal uses of *A. leiocarpa*. For these uses (= 1.axis), we found significant differences between villages (Table 2). They were mainly explained in different medicinal uses of *A. leiocarpa* in Tapoa Djerma in comparison to all other villages. The use of the leaves to heal yellow fever was well-known in Tapoa Djerma, while it was less mentioned in all other villages. Furthermore, the uses of bark and leaves to heal diarrhea and stomach ache were never mentioned by respondents in Tapoa Djerma, while they were often reported in all other villages. The second axis correlated mostly with two other medicinal uses and one household use. For these uses (= 2.axis), we found also significant differences between villages (Table 2). The use of the wood to prepare soap was only mentioned in one village, Toptiagou. Furthermore, the use of bark and roots to heal hemorrhoids was mentioned only by respondents of three villages (Topiagou, Kotchari, Kombongou).

Table 2 Results of LM, testing whether knowledge of *A. leiocarpa* uses differs between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					**2.axis**				
	Diarrhea (bark, leaves), stomach ache (bark), yellow fever (leaves)					Hemorrhoids (bark, roots), soap (wood)				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	-1.42	0.56	-2.55	0.014	*	-1.31	0.54	-2.40	0.021	*
Village	0.39	0.14	2.84	0.007	**	0.36	0.14	2.68	0.010	*

*p < 0.05, **p < 0.01, S.E. = Standard error.
Eigenvalue of first axis: 3.12 and of second axis: 2.93, explained variance of first axis: 11.6% and of second axis: 10.8%.
Correlations of axes with variables: Diarrhea (bark): r = 0.697, p < 0.001; diarrhea (leaves): r = 0.650, p < 0.001; stomach ache (bark): r = -0.585, p < 0.001; yellow fever (leaves): r = -0.552, p < 0.001; hemorrhoids (bark): r = 0.714, p < 0.001; hemorrhoids (roots): r = 0.549, p < 0.001, soap (wood): r = 0.514, p < 0.001.

Harvesting modes of A. leiocarpa

Wood, bark, and roots were harvested at any time of the year (90%, 80%, and 31% of respondents, respectively). Bark was mainly harvested with a hoe (86% of respondents), but sometimes also with an axe (33% of respondents), or a machete (locally called *coupe-coupe* or in Gulimancema *gu handagu*) (10% of respondents). Roots were also harvested with a hoe (33% of respondents) or an axe (6% of respondents). Leaves and fruits were collected by hand (53% and 33% of respondents, respectively). Three-fourth of the informants declared that they use an axe or a machete to chop the wood. Often they also used a hoe to chop the branches. Some of the respondents (14%) reported that they do not chop all trees of *A. leiocarpa*, but prefer certain trees due to their wood quality, i.e. hard and resistant wood. According to harvesting areas, most respondents (90%) stated fallows as the main area of harvesting. Villages were less mentioned as harvesting area (12% of respondents) and croplands were never mentioned.

There was no pattern in the ordination diagram (Appendix 3). The first axis of the ordination correlated mostly with harvesting tools. For these harvesting modes (= 1.axis), we found significant differences between villages (Table 3). While the use of a hoe for bark harvesting was mentioned by respondents of all villages, the use of the axe was never mentioned in the two southernmost villages. For the second axis, we found no significant differences.

Table 3 Results of LM, testing whether harvesting modes of *A. leiocarpa* differ between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					**2.axis**				
	Axe (bark, wood), hands (fruits), all the year (wood), fruiting period (fruits)					Hands (leaves), hoe (roots), all the year (roots), foliage period (leaves)				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	75.15	7.29	10.32	<0.001	***	43.65	3.56	12.26	<0.001	***
Village	-6.75	1.83	-3.69	0.001	***					

***p < 0.001, S.E. = Standard error.
Eigenvalue of first axis: 3.41 and of second axis: 2.51, explained variance of first axis: 18.9% and of second axis: 14.0%.
Correlations of variables with axes: Axe (bark): r = 0.561, p < 0.001, axe (wood): r = 0.581, p < 0.001; hands (fruits): r = 0.728, p < 0.001; all the year (wood): r = 0.641, p < 0.001; fruiting period (fruits): r = 0.728, p < 0.001; hands (leaves): r = 0.578, p < 0.001; hoe (roots): r = 0.766, p < 0.001; all the year (roots): r = 0.752, p < 0.001; foliage period (leaves): r = 0.585, p < 0.001.

Population development of A. leiocarpa

More than half of the informants (55%) claimed that the number of *A. leiocarpa* trees decreased in this area, while 39% stated that the population is stable. Respondents attributed the decline to destructive harvesting modes (14% of respondents), poor rainfall (12% of respondents), human population growth (6% of respondents), and destructive fire (4% of respondents).

Regarding knowledge distribution, the first axis of the ordination correlated strongest with the perception that the population is decreasing or stable. For these perceptions (= 1.axis), we found significant differences between age-classes, gender, and villages (Table 4). People from the southernmost village Kombongou did not see a decline of *A. leiocarpa*, but thought that the population is stable. In contrast, most respondents from the other five villages reported a decline of the *A. leiocarpa* population. Furthermore, younger people and men mostly saw a decrease of this species. The second axis of the ordination correlated mostly with the perception that the population is decreasing due to lower rainfall and destructive harvesting modes. For this perception (= 2.axis), we found significant differences between age-classes (Table 4). While younger people attributed the decline of *A. leiocarpa* to destructive harvesting modes, older people attributed it to lower rainfall.

Table 4 Results of LM, testing whether perception to population development of *A. leiocarpa* differs between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis					**2.axis**				
	Population development (decrease), population development (stable)					Regression (due to destructive harvesting modes and due to lower rainfall)				
	Estimate	S.E.	t value	p-value		Estimate	S.E.	t value	p-value	
Intercept	119.02	65.71	1.81	0.077		76.87	12.77	6.02	<0.001	***
Village	28.52	11.10	2.57	0.014	*					
Age	-74.74	25.90	-2.89	0.006	**	-10.33	4.92	-2.10	0.041	*
Gender	-64.38	43.40	-1.48	0.145						
Village*gender	-14.88	7.29	-2.04	0.047	*					
Age*gender	51.01	17.10	2.98	0.005	**					

*p < 0.05, **p < 0.01, ***p < 0.001, S.E. = Standard error.
Eigenvalue of first axis: 2.27 and of second axis: 1.15, explained variance of first axis: 32.4% and of second axis: 16.5%.
Correlations of variables with axes: Population development (decrease): r = -0.967, p < 0.001; population development (stable): r = 0.934, p < 0.001; regression (due to destructive harvesting modes): r = 0.772, p < 0.001; regression (due to lower rain fall): r = -0.740, p < 0.001.

Conservation practices for A. leiocarpa

Half of the informants (55%) declared that they do not protect trees of *A. leiocarpa*. However, one third of respondents (37%) affirmed that they spare individuals of this species in croplands. Planting or transplanting seedlings of *A. leiocarpa* was never mentioned. The first axis of the ordination correlated most strongly with these two declarations. For these statements (= 1.axis), we found significant differences between villages (Table 5). A high proportion of people from the two northernmost villages stated that they do not protect or spare individuals of *A. leiocarpa* in croplands. In contrast, one third of the respondents from the four other villages declared that they spare individuals of *A. leiocarpa* in croplands. Overall, there was no significant difference between men and women and between age classes in conservation practices.

Table 5 Results of LM, testing whether conservation strategies for *A. leiocarpa* differ between age, gender, and villages. All non-significant explanatory variables were removed.

	1.axis				
	None protection, protection of trees in croplands				
	Estimate	S.E.	t-value	p-value	
Intercept	6.67	13.28	0.50	0.618	
Village	8.27	3.336	2.48	0.017	*

*p < 0.05, ***p < 0.001, S.E. = Standard error.
Eigenvalue of first axis: 2.29, explained variance of first axis: 76.4%
Correlations of variables with axes: None protection: r = -0.967, p < 0.001; protection of trees in croplands: r = 0.771, p < 0.001.

Discussion

Uses of A. leiocarpa

Interviews reveal that villager harvest NTFPs of *A. leiocarpa* for multipurpose and emphasize its importance for local people, especially as construction and fire wood and for medicine. This is consistent with other studies in West Africa (Lykke et al., 2004; Thiombiano, 2005; Belem et al., 2007; Paré et al., 2010). In our study, the high number of mentioned uses indicates that Gulimanceba people have a deep knowledge about uses of *A. leiocarpa*. Especially the use of *A. leiocarpa* as construction- and firewood were mentioned by a high proportion of respondents. The wood is well appreciated for construction due to its very hard, fast growing, and fairly insect and termite resistant properties (Sobey, 1978; Sacande and Sanogo, 2007). The density of the wood is high (720–1200 kg/m^3) and the moisture content is low (15%). It is excellent firewood because it is giving out great heat and provides good charcoal (Burkill, 1985-2000; Andary et al., 2005). Furthermore, interviews reveal that many household uses of *A. leiocarpa* that have been reported in literature - e.g. dyeing of clothes, tanning of hides to leather, using as mordant (e.g. Andary et al., 2005; Sacande and Sanogo, 2007) - were not of importance for villagers in this area.

Among the interviewed Gulimanceba people, the number of medicinal uses of *A. leiocarpa* was higher than that of the household uses. The antimicrobial and anthelmintic activity of its plant parts, based on its tannin content (up to 17%, based on dry matter), explain the medicinal properties of *A. leiocarpa* (Andary et al., 2005). Gansané et al. (2010) showed that the bark and leaves could even be used for the treatment of malaria. However, our interviews reveal that this use of *A. leiocarpa* was not of importance for Gulimanceba people in this area. In addition, the use of the bark to treat skin problems was also not mentioned by local people, though research has shown that the bark shows a specific activity on skin, called *anogelline*, which is now used in France in cosmetic anti-aging/smoothness skin creams (Andary et al., 2005).

Harvesting modes of A. leiocarpa

According to harvesting tools, our results suggest that leaf and fruit harvesting techniques resulted in sustainable use in this area as most people collected them by hand. Harvesting by hand causes less damage than with tools as it is more specific and removes less shoots and flower buds. However, chopping with an axe or a hoe to gain the branches is less specific and causes more damage. Nevertheless, Schumann et al. (2011) showed that *A. leiocarpa* is fairly resilient to chopping by producing a high number of sprouts and thus, secondary trunks.

In regard to preferences of tree individuals, our interviews reveal that some people prefer certain trees due to their wood quality. Further studies should investigate which criteria people use to differentiate *A. leiocarpa* individuals as a guide for harvesting and if the locally-recognized morphotypes seem to include a substantial amount of genetic variation.

Regarding the harvesting area, respondents stated fallows as their main areas of harvesting of *A. leiocarpa* which corresponds with results from Schumann et al. (2011).

Population development of A. leiocarpa

Presumably due to its high uses in this area, one would expect that the population of *A. leiocarpa* is declining. However, only half of the interviewed Gulimanceba people saw a decline of *A. leiocarpa* in this area. The results of Schumann et al. (2011) support the view of the respondents: Despite the high land-use and harvesting impact, the population of *A. leiocarpa* is still well preserved in this area, especially in fallows, due to its species ability of fast growing and high sprouting, and due to indirect positive influences of human activities by providing better environmental conditions for its recruitment. For Northern Burkina Faso, it was also shown that people did not see a decline of *A. leiocarpa* (Lykke et al., 2004). However, increasing pressure on *A. leiocarpa* due to current land-use intensifications may lead to a decline of the population in the future.

Conservation practices for A. leiocarpa

Even though respondents of our study did not actively protect and plant *A. leiocarpa*, one third of them declared that they spare some adult individuals of *A. leiocarpa* on croplands, when chopping the vegetation for agriculture. Nevertheless, most adult individuals on croplands are removed and recruiting individuals are generally removed. In fact, Schumann et al. (2011) demonstrated that individuals of bigger size classes (dbh >25 cm) were present on croplands, while saplings (dbh 1-5 cm) and individuals of small size classes (dbh 5-15 cm) were absent. Although local people did not spare seedlings (dbh 0-1 cm) of *A. leiocarpa* on croplands, Schumann et al. (2011) found a high number of seedlings on croplands. This is explained by the fact that *A. leiocarpa* is a fire-sensitive and shade intolerant pioneer species (Hennenberg et al., 2005; Sobey, 1978) and thus, the survival and the growth of seedlings of *A. leiocarpa* is favored on open areas. The absence of saplings and individuals of small size classes gives evidence of a declining population in croplands. However, the fact that *A. leiocarpa* has the ability to establish successfully during the fallow period (Schumann et al., 2011) permits a current maintenance of this important species in the agricultural cycle of cultivation and fallows. Even though, ongoing land-use intensifications due to strongly increasing cash-crop cultivation may lead to an increasing pressure on *A. leiocarpa* in the future. In fact, shortening or absence of fallow periods may prevent successful establishment of *A. leiocarpa* during the fallow period.

Overall, Gulimanceba people have a more passive attitude concerning the conservation of trees as they did not see the sparing of *A. leiocarpa* individuals on croplands as an active management and that sowing or planting of *A. leiocarpa* was never mentioned. Similarly, several studies across West Africa (e.g. Kristensen and Lykke, 2003) showed that local people have no tradition for planting of indigenous trees, as they are considered as “wild”.

Distribution of knowledge

Knowledge and perceptions of *A. leiocarpa* were fairly similar between men and women as well as between young and old people. However, harvesting and preparation were partly linked to gender as for instance, women are mainly responsible for chopping of branches of *A. leiocarpa* for fuel as they are in charge of cooking. In contrast, men are responsible for chopping of trunks and performing of construction works (personal observation). The lack of age differences suggests that the traditional knowledge about *A. leiocarpa* is not disappearing and that knowledge is passed on from one generation to another. Nevertheless, it has to be considered that the questions were relatively broad, whereas more detailed questions on medicinal use, for instance, could probably have revealed age differences (Lykke et al., 2004).

The informants' village origin influenced slightly knowledge and perception of *A. leiocarpa* even though villages are not situated far away from each other. Kristensen and Lykke (2003) also found more differences in knowledge between people from different villages than between genders and age-classes. Particularly people from the northernmost village Tapoa Djerma and southernmost Kombongou had slightly different knowledge and perceptions of *A. leiocarpa* in comparison to people from the other villages. These differences might be explained by influences resulting from the close neighborhood of these villages to the countries Niger and Benin. The fact that people did not spare individuals of *A. leiocarpa* on croplands in Tapoa Djerma might have led to a lower density of *A. leiocarpa* individuals in comparison to the other villages (personal observation). Furthermore, people from the southernmost village Kombongou did not see a decline of *A. leiocarpa*. This is in concordance with our field observations that individuals of *A. leiocarpa*, and especially recruiting individuals, are very common around this village.

Implication for conservation and sustainable management of A. leiocarpa

Our results provide, in combination with the results of Schumann et al. (2011) and other literature, appropriate management recommendations that are reliable under currently practiced management strategies in this area. Current local harvesting modes and management strategies resulted in sustainable use. Due to ongoing land-use intensifications, adapted harvesting and management techniques are required to guarantee the persistence of this species and to secure the harvesting for future generations. This might include the use of leaves instead of the bark of *A. leiocarpa* for the four most mentioned medicinal purposes in this area as leaf harvesting has less effect on the plant vitality and survival than bark removing. For instance, Gansané et al. (2010) showed that the leaves of *A. leiocarpa* could be alternatively used for the treatment of malaria instead of the bark as they display similar antiplasmodial activities. In our study area, the bark of *A. leiocarpa* was mainly harvested with a hoe. This tool seems appropriate as far as only small pieces are removed and if regeneration time is long enough. The National Forestry Department of Burkina Faso issued “good harvesting practices” for bark harvesting of *A. leiocarpa* to limit the damage to the trees; they include rules for the maximum quantity of bark that can be harvested (1–1.5 kg fresh bark per tree) (Andary et al., 2005). Regarding the harvesting period, the bark of *A. leiocarpa* was harvested at any time of the year in our study area. Andary et al. (2005) declared that the best period to harvest the bark of *A. leiocarpa* is at the end of the dry season because of the optimum concentration and condition for exploitation of the active principle *anogelline* present in the bark. However, Delvaux et al. (2010) demonstrated for other tree species that bark regeneration depends on humidity as the moisture content of the exposed wound is the most important factor allowing the start of the bark recovery process. Thus, bark harvesting at the end of the rainy season is more adequate to allow bark regeneration.

With regard to wood harvesting, chopping of branches can even exceed 50% of total branches per individual due to the high sprouting ability (Schumann et al., 2011). However, individuals with a dbh > 25 cm that have significantly higher seed production should be chopped to a lower degree. This would secure sufficient seed production. Furthermore, manual thinning of sprouts could be important to reduce the number of sprouts on the stump and encourage faster development of stems.

Conclusion

Our study is the first detailed quantitative ethnobotanical study of *A. leiocarpa*. Our interviews reveal that many uses of *A. leiocarpa* that have been reported in other parts of West Africa, e.g. dyeing of clothes, treatment of malaria, and skin problems, were not of importance for villagers in this area. Therefore, we conclude that local people could even more benefit from this important species given that the harvesting is carried out in a sustainable way. Furthermore, our study demonstrates how local knowledge and perceptions combined with ecological background information can help to design appropriate management recommendations. Hereby, our study emphasizes the importance of ethnobotanical studies on a small-scale level in order to develop management strategies that are reliable in the specific area under the specific circumstances.

Acknowledgments

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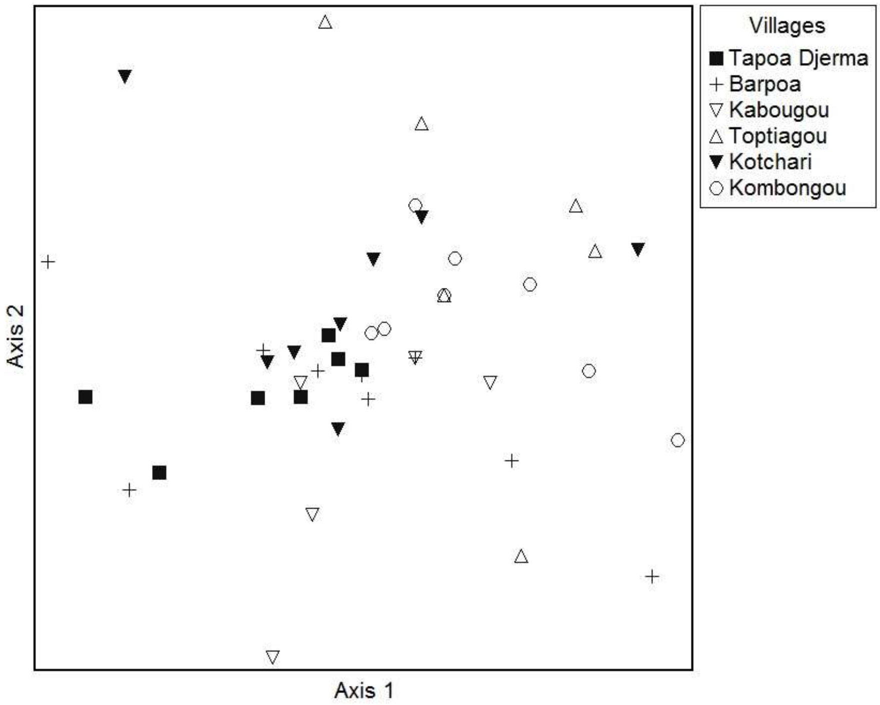
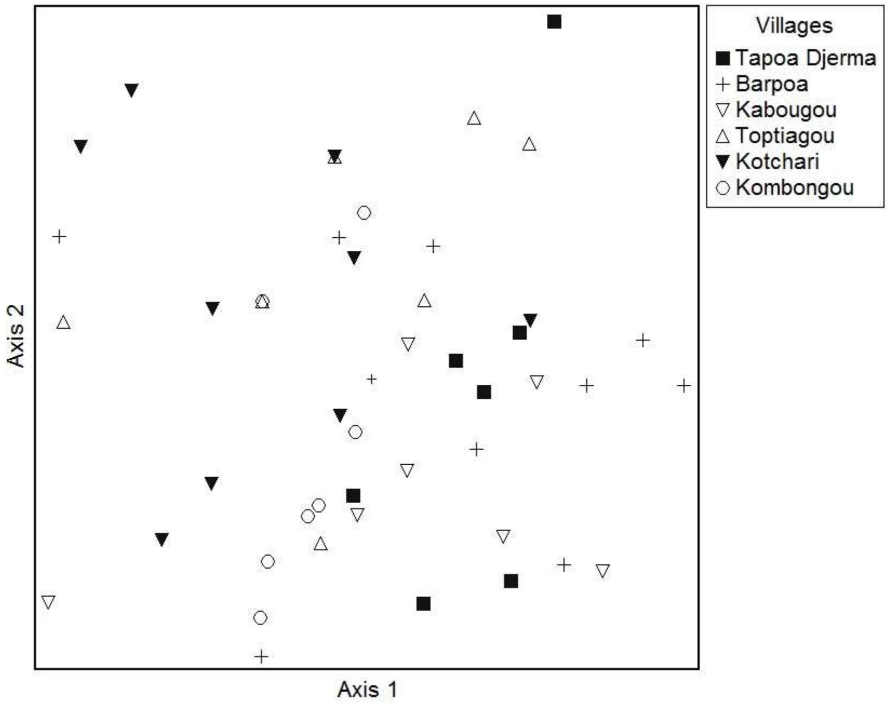
Appendix

Appendix 1 Preparation and application of the different medicinal and household uses.

	Preparation and application
Medicinal uses	
Cough	The decoction of the bark is served as drink.
Diarrhea	Bark: The decoction is served as drink (often with *bouillie*). Fruits: The decoction is served as drink. Leaves: The decoction is served as drink (often served with *bouillie*). Roots: The decoction is served as drink.
Dysentery	The decoction of the leaves is served as drink.
Eye disease	The eyes are washed with the decoction of the bark.
Fatigue	The body is washed with the decoction of the bark.
Hemorrhoids	Bark: The decoction is served as drink (often with *bouillie*) or used for washing. Leaves: The decoction is served as drink (often with *bouillie*) or used for washing. Roots: The decoction is served as drink (often with *bouillie*).
Parasites	Fruits: The roasted and crushed fruits are prepared with *bouillie* and served as drink. Leaves: The decoction is served as drink.
Stomach ache	Bark: The decoction is served as drink (often with *bouillie*). Fruits: The decoction is served as drink. Leaves: The decoction is served as drink (often served with *bouillie*). Roots: The decoction is served as drink.
Tooth ache	The teeth are washed with the decoction of the bark.
Vitamins for newborns and babies	The decoction of the leaves is served as drink and the babies are washed with the decoction.
Vomiting	The decoction of the leaves is served as drink.
Wounds	Fruits: The fruits are pounded and applied on the wound. Roots: The wound is washed with the decoction.
Yellow fever	Bark: The decoction is served as drink (often with *bouillie*) or used for washing. Fruits: The decoction is served as drink or used for washing. Leaves: The decoction is served as drink or used for washing. Roots: The decoction is served as drink or used for washing.
Household uses	
Construction wood	The poles and branches are used to build cases, roofs, sheds etc.
Dyeing of clothes	The decoction of the bark is used for dyeing of clothes.
Firewood	The branches are used to produce fire.
Soap	The wood is burned, the ash is filtered and deposed in a vessel, boiled, and mixed with sheabutter.
Surrogate for potash	The bark is burned and the ash is filtered and the potash is removed. The potash is used to prepare beans.



Appendix 2 PCA-scores along the first two axes of PCA analysis of *A. leiocarpa* uses. Each dot represents one informant (n = 46). Eigenvalue of first axis: 3.12 and of second axis: 2.93, explained variance of first axis: 11.6% and of second axis: 10.8%. Informants are indicated with symbols marking the village (correlation of village with first axis: t = 2.841, d.f. = 44, p < 0.01, r =-0.394).



Appendix 3 PCA-scores along the first two axes of PCA analysis of harvesting modes. Each dot represents one informant (n = 49). Eigenvalue of first axis: 3.41 and of second axis: 2.51, explained variance of first axis: 18.9% and of second axis: 14.0%. Informants are indicated with symbols marking the village (correlation of village with first axis: t = -3.685, d.f. = 47, p < 0.001, r = -0.473).

Chapter 7

Synthesis

During the last decades, West African savannas were subject to drastic human induced land-use changes. These changes have enormous ecological, economic, and social consequences. Understanding the impact of land-use on savannas is therefore necessary to cope with the increased land-use and provides insights for appropriate management activities that ensure the maintenance and sustainable use of savannas. The major objective of this thesis was to study the impact of land-use on savanna vegetation and plant species diversity as well as on populations of two important NTFP-providing tree species (*Adansonia digitata* and *Anogeissus leiocarpa*) in a West African savanna area.

By comparing the savanna vegetation and plant diversity of a protected area with its surrounding communal area (chapter 2), it has turned out that land-use influences savanna vegetation and diversity in multiple ways. The land-use effects were not only negative, as the diversity of the woody layer was even increased under human disturbances. Our findings suggest that land-use does not automatically lead to a lower number of plant species and to a degradation of savanna habitats and that communal areas are not necessarily characterized by lower diversity. However, there is a need for more studies that thoroughly analyze the “value” of the biodiversity (e.g. the commonness of the species and the importance of species for local people) in communal areas.

In conclusion, both protected areas as well as communal areas are of great importance for the conservation of savanna vegetation and plant diversity. However, it has to be considered that protected areas play a crucial role for the conservation of rare and highly used species by reducing the land-use impact. Furthermore, protected areas are important for the protection of vegetation and biodiversity on habitats that are frequently used for agriculture in communal areas. Land-use might have a greater impact on savanna vegetation and plant diversity in areas with higher human population densities. Therefore, more local case studies are needed to verify this assumption. Today with increasing cultivation of cash-crops and high demand for land, the vegetation of communal areas is at high risk of degradation and of biodiversity loss. Therefore, the effect of the intensified land-use on savanna vegetation and diversity should be investigated over the long-term. In addition, more studies are required that investigate the impact of land-use on population of tree species. Consequently, the impact of land-use – and in particular of harvesting - on populations of *A. digitata* and *A. leiocarpa* (chapter 3 and 4) were investigated. These two tree species were chosen as their NTFPs are highly used by the local population and as they show different levels of human protection and opposed life histories. *A. digitata* is protected on croplands by farmers during the agricultural cycle of cultivation and fallows, while *A. leiocarpa* is not or only partly preserved. *A. leiocarpa* is a pioneer species that displays high recruitment and *A. digitata* is a long-lived species, with low recruitment rates. The comparison of the findings of these two studies allows assessing if tree species with different life histories and protection levels respond differently to the land-use and harvesting impact.

Despite the intense harvesting and the land-use impact, populations of both species are still well preserved due to their specific, but opposed life histories and due to positive direct and indirect human activities. *A. digitata* can withstand the harvesting and land-use pressure by its longevity, extremely low adult mortality rates, and particularly due to positive human influences. In contrast, *A. leiocarpa* is able to withstand the impact of harvesting and land-use by its fast growing, high recruitment, and high sprouting ability. Populations of *A. digitata* benefit enormously from human activities, both directly (they are traditionally protected on croplands) and indirectly (dispersal of seeds with garbage). On the contrary, populations of *A. leiocarpa* profit only slightly and indirectly by human activities (providing of favorable environmental conditions for its recruitment). After all, I conclude that a none protected tree species (*A. leiocarpa*) is not necessarily at higher risk to harvesting and land-use than a protected tree species (*A. digitata*) as the adverse impact of harvesting and land-use can be compensated by its specific life history. In contrast, other studies in West Africa have shown that populations of none protected and harvested tree species (e.g. *Acacia* sp., *Afzelia africana*, *Khaya senegalenis, Pterocarpus erinaceus*) are declining due to land-use and harvesting impacts (Gaoue and Ticktin, 2007; Traoré et al., 2008; Nacoulma et al., 2011). This is presumably due to the fact that the adverse impact of harvesting and land-use on their population may not be compensated by their specific life histories. Nevertheless, it has to be considered that the response of species to land-use and harvesting may vary in combination with other factors, such as climatic conditions (e.g. Gaoue and Ticktin, 2007) or species-specific recovery rates from harvesting, e.g. wound recovery after bark harvesting (Delvaux et al., 2009). Thus, more population studies are required in order to detect these species-specific responses to harvesting and land-use and to develop adapted management strategies for each species or for species with similar protection levels and life histories. In conclusion, the two studies show the importance of jointly considering the protection status and the life history of species, when studying the impact of land-use and harvesting on population statuses and sustainable use of tree species.

Even though current management of both species in this area seems to be appropriate for sustainable use, land-use intensifications may lead to an increasing pressure on these species in the future. Therefore, adapted management strategies are needed to guarantee the persistence of these important species and to avoid a shortage of their products. The findings of both studies provide insight on the kind of management activities that may be most appropriate. Important additional information to these ecological findings can be provided by local people. Consequently, quantitative ethnobotanical interviews among the local people in the communal area of the W National Park were conducted (chapter 5 and 6).

Results show that local information about management strategies and perceptions about the population status of both species correspond well to ecological findings (chapter 3 and 4) and highlight the awareness of local people to their environment. The combination of the findings of the ecological and ethnobotanical studies (chapter 3-6) provides appropriate management recommendations for *A. digitata* and *A. leiocarpa* that are reliable under currently practiced management strategies in this area. These recommended management strategies may also be applicable outside the study area. However, more comparative studies in different climatic zones are required to evaluate this.

Overall, this thesis contributes to the improved understanding of the positive and negative impacts of land-use on both savanna vegetation and populations of important tree species in West Africa. A major conclusion that can be drawn from this thesis is that land-use influences savanna vegetation in a very complex way and that land-use does not necessarily lead to a decline of tree populations, loss of species, and degradation of savanna habitats. However, today with increasing cash-crop cultivation and high demand for land, savannas are at higher risk of degradation. Therefore, there is a need for more studies that assess the impact of land-use on population dynamics and structures of herb and woody species. These studies should consider the protection status and life history of the targeted species and should be conducted in different climatic zones. Furthermore, monitoring programs are required to investigate vegetation and population changes and to evaluate the effectiveness of management strategies being applied.

Summary

Savannas are the most important timber and non-timber forest products (NTFPs) providing ecosystems in West Africa. They have been shaped by traditional human land-use (i.e. agriculture, grazing, and harvesting) for thousands of years. In the last decades, land-use has drastically changed due to the rapid population growth and the growing production of cash-crop in West Africa and this process is still continuing. The percentage of land intensively used for agriculture has increased, while the length of fallow periods has decreased. Such changes have enormous ecological, economic, and social consequences. In the context of land-use changes, there is an urgent need to better understand and evaluate the impact of land-use on savannas. Such an understanding provides insights on appropriate management activities that ensure the maintenance of savannas and guarantee the availability of savanna products for subsistence and commercial use of rural West African people.

The major objective of the present thesis was to study the impact of land-use on savanna vegetation and diversity as well as on populations of two important NTFP-providing tree species in a semi-arid area in West Africa. The study area was located in the south-eastern part of Burkina Faso and comprised the protected W National Park and its adjacent communal area.

In the first study (chapter 2), I investigated in cooperation with a colleague from Burkina Faso (Blandine Nacoulma) the impact of land-use on the savanna vegetation. We analyzed which environmental factors determine the occurrence of the vegetation types and investigated the effect of land-use on vegetation structure and the occurrence of life forms and highly valued tree species. Furthermore, we tested whether land-use has an impact on plant diversity pattern and if this impact differed between the vegetation types and layers (woody and herb layer). Vegetation relevés were performed and the vegetation and plant diversity of the protected W National Park were compared with those of its surrounding communal area. Our results reveal five vegetation types occurring in both areas. Elevation and physical soil characteristics and thus soil water availability for plants played the most important role for the occurrence of the vegetation types. The influence of land-use on plant diversity differed between the five vegetation types and the two layers. The impact was highest on the vegetation types with the most favorable soil conditions for cultivation and lowest on rocky habitats with poor soils. While the diversity of the woody layer was increased under human land-use, the diversity of the herb layer was diminished. Overall, as land-use effects were not only negative, our findings suggest that land-use does not automatically lead to a loss of plant species and to a degradation of savanna habitats. We conclude that both protected and communal areas are of great importance for the conservation of savanna vegetation and diversity. Our study highlights furthermore the importance of different management strategies for each vegetation type.

In the following two studies (chapter 3 and 4), the impact of land-use - and in particular of harvesting - on populations of *Adansonia digitata* L., the baobab tree, and *Anogeissus leiocarpa* (DC.) Guill. & Perr. was examined. These two tree species were chosen as they provide several NTFPs for the local population and as they show different levels of human protection and opposed life histories. Thus, they may react differently to land-use. Stands of the protected W National Park were compared with those of its surrounding communal area (in fallows, croplands, and villages). I applied dendrometric methods to study the population structures and combined it with rates and patterns of NTFP-harvesting (debarking and chopping/pruning). Furthermore, the impact of land-use and harvesting on the fruit production of *A. digitata* and on the sprouting ability of *A. leiocarpa* were studied. The inverse J-shaped size class distribution curve indicates that the stands of *A. digitata* were in a healthy state in the park, while the low number of smaller size classes in fallows, croplands, and villages may give evidence of an ageing population. However, a high number of seedlings were recorded in villages. The stands of *A. leiocarpa* were also in healthy states in the park and likewise in fallows. In contrast, the absence of saplings gives evidence of a declining population in croplands. Both species were strongly harvested by local people and harvesting was tree size-specific. Pruning in interaction with tree-size had a significant impact on fruit production of *A. digitata*. While smaller trees were more vulnerable to pruning, bigger trees benefited from slight-pruning. *A. leiocarpa* had a great ability to respond to chopping by sprouting. The sprouting ability increased even with higher chopping intensity. Results suggest that despite the intense harvesting and the land-use impact, populations of both species are still well preserved. While *A. digitata* can withstand the harvesting and land-use pressure by its longevity, extremely low adult mortality rates, and particularly due to positive human influences, *A. leiocarpa* is able to withstand the use pressure by its fast growing, high recruitment, and high sprouting ability. I conclude that a none protected tree species (*A. leiocarpa*) might not necessarily be at higher risk to the harvesting and land-use impact than a protected tree species (*A. digitata*) as the adverse impact of harvesting and land-use can be compensated by its specific life history.

Important additional information to such ecological findings can be provided by local people. Learning from traditional knowledge and management systems of local people will help to produce culturally and ecologically reasonable conservation and management strategies. Thus, I investigated local uses and management strategies of *A. digitata* and *A. leiocarpa* in the last two studies (chapter 5 and 6). Quantitative ethnobotanical surveys among the Gulimanceba people were conducted in the communal area in order to document uses of the different plant parts, harvesting modes, perceptions about the population status, and conservation status of both species. Hereby, differences in knowledge between gender, generations, and people from different villages were tested. Interviews reveal that both species are harvested for multipurpose and emphasize the high importance of both species for local people. Especially the leaves and fruits of *A. digitata* add valuable minerals and vitamins to the otherwise micronutrient-“poor” staple crops of the Gulimanceba people. In comparison with other studies in West Africa, it has turned out that people in this area could benefit even more from *A. leiocarpa*, e.g. for dyeing of clothes, for treatment of malaria and skin problems. Local knowledge did not differ between genders and generations, while it slightly differed between people from different villages. The lack of age differences suggests that the traditional knowledge about these two species is passed on from one generation to another. Differences between people from different villages might be explained by influences from the neighboring countries Niger and Benin. Current local harvesting modes and management strategies of both species resulted in sustainable use. However, ongoing land-use intensifications require adapted harvesting and management techniques to guarantee the persistence of these economically important species. These results provide, in combination with the ecological findings (chapter 3 and 4), appropriate management recommendations for *A. digitata* and *A. leiocarpa* that are reliable under currently practiced management strategies.

Zusammenfassung

Die Savannen Westafrikas sind uralte Kulturlandschaften, die seit Jahrtausenden durch traditionelle menschliche Landnutzung (Ackerbau, Viehhaltung und Sammeln von Nichtholzprodukten) geformt werden. Die von den Savannen bereitgestellten Produkte und Dienstleistungen sind seit jeher von essenzieller Bedeutung für die ländliche Bevölkerung in Westafrika. Eine besondere Rolle nehmen dabei Nichtholzprodukte (z.B. Blätter, Borke, Früchte und Wurzeln) verschiedenster Pflanzenarten ein. Diese werden vor allem als Nahrung, Futtermittel, Heilpflanzen, Brennmaterial, Kosmetik, zum Bau von Häusern, Möbeln und Werkzeugen von der westafrikanischen Bevölkerung genutzt. Mit steigenden Populationszahlen ist der Druck auf die natürlichen Ressourcen in Westafrika stark gestiegen. Zur Sicherung des Lebensunterhaltes werden daher immer mehr natürliche Habitate in den Ackerbau mit einbezogen, die Brachezeiten verkürzt und es erfolgt ein verstärkter Einsatz von Düngemitteln und Pestiziden. Hinzu kommt, dass viele Kleinbauern vermehrt auf den gewerblichen Anbau von *cash-crops* (z.B. Baumwolle) setzen. Solche tiefgreifenden Veränderungen in der Landnutzung führen zu einem Verlust von natürlichen Habitaten und Artenvielfalt und bedrohen somit die Lebensgrundlage der ländlichen Bevölkerung in Westafrika. Im Zuge des Landnutzungswandels ist es daher dringend erforderlich, den Einfluss der Landnutzung auf Savannen besser verstehen und bewerten zu können. Ein solches Verständnis trägt dazu bei geeignete Managementstrategien entwickeln zu können, die den Schutz von natürlichen Habitaten und die Verfügbarkeit von Savannenprodukten für die ländliche Bevölkerung langfristig gewährleisten.

In der vorliegenden Arbeit habe ich den Einfluss der Landnutzung auf die Savannenvegetation und auf Populationen von zwei wichtigen Nutzholzarten in einem semiariden Gebiet in Westafrika untersucht. Das Untersuchungsgebiet befindet sich im südöstlichen Teil Burkina Fasos und umfasst den geschützten „W“ Nationalpark und sein angrenzendes Siedlungsgebiet. Der Landnutzungsdruck ist im Nationalpark relativ gering (illegale Beweidung und Jagd), wohingegen die natürlichen Ressourcen des Siedlungsgebiets stark durch den Menschen genutzt werden (Beweidung, Feldbau, Jagd und Sammeltätigkeiten). Ackerbau wird überwiegend in Form des Wanderfeldbaus betrieben, bei dem Anbau- und

Brachephasen alternieren. Abgesehen von einigen, kaum ertragreichen Standorten (sehr nasse, felsige oder flachgründige Böden), sind alle Flächen in den Anbau mit einbezogen. Dabei werden einige wichtige Gehölzarten auf den Feldern stehen gelassen (Agroforstwirtschaft). Es entsteht ein, für die westafrikanische Savannenlandschaft typisches, Feld-Brache-Mosaik.

In der ersten Studie (Kapitel 2) habe ich in Zusammenarbeit mit einer Kollegin aus Burkina Faso (Blandine Nacoulma) die Auswirkungen der Landnutzung auf die Savannenvegetation untersucht. Im Zentrum dieser Studie stand die Frage, welche Umweltfaktoren das Auftreten der Vegetationstypen bestimmen und welche Auswirkung die Landnutzung auf die Vegetationsstruktur und das Vorkommen von verschiedenen Lebensformen sowie wichtigen Gehölzarten hat. Darüber hinaus wurde untersucht, ob Landnutzung einen Einfluss auf die Pflanzenvielfalt hat und ob sich dieser Einfluss zwischen den verschiedenen Vegetationstypen und zwischen der Gehölz- und Krautschicht unterscheidet. Hierfür wurden Vegetationsaufnahmen durchgeführt und anschließend die Vegetation und Artenvielfalt des Nationalparks mit der des umliegenden Siedlungsgebiets verglichen.

Insgesamt konnten fünf Vegetationstypen unterschieden werden, die sowohl im Nationalpark als auch im Siedlungsgebiet vorkamen. Die Differenzierung der Vegetation war hauptsächlich durch das Relief und physikalische Bodeneigenschaften beeinflusst. Die Landnutzung hatte einen deutlichen Einfluss auf das Vorkommen von Lebensformen und wichtigen Gehölzarten. Sieben stark genutzte Baumarten wurden nur im Nationalpark gefunden und weitere wichtige Arten konnten nur selten im Siedlungsgebiet nachgewiesen werden. Dies mag zum einen an ihrer Übernutzung und der zunehmenden Zerstörung von natürlichen Habitaten liegen und zum anderen an der Tatsache, dass diese Arten nicht auf den Feldern geschützt werden. So konnten weitere stark genutzte, aber auf den Feldern stehen gelassene Baumarten häufiger in der Siedlungszone als im Nationalpark nachgewiesen werden. Der Einfluss der Landnutzung auf die Artenvielfalt unterschied sich eindeutig zwischen den fünf verschiedenen Vegetationstypen sowie zwischen der Gehölz- und Krautschicht. Am stärksten erwies sich der Einfluss auf Vegetationstypen mit den für den Ackerbau günstigsten Bodenverhältnissen und am niedrigsten auf Vegetationstypen mit kargen Böden auf felsigen Standorten. Während die Gehölzschicht generell eine höhere Artenvielfalt unter erhöhtem Landnutzungsdruck aufwies, zeigte die Krautschicht eine verminderte Artenvielfalt. Diese Ergebnisse unterstreichen die Bedeutung von vegetationstypbezogenen Managementstrategien und verdeutlichen, dass Landnutzung nicht ausschließlich negative Auswirkungen mit sich bringt und nicht unmittelbar zu einem Verlust von Arten und einer Degradierung von natürlichen Savannenhabitaten führen muss. Insgesamt lässt sich somit schlussfolgern, dass sowohl Schutzgebiete als auch angrenzende Siedlungsgebiete von großer Bedeutung für die Erhaltung der Savannenvegetation und Pflanzenvielfalt sind.

In den beiden darauffolgenden Studien (Kapitel 3 und 4) habe ich den Einfluss der Landnutzung - und im Besonderen der Sammeltätigkeiten - auf die Populationen von *Adansonia digitata* L., dem Affenbrotbaum, und *Anogeissus leiocarpa* (DC.) Guill. & Perr. untersucht. Diese beiden wichtigen Nutzholzarten wurden exemplarisch ausgewählt, da sie unterschiedlich stark vom Menschen geschützt werden und sich in ihren biologisch-ökologischen Eigenschaften unterscheiden. Die Grundannahme der Untersuchungen bestand daher darin, dass beide Arten unterschiedlich stark auf den Landnutzungseinfluss reagieren. Zur Untersuchung dieser Hypothese wurden die Populationsstrukturen beider Arten im „W“ Nationalpark mit denen im angrenzenden Siedlungsgebiet (in verschiedenen Landnutzungseinheiten: Brachen, Feldern und Dörfern) mit Hilfe dendrometrischer Methoden verglichen. Anschließend wurden die Populationsstrukturen der verschiedenen Landnutzungseinheiten in Zusammenhang mit Sammelintensitäten und -muster (Entborkung und Abholzung/Schneiteln) analysiert. Des Weiteren wurden die Auswirkungen der Landnutzung und des Sammelns auf die Fruchtproduktion von *A. digitata* und des Stockausschlags von *A. leiocarpa* untersucht.

Die Ergebnisse dieser Studien zeigen, dass die Populationen beider Arten stark durch die Landnutzung beeinflusst wurden. Eine relativ gute, natürliche Verjüngung und eine ausgeglichene Populationsstruktur konnten für *A. digitata* im Nationalpark nachgewiesen werden. Die geringe Anzahl von Individuen in den kleinen Durchmesserklassen weist hingegen auf überalterte Populationen in Brachen, Feldern und Dörfern hin. Eine hohe Anzahl von Keimlingen wurde jedoch in Dörfern gefunden. Die Bestände von *A. leiocarpa* befanden sich sowohl im Nationalpark als auch in den Brachen in einem guten, sich verjüngenden Zustand. Im Gegensatz dazu deutet das Fehlen von Jungwuchs auf den Feldern auf eine dort abnehmende Population hin. Die Studien zeigen außerdem, dass beide Arten, abhängig von ihrer Größenklasse, stark von der lokalen Bevölkerung besammelt wurden. Schneiteln wirkte sich nachteilig auf die Fruchtproduktion von kleineren *A. digitata* Individuen aus, während geringes Schneiteln die Fruchtproduktion größerer Bäume förderte. *A. leiocarpa* reagierte auf Abholzung mit starkem Stockausschlag und mit zunehmender Abholzungsintensität nahm die Anzahl der Stockaustriebe zu.

Die Ergebnisse verdeutlichen, dass die Populationen beider Arten trotz der intensiven Besammlung und des Landnutzungseinflusses noch relativ gut erhalten sind. *A. digitata* kann den Sammel- und Landnutzungsdruck durch seine Langlebigkeit, eine extrem geringe Sterberate und vor allem durch parallel stattfindende anthropogene Förderung kompensieren. In der Tat profitieren Populationen von *A. digitata* in großem Maße, sowohl direkt (sie werden traditionell auf Feldern stehen gelassen) als auch indirekt (die Samen werden im Müll ausgebreitet) von anthropogenen Aktivitäten. *A. leiocarpa* hingegen hält dem Nutzungsdruck durch schnelles Wachstum, hohen Verjüngungsraten und starkem Stockausschlag stand. Populationen von *A. leiocarpa* werden nur geringfügig und indirekt durch menschliche Aktivitäten (Schaffung von günstigen Bedingungen für den Jungwuchs) gefördert. Insgesamt lässt sich also feststellen, dass eine nicht durch den Menschen geschützte Baumart (*A. leiocarpa*) nicht zwangsläufig einem größeren Risiko gegenüber dem Sammeln und der Landnutzung ausgesetzt ist als eine geschützte Art (*A. digitata*). Die nachteiligen Einflüsse der Nutzung können durch artspezifische biologisch-ökologische Eigenschaften kompensiert werden. Andere Studien in Westafrika haben hingegen gezeigt, dass sich Populationen von nicht geschützten Nutzholzarten (z.B. *Acacia* sp., *Afzelia africana*, *Khaya senegalenis, Pterocarpus erinaceus*) aufgrund des Sammel- und Landnutzungseinflusses im Rückgang befinden. Bei diesen Arten können offensichtlich die nachteiligen Auswirkungen des Sammelns und der Landnutzung nicht durch artspezifische biologisch-ökologische Eigenschaften kompensiert werden. Hierbei ist jedoch zu bedenken, dass der Einfluss der Landnutzung und des Sammelns in Kombination mit anderen Faktoren, wie zum Beispiel klimatischen Bedingungen und artspezifischen Eigenschaften (z.B. Wundheilung nach Entborkung) variieren kann. Zudem hängt der Einfluss stark von der Bevölkerungsdichte und somit von der Nutzungsintensität ab. Es wird also deutlich, dass weitere arteigene Populationsstudien dringend erforderlich sind, um diese spezifischen Reaktionen auf das Sammeln und die Landnutzung zu ermitteln und angepasste Managementstrategien entwickeln zu können.

Die Berücksichtigung von lokalem Wissen und traditionellen Managementsystemen kann erheblich dazu beitragen, kulturell und ökologisch sinnvolle Schutz- und Managementstrategien zu entwickeln. Folglich habe ich in den letzten beiden Studien (Kapitel 5 und 6) lokale Verwendungen und Managementstrategien von *A. digitata* und *A. leiocarpa* untersucht. Dazu wurden quantitative ethnobotanische Befragungen bei den Gulimanceba, der dominierenden lokalen Bevölkerungsgruppe im Untersuchungsgebiet, durchgeführt. Die lokalen Verwendungen der verschiedenen Pflanzenteile und Sammelpraktiken wurden dokumentiert und die Wahrnehmung über den Schutz und Zustand beider Arten wurden erfasst. Dabei wurden Unterschiede im Wissen zwischen den Geschlechtern, Generationen und zwischen Bewohnern verschiedener Dörfer untersucht.

Die Ergebnisse der Umfragen zeigen, dass beide Arten für zahlreiche Zwecke genutzt werden (z.B. zur Ernährung, als Medizin, als Bau- und Brennholz) und unterstreichen deren hohe Bedeutung für die lokale Bevölkerung. Vor allem die Blätter und Früchte von *A. digitata* ergänzen die spurenelementarme Nahrung der Gulimanceba mit wertvollen Mineralien und Vitaminen. Im Vergleich mit anderen Studien in Westafrika stellt sich heraus, dass die Menschen aus dieser Gegend sogar noch mehr von *A. leiocarpa* profitieren könnten, z.B. beim Färben von Kleidung, bei der Behandlung von Malaria und Hautproblemen. Das lokale Wissen über die beiden Arten unterschied sich kaum zwischen den Geschlechtern und Generationen. Dies lässt darauf schließen, dass traditionelles Wissen nach wie vor von Generation zu Generation weiter gegeben wird und nicht verloren zu gehen droht. Geringfügige Unterschiede konnten hingegen zwischen den Antworten von Befragten verschiedener Dörfer ermittelt werden. Dies hängt vor allem mit Einflüssen aus den benachbarten Ländern, Benin und Niger, zusammen. Anhand der Befragungen lässt sich ferner feststellen, dass die gegenwärtigen lokalen Sammeltechniken und Managementstrategien beider Arten nachhaltig sind. Allerdings erfordern anhaltende Landnutzungsintensivierungen angepasste Sammel- und Managementtechniken, um das Fortbestehen dieser ökonomisch wichtigen Arten zu gewährleisten. Mit Hilfe der Ergebnisse aus diesen beiden Studien und in Kombination mit den gewonnenen Erkenntnissen aus den ökologischen Studien (Kapitel 3 und 4) können angemessene Managementempfehlungen für *A. digitata* und *A. leiocarpa* formuliert werden, die unter den derzeit praktizierten Managementstrategien anwendbar und tragbar sind.

Insgesamt trägt die vorliegende Arbeit zu einem besseren Verständnis des sowohl positiven als auch negativen Landnutzungseinflusses auf die Savannenvegetation und auf die Populationen von wichtigen Gehölzarten in Westafrika bei. Die Studien zeigen, dass Savannen in einer sehr komplexen Weise durch die Landnutzung beeinflusst werden. Die hier dargelegten Ergebnisse zeigen ferner, dass Landnutzung nicht zwangsläufig zu einem Rückgang von Baumpopulationen, dem Verlust von Arten und einer Zerstörung von Savannenhabitaten führen muss. Durch die anhaltenden Landnutzungsintensivierungen sind Savannenhabitate jedoch einem immer größeren Risiko der Zerstörung ausgesetzt. Deshalb sind weitere Studien erforderlich, die den Einfluss der Landnutzung auf Populationsdynamiken und –strukturen von krautigen und holzigen Arten untersuchen. Diese Studien sollten den Schutzstatus und die biologisch-ökologischen Eigenschaften der untersuchten Arten berücksichtigen und in verschiedenen klimatischen Zonen durchgeführt werden. Darüber hinaus sind Monitoring-Programme notwendig, um Vegetationsveränderungen der Savannen zu beobachten und um den Erfolg der angewendeten Managementstrategien zu überprüfen.

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