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Documentation, Evaluation and Impact Assessment of Sustainable Land Management Technologies on Vegetation Cover in Senegal

Two case studies from a silvopastoral and an agropastoral land use system

Master thesis "Environmental Sciences"

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WOCAT
World Overview of Conservation Approaches and Technologies

CSE

Pictures on cover page:

Sustainable agroforestry parkland (left) and conventional pastureland (right) in the silvopastoral land use system of the Ferlo, northern Senegal (pictures by J. Zähringer, 2009)

Abstract

Land degradation (or desertification) is a big concern in semi-arid landscapes and land users are applying a wide range of sustainable land management (SLM) technologies in order to mitigate this threat. Vegetation cover through tree species is important for reducing wind and water erosion through soil stabilization, improving soil fertility and water availability and at the same time providing resources for humans and cattle. Many SLM technologies are therefore based on the improvement of vegetation cover. The WOCAT (World Overview of Conservation Approaches and Technologies) database aims at documenting the local SLM knowledge and distributing it around the globe.

In the present thesis different agroforestry and forestry technologies applied by local land users in a silvopastoral and an agropastoral region in northern Senegal were documented for the WOCAT database. Different parameters of woody vegetation were investigated in SLM sites and the conventional land use system in the respective area. The aim was to see if tree biodiversity parameters, canopy cover and regeneration density were higher under sustainable than conventional land management. In addition it was tested if SLM technologies increased the availability of tree species useful to the local population.

In the silvopastoral land use system tree density, species richness and diversity and canopy cover were significantly higher in sites under SLM than under the conventional land management systems of extensive pastoralism and crop production. The same applied to tree regeneration. SLM technologies further harbored higher densities of trees providing fodder, food or medicine than sites under CLM. For the agropastoral land use system no general difference of vegetation parameters was found between SLM and CLM but single SLM technologies either had higher trees species richness and diversity or higher tree density than the CLM of extensive pastoralism. In general regeneration of tree species was rare in the majority of the assessed land use types in the silvopastoral as well as the agropastoral land use system (the two prevailing land use systems in the North). This indicates that despite the variety of sustainable land management technologies applied, vegetation cover in northern Senegal is facing decline and specific action is needed in order to avoid further land degradation.

Résumé

La dégradation des terres dans les zones semi-arides est une contrainte majeure pour les exploitants locaux qui par conséquence ont recours à des technologies de gestion durable à fin d'atténuer cette menace. La couverture végétale des espèces ligneuses joue un rôle important dans la réduction de l'érosion éolienne et aquatique, dans l'amélioration de la fertilité du sol ainsi que dans la disponibilité de l'eau dans le sol. En même temps, elle offre une variété de produits utilisés par l'homme et son bétail. Une bonne partie des technologies utilisées est de ce fait basée sur l'amélioration de la couverture végétale. La base de données du WOCAT (Panorama Mondial des Approches et Technologies de Conservation) a comme objectif de documenter les connaissances locales sur la gestion durable ainsi que de les vulgariser dans le monde.

Dans le cadre de ce travail de Master, les technologies agroforestières ou forestières dans deux systèmes d'occupation du sol - sylvo-pastoral et agro-pastoral - au nord du Sénégal ont été documentées pour la base de données du WOCAT. Pour ces deux systèmes, la végétation ligneuse des sites sous gestion durable et sous système conventionnel a été investiguée. Le but était de déterminer si les paramètres de la biodiversité ligneuse, la couverture et la densité de la régénération étaient plus élevés dans les sites sous gestion durable par rapport aux sites sous gestion conventionnelle. En outre, les différences dans la disponibilité des espèces utilisées par les populations locales ont été analysées.

Dans la zone sylvo-pastorale, la densité des arbres, ainsi que la richesse et la diversité des espèces ligneuses étaient considérablement plus élevées dans les sites sous gestion durable que dans ceux sous gestion conventionnelle (pastoralisme extensif et agriculture pluviale). Les mêmes résultats ont été obtenus concernant la régénération des espèces ligneuses. Par ailleurs, la densité d'arbres exploités pour la nourriture, le fourrage ou les produits médicinaux était élevée sous gestion durable. Dans la zone agro-pastorale, les résultats n'ont pas révélé de différences significatives entre les paramètres de la végétation dans les sites sous gestion durable et dans ceux sous gestion conventionnelle. Néanmoins, les sites sous gestion durable présentent soit une richesse et une diversité plus élevées, soit une densité plus élevée que dans les zones sous gestion conventionnelle (pastoralisme extensif). En général, la présence de la régénération ligneuse était très faible dans la majorité des systèmes sylvo-pastoraux et

agro-pastoraux. Ceci indique qu'en dépit des technologies de gestion durable utilisées, la couverture végétale au Nord du Sénégal fait face à un déclin. Des actions spécifiques de plantation, régénération naturelle assistée ou préservation de la végétation naturelle sont nécessaires pour éviter une dégradation accélérée de la terre.

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List of abbreviations

Institutional

ACDI	Agence Canadienne pour le Développement International
CSE	Centre de Suivi Ecologique
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCFA	Franc Communauté Financière d'Afrique
GEF	Global Environmental Facility
GPF	Groupe de Promotion des Femmes
IMF	International Monetary Fund
JICA	Japan International Cooperation Agency
LADA	Land Degradation Assessment in Drylands
NGO	Non Governmental Organization
PAPEL	Projet d'Appui à l'Elevage
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
USD	United States Dollar
WOCAT	World Overview of Conservation Approaches and Technologies

Technical / Scientific

C	Carbon
Ca	Calcium
CBH	Circumference at Breast Height
CLM	Conventional Land Management
DBH	Diameter at Breast Height
ex	exotic
GAA	Geographical Assessment Area
GDP	Gross Domestic Product
GPS	Global Positioning System
H'	Shannon diversity index
ind	indigenous
Ind.	Individuals
K	Potassium
LM	Land Management
Log	Logarithm
Mg	Magnesium
N	Nitrogen
No.	Number
P	Phosphorus
QA	Questionnaire on SLM Approaches
QT	Questionnaire on SLM Technologies
SLM	Sustainable Land Management

SPSS	Statistical Package for the Social Sciences
SWC	Soil and Water Conservation
UTM	Universal Transverse Mercator

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1. Introduction

1.1. Context

About 41% of the earth's surface is covered by drylands and it is thought that about 10-20% of the formerly productive world's drylands suffer from the process of desertification (Dregne, 2002). Desertification is defined by the United Nations Convention to Combat Desertification (UNCCD) as "land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1994). Land degradation means the diminution or reduction of the resource potential (biological productivity) through one or a combination of processes acting on the land. These processes include water erosion, wind erosion, sedimentation, crusting and hardsetting of soils, salinization and alkalinization, and long-term reduction in the amount or diversity of natural vegetation (Dregne, 2002). The consequences of land degradation are diverse and include reduced productivity, damage to ecosystems and socio-economic problems such as uncertainty in food security, migration or limited development (FAO, 2008). Desertification is linked to climate change trough the release of CO_2 from cleared and dead vegetation and through the reduction of the carbon sequestration potential of desertified land (Gonzalez, 2001). Tree species protect land from degradation and mitigate climate change through the provision of multiple ecosystem services, including soil erosion control, storage and transpiration of water required for precipitation, carbon sequestration and the availability of habitats for plant and animal species (Gonzalez, 2001). The total annual cost of desertification expressed as income foregone, is estimated at about 42 thousand million US-Dollars in 1990 (Dregne & Chou, 1992). This number does not take into account the hidden costs of increased fertilizer use, loss of biodiversity etc. (FAO, 2008). Rehabilitation of degraded land is very costly and depending on the extent of degradation it might not be possible to restore the ecosystems functions.

Despite the global importance of this issue, to date only two studies of global coverage have been conducted to assess the extent of land degradation in drylands. The best known is the Global Assessment of Soil Degradation (Oldeman et al., 1991) which has been based only on expert opinion whereas the second one by Dregne and Chou (1992) was based on secondary sources but no measurement-based global follow-up was conducted (Safriel & Adeel, 2006). The ongoing LADA project implemented by FAO and UNEP is trying to fill this gap. The goal of creating a basis for informed policy advice on land degradation at global, national and local level is to be reached through the assessment of land degradation at different spatial and temporal scales. However, knowledge about the degradation of land is not the only issue of importance but also about what is being done to halt it. WOCAT is a global network developed by soil and water conservation (SWC) specialists with the mission to document the valuable knowledge of locally used SWC technologies and approaches. It provides the tools for SWC specialists to share their knowledge and to facilitate the search for existing technologies and approaches.

Senegal is one of six pilot countries which participate in the LADA project with the "Centre de Suivi Ecologique" (CSE) as the implementing body (FAO, 2008). In Senegal, land degradation is a big concern with 47% of soil being unfit for farming and 37% having a poor-average production capacity (Lô Planchon, 2003). A quick survey conducted by the CSE showed that local land users apply a wide range of sustainable land management (SLM) technologies in order to halt land degradation (CSE, 2009c), as they do in the neighboring Sahelian countries (Kessler et al., 1998; Liniger & Critchley, 2007; Wezel & Rath, 2002). Only three of these technologies have been documented within the WOCAT network so far and all of them are structural measures[1]. This thesis intends to make local knowledge about further SLM technologies available to a wide range of land users, researchers, policy makers or donors through the WOCAT network.

1.2. Objectives

The greater objective of this work is to contribute to the extension of sustainable land management in drylands through the LADA (Land Degradation Assessment in Drylands) project and the WOCAT (World Overview of Conservation Approaches and Technologies) network.

[1] Written personal communication of Hauert, C.; Bern, 01.02.2010.

Main objectives are:

- to document local sustainable land management technologies from Senegal for the WOCAT database
- to assess the impact of SLM technologies on the extent of vegetation cover and vegetation composition compared to areas under conventional land use

Subordinate objectives are:

- to document local approaches that led to the establishment of SLM technologies for the WOCAT database
- to see which SLM practices contribute to the preservation of plant species useful for local communities

1.3. Land Degradation Assessment in Drylands (LADA)

LADA is a four-year project which was started in 2006 to respond to the need for up-to-date and comparable information on land degradation in drylands (FAO, 2008). The main purpose is to create a basis for informed policy advice on land degradation at global, national and local level (FAO, 2008). The project is funded by the Global Environmental Facility (GEF), implemented by the United Nations Environmental Program (UNEP) and executed by the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2008).

LADA contributes to the fight against land degradation by:

- providing a framework of tools and methods to assess land degradation from the local to the national, regional and global scale
- accessing the extent, type, rate and impact of land degradation at a global level in six pilot countries (Argentina, China, Cuba, Senegal, South-Africa, Tunisia)
- providing a framework for establishing a baseline in order to monitor the success of activities that fight land degradation
- increasing national capacities for assessing and monitoring land degradation

Using the LADA methods, the areas at greatest risk for land degradation can be identified. The detailed local assessment can focus on the root cause analysis for land degradation and on local (traditional and adapted) technologies for sustainable land management (SLM). The project is based on the assumption that human activities are the main driver for land degradation (FAO, 2008).

In Senegal, the Centre de Suivi Ecologique (CSE) was implementing the LADA methodology to assess the state of land degradation on different scales. This thesis was conducted in the frame of the LADA local assessment and data was collected during fieldwork in two out of three chosen geographical assessment areas (GAA) in Senegal: Barkédji and Lompoul. GAA's represent nationally important land use systems containing areas of significant land degradation or sustainable land management activity. Within each GAA several study areas are chosen that are small enough to be covered during a field assessment. They can be community territories, watersheds or other areas representative of the land use system (McDonagh & Bunning, 2009a).

1.4. World Overview of Conservation Approaches and Technologies (WOCAT)

One of the reasons why soil and water degradation still persists despite many years of effort and investment in SWC measures, is that SWC knowledge often remains a local resource, unavailable to others who work in the same area. WOCAT is a global network developed by SWC specialists with the mission to document this knowledge. It has therefore developed tools to document and analyze SWC know-how and to allow it to spread around the globe. The tools include three comprehensive questionnaires and a database to document all relevant aspects of SLM technologies (Liniger & Schwilch, 2002). SLM in the context of WOCAT is defined as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long term productive potential of these resources and the maintenance of their environmental functions". The idea of WOCAT is that by analyzing field experience, the effectiveness of SLM measures should be improved. To reach this goal a better understanding of the reasons behind successful experiences with SLM has to be achieved. As the reasons for failure are equally important for the analysis, not only so-called successful examples of SLM should be documented. SWC specialists who are interested in finding a SLM technology that can be adapted to their situation in the field have access to this information through the WOCAT query system. This system includes e.g. climatic and slope conditions, the degradation processes to be tackled, farming systems or the desired level of costs and inputs. The database is accessible on the internet and on CD-ROM. Hopefully, with the help of WOCAT, decision-making in land management will be improved and funds for SWC measures spent in a better way (Liniger et al., 2008).

1.5. Senegal

1.5.1. Physical conditions and climate

Senegal is located at the westernmost tip of Africa in the Sahel region with a surface of 200,000 km^2. It has a common border with Mauritania in the North, Mali in the Southeast, Guinea and Guinea-Bissau in the South (Seck et al., 2005). The estimated population size is 13,512,000 (CIA, 2009). The Human Development Index for Senegal is 0.502 which gives it a rank of 153rd of 179 countries with data available (UNDP, 2009). Since the first big drought in 1972 and the oil recessions in 1973 the country has been in an economically severe situation.

The climate in Senegal is mainly Sahelian with the following climate types from North to South:

- Desert-like Sahelian climate with annual rainfall < 350 mm
- Dry-continental Sahelian-Sudanese climate with annual rainfall between 350 and 700 mm
- Cooler and drier Sahelian-Sudanese climate with annual rainfall between 700 and 900 mm
- Sudanese climate with annual rainfall between 900 and 1'000 mm
- Sudanese-Guinean climate with annual rainfall between 1'000 and 1'200 mm

Two distinct seasons can be distinguished:

- A rainy season from June to October caused by hot and humid monsoon wind from the St.Helena anticyclone
- A dry season from November to May where prevailing winds blow from the North (maritime trade winds from the Azores anticyclone and the Harmattan from the Libyan anticyclone)

Senegal's winds play a critical role in the productivity of its agricultural systems (Seck et al., 2005).

West Africa has experienced the most substantial decline in rainfall recorded in the world since measurements began in the late 1800s (Nicholson, 2000). Over the last 3 decades rainfall has dropped by 30-40 %. The period from 1972 to 1984 has been marked by a succession of very dry years. As with other Sahelian countries, Senegal has been hit hard by these droughts (Seck et al., 2005).

1.5.2. Socio-economic situation

The gross domestic product (GDP) per capita was estimated at 1,800 USD in 2008 and GDP growth was averaging over 5% annually from 1995 to 2008. Unemployment concerns 48% of the population (2007 estimate). In 2001, 54% of the population was estimated to live below the poverty line (CIA, 2009). *Table 1* presents some socio-economic indicators for Senegal.

Table 1. Socio-economic data for Senegal

Economic Indicator[2]	GDP (2008) per capita	1,800 USD
	GDP	21.9 billion USD
Agriculture[1]	Arable land (2001)	3,800,000 ha
	Irrigated land (2001)	76,000 ha
Population	Annual growth rate (2009)[2]	2.709 %
	Rural population (2003)[1]	51.1 %
	Urban population (2003)[1]	48.9 %
	Life expectancy (2009)[2]	59 years
Distribution (2001)[1]	Agriculture	70%
	Services	15%
	Industry	15%

[1] Seck, Na Abou et al. (2005)
[2] CIA 2009

As is the case for the rest of the Sahel region, the most important constraints for rural development are extremely poor soil fertility, extreme aridity during a long dry season and socio-economic conditions (Breman & Kessler, 1997).

1.5.3. Agriculture

Agriculture represents an essential sector of the Senegalese economy, involving about 60% of the population (Ndiaye, 2001). About 12% of the territory is under agricultural production. The main constraints are irregular rainfall and productive soils which suffer from erosion, salinization and a decline of fertility. Irrigation is only present on 4% of the cultivated area while the rest of production depends on rainfall (Boye, 2001).

For a long time Senegal was the world's leading groundnut producer and groundnut production was seen as the driver for economic growth. However, the monoculture production created huge damage to its' soil resources (Ndiaye, 2001; Seck et al., 2005). The drought of the 1970's revealed this crisis and stimulated the World Bank and the International Monetary Fund (IMF) to encourage a new agricultural policy. The green revolution that was expected as an outcome was never achieved (Mbow et al., 2008; Ndiaye, 2001). Today there are still few diversifications. The main cultures are millet, sorghum, maize, rice, cotton, groundnut and cowpeas. Only cotton and groundnut are produced for exportation. As the country is not able to satisfy its demand for food, about 500,000 tons of cereal are imported every year (Boye, 2001).

Agricultural production is mainly a family business. About 120 agricultural production units, each with a surface of up to 10,000 ha are in the hand of Islamic leaders, the marabous. The rest of agricultural production stems mainly from small family enterprises with a surface of 1 to 10 ha (Boye, 2001).

In general, production has declined during the last 10 to 15 years because of slow modernization, climatic change, decreasing soil fertility and political factors (Boye, 2001; Ndiaye, 2001).

1.5.4. State of the environment

During the last 40 years a threefold increase of the population in Senegal has left its scars on the state of the environment (FAO, 2007). An analysis of land cover and land use changes in Senegal over the past 35 years showed that the country is still dominated by a great diversity of land cover types, with less than a quarter of its area devoted to food production. One area of concern is the loss of more than half of the country's forests in just 35 years (Tappan et al., 2004). Forest degradation in Senegal is estimated at 250,000 ha of wooded savanna every year or 2% of the country's wood resources (UNDP & GEF, 2002). Humans are probably the most important agent of change, responsible not only for agricultural transformation but also for great modifications in wooded savannas. The demand for fuel, particularly in the form of charcoal, is the driver of logging in all regions with woody resources. It has led to a moderate to severe degradation of 28% of the wooded savannas and woodlands (Tappan et al., 2004).

Soils in Senegal are often highly weathered and have low to moderate fertility. Low organic matter contents, low native phosphorus (P) concentration and low cation exchange capacity are characteristics of soils with sandy to sandy loam surface horizons (Bernatchez et al., 2008). In the agricultural zones the majority of soils is degraded due to effects linked to the rotation of groundnut-millet without the application of fertilizers, shortened fallow periods and the overexploitation of vegetation cover (Floret et al., 1993). These processes accelerate the wind and water erosion through which the fertile topsoil layer is being removed, causing a decline of soil organic matter and a decrease in the water retention capacity of the soil. The consequence is a dramatic decrease of crop yields (Sanogo et al., 2000).

In order to halt desertification, reduce water and wind erosion hazards, improve biodiversity, food security and other services, so-called "improved" agroforestry practices have been promoted in the region in addition to already existing traditional agroforestry systems (Takimoto et al., 2008).

2. State of research

2.1. Drylands and desertification

Drylands are defined as areas with an aridity value index of less than 0.65 which is defined as the ratio of mean annual precipitation to mean annual evaporative demand. Scarcity of water constrains their two major interlinked services: primary production and nutrient cycling. Drylands occupy around 41% of the earth's surface and are home to about one third of the world's human population. As 90% of those people live in developing countries, socio-economic conditions lag far behind that of people in other areas. Rangeland and cropland account for 90% of the drylands area, often supporting an agropastoral livelihood (Safriel & Adeel, 2006). *Figure 1* shows the distribution of drylands and the different sub-types in the world.

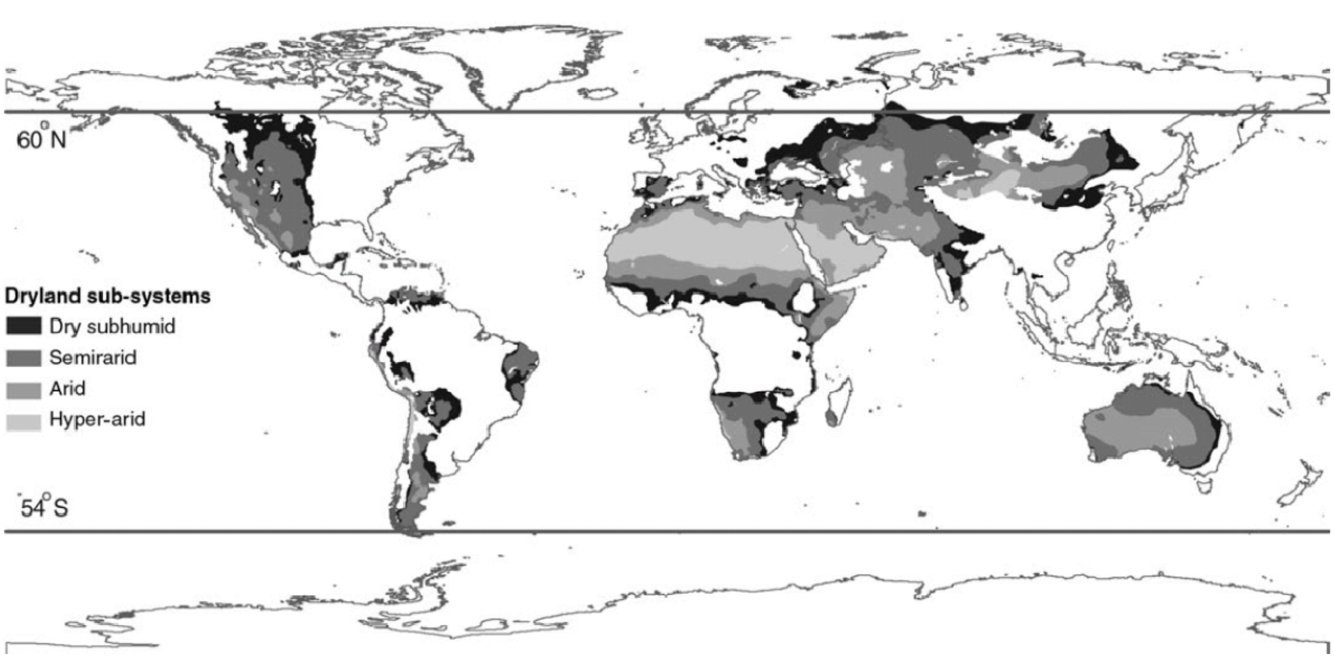


Figure 1. Dryland systems and subtypes; source: Safriel & Adeel (2006)

Two approaches exist to explain the causes of land degradation in drylands: The non-equilibrium approach (Westoby et al., 1989) focuses on the role of external disturbances such as annual rainfall and its variability. Carbon cycling, productivity and species composition in drylands are controlled by disturbances rather than by internal regulatory mechanisms such as density or competition. Especially in arid lands drylands are far-from-equilibrium systems. Apart from rainfall variability, other forcing factors can be depletion of vegetation by herbivores or fire (Puigdefabregas, 1998). The equilibrium approach on the other hand favors anthropogenic pressures as the cause of degradation (Breman & Dewit, 1983). The greatest difficulty in assessing land degradation in semi-arid regions is to separate the effect of human influence from the effect of inter annual climatic fluctuations (Diouf & Lambin, 2001). In the Sahel a decline in rainfall and an increase in human population occurred simultaneously during the last century. Therefore it is likely that both approaches are important to explain the degradation of its ecosystems (Vincke et al., 2010).

Numerous dryland plant species with different growth forms provide the ecosystems most important services such as water regulation and soil conservation through their ground cover and structure. Some single species are directly involved in a wide range of ecosystem services. *Acacia senegal* for example provides for soil development and conservation (roots, canopy and litter), forage (leaves and pods), fuel wood (dead twigs) and food (edible gums) (Safriel & Adeel, 2006). Many of the world's widely cultivated crops such as wheat, barley, sorghum, millet and cotton, have their origin in drylands. In the past, civilizations relied heavily on those resources (Puigdefabregas, 1998).

2.2. Soil fertility and the importance of trees

Soil fertility is the capacity of soil to support the growth of plants on a sustained basis (Young, 1990). Tropical soils naturally have low fertility for the following reasons: weak cation retention capacity, deficiency of major elements because of thousands of years of soil impoverishment, frequent deficiency in micro elements and aluminum toxicity. Root growth and therefore plant nutrition can seriously be limited by aluminum toxicity which can block root nodulation and therefore reduce nitrogen fixation in leguminous species (Legros, 2007).

Soils suffer from many forms of degradation such as erosion, physical, chemical and biological degradation, salinization and pollution. All of these lead to a decrease in soil fertility and land productivity. A decline in soil fertility is one of the most frequent problems observed over a wide range of environments. It lowers obtainable crop yields on the basis of intrinsic soil fertility but can also reduce the response to fertilizers or other inputs. The primary objective of soil conservation is therefore to maintain fertility. To achieve this, erosion control is an important condition, together with maintenance of the physical, chemical and biological properties (Young, 1990). Soil conservation is essential for maintaining the soil supporting services of dryland ecosystems and it’s failure is a key driver for desertification (Safriel & Adeel, 2006).

Trees occupy a very important role in soil conservation as they strongly influence the density and quality of organic matter (Swift et al., 2006). Their main functions are to increase soil cover by litter and pruning, to provide partially permeable hedgerow barriers, to enable the development of terraces through soil accumulation upslope of hedgerows, to increase soil resistance to erosion and to stabilize earth structures by root systems (Young, 1990). It is debated if soil fertility is improved through the contribution of litter or rather due to decomposition of understory herbs or root turnover (Grouzis & Akpo, 1997). The contribution of biological N_2 fixation is limited in the Sahel due to low levels of phosphor availability and severe drought conditions. Soil organic matter strongly influences most of the functions related to soil quality. The small portion that is responsible for feeding the soil food web and is associated with nutrient cycling and other important biological functions in the soil is termed labile or “active” organic carbon. For field surveys, techniques have been developed to fractionate carbon on the basis of lability as these sub-pools of “active” carbon might be more sensitive indicators of carbon dynamics in agricultural systems than total carbon values (FAO, 2007; McDonagh & Bunning, 2009b). Furthermore, water availability under tree canopies is improved due to a decrease in potential evapotranspiration, better water infiltration or due to deep roots which facilitate water transfer towards the superficial soil horizon (Grouzis & Akpo, 1997).

2.3. Vegetation cover

The extent of soil vegetation cover is an important feature of sustainable land management as it has been proofed that it associates negatively with erosion and runoff coefficients (Morgan et al., 1997). Severely degraded landscapes are relatively dysfunctional in retaining soil particles, nutrients and water due to poor vegetation coverage (Huang et al., 2006). In silvopastoral systems the presence of woody plants leads to higher nutrient concentrations of fodder, a prolonged growing season under woody canopies and the replacement of C_4 by C_3 species (the latter having higher nutrient concentrations) (Breman & Kessler, 1995). However, natural vegetation competes for water and nutrients with planted crops or herbs in pastures and is therefore often regarded with skepticism by local land users (Kessler & Breman, 1991). Vegetation changes in the Sahel do not only cause ecological problems but also influence the rural economy because a broad spectrum of natural plants is used for food, firewood or medicinal purposes (Wezel & Haigis, 2000).

Several studies in Niger found that farmers have a big interest in the regeneration of natural vegetation cover to reduce wind erosion. Most farmers participating in the surveys believed that large scale vegetation degradation is the cause of the observed increase in wind erosion problems (Sterk, 2003). During a five year study period in silvopastoral lands in Burkina Faso three restoration measures were implemented to rehabilitate formerly degraded land and the change of vegetation cover was monitored. These “traditional” methods consisted of alignments of dead wood along the contour, spreading (mulching) of dead wood on crusted soil or alignments of small stones along the contour. Herbaceous layer and woody plant cover consistently increased by 229% and 92% respectively during the study period. The species composition showed much variation between years, but the number of species increased both in the herbaceous and woody plant layer. The species that increased the cover area were comparable in pasture quality, and were all annuals and not leguminous. Significant improvements in pasture quality however, would require an increase of perennial grasses and / or leguminous herbs (Kessler et al., 1998).

2.4. Sustainable land management

Problems of low farm productivity cannot be solved with isolated solutions. Instead, solutions should address soil fertility problems as an integral part of SLM. SLM practices harbor great potential for the preservation and enhancement of ecosystem services in different land use systems. They can limit degradation of water, soil and vegetation as well as gas emissions contributing to climate change and simultaneously conserve natural resources and increase crop yields. Three different types of ecosystem services, namely provisioning, regulating and supporting, and cultural / social services can be provided through SLM. The goal to enhance provisioning services is pursued through multi-functional land use which makes it possible to meet basic human needs such as food, water and energy. At the core of multi-functional land use is the integration of crop and livestock production to optimize on-farm and local nutrient and biomass cycles. An example from Africa would be a *Grevillea* agroforestry system in Kenya. *Grevillea robusta* is a multipurpose tree that provides fuelwood and timber, serves to form boundaries and carries ornamental functions. It further controls raindrop splash, increases organic matter, provides mulching materials, reduces wind speed and encourages nutrient recycling due to deep rooting. Regulating and supporting functions of drylands can be seriously affected by inappropriate management of soil and vegetation cover. SLM practices for better soil cover management are essential to improve soil fertility and water availability. Examples of such practices are no-tillage agriculture or furrow-enhanced runoff harvesting. Because intact natural and cultural landscapes and endemic crops contribute significantly to cultural identity it is important to preserve them through SLM practices. A benefit for biodiversity conservation can arise at the same time, since these landscapes are often exceptionally rich in biodiversity. An example is known from Ethiopia where islands of natural forests survived on sacred land around Ethiopia's churches and monasteries (Gabathuler et al., 2009).

Common SLM practices in the Sahel can be split up into "traditional" and "improved" practices. Traditional practices include traditional fallow, parkland or application of manure whereas improved fallow, forest fallow, alley cropping, cover crops and application of composted manure are seen as improved technologies. Since the majority of SLM practices documented and analyzed in this thesis can be classified as agroforestry, the following chapter is entirely dedicated to this topic.

2.5. Agroforestry

2.5.1. General characteristics

"Agroforestry is a collective name for land use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and / or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system" (Young, 1990). The significant gains that have been attained in agriculture and forestry worldwide during the past 50 years can be largely attributed to monoculture systems. Only when the adverse ecological and social consequences of such input-intensive production systems became suspicious the age-old practice of growing trees and crops together on the same unit of land was recognized again (Nair, 2007).

An agroforestry practice describes the distinctive arrangement of these components in space and time whereas an agroforestry system is a specific local example of a practice, characterized by environment, plant species and arrangement, management, and social and economic functions. Whereas there are hundreds or possibly thousands of agroforestry systems, only about 20 distinct practices are known (Young, 1990). Agroforestry is an approach to sustainable land use based on these practices. It offers a wide set of opportunities for halting land degradation, and providing ecosystem services in both low-income and industrialized nations. Land use systems that are structurally and functionally more complex than either crop or tree monocultures result in more efficient capture and utilization of resources (nutrients, light and water). Benefits of agroforestry include the provision of environmental services by adding plant and animal biodiversity to landscapes that might otherwise contain only monocultures of agricultural crops, by improving soil quality, sequestering substantial quantities of carbon or saving further land from deforestation, or by improving water quality by reducing nutrient leaches from the soil (Nair, 2007). Agroforestry is a practical management option for several reasons: it can be applied over a wide variety of environmental conditions, it does not require inputs that are costly or in short supply and the technology of managing trees is generally familiar to farmers (Young, 1990). The economic advantage of diversified income is a major motivation for practicing such systems especially in the tropics. A characteristic of tropical agroforestry systems are subsistence farming and the emphasis on the role of trees in improving soil quality.

2.5.2. Examples of agroforestry systems in the Sahel

2.5.2.1. Parkland systems

For centuries, subsistence farmers in semi-arid West Africa have maintained a traditional land use system known as the "agroforestry parkland" system, in which scattered trees are present in cultivated or recently fallowed fields. The term parkland applies to landscapes in which the density and composition of woody vegetation has been altered by human activities to satisfy specific needs. They are especially common in the Sahel and Sudan zones of Africa and are a characteristic landscape feature in wide parts of Senegal. Although most only contain one or a few dominating tree species, other parklands can be more species rich, especially further away from villages (Boffa, 1999).

One of the prominent parkland species in Senegal is *Faidherbia albida* (syn. *Acacia albida*). The species has received a lot of attention in the past because of its positive impacts on soil fertility and crop production (Boffa, 1999). This results from the combined effect of *F. albida* on sub-canopy microclimate and the impact of litter inputs on soil nutrient availability (Rhoades, 1995). Its' unusual characteristic of reverse foliation (bearing leaves during the hot dry season and shedding them at the beginning of the rainy season) increases the nutrient stock of the soil for starting crop cultivation and minimizes competition with crops for light (ICRAF, 2009). The primary processes held responsible for the increase of soil fertility under trees compared to open land relate to improved biological processes such as the return of nutrients to the soil through litterfall, root decomposition and exudation or improved nitrogen mineralization (Boffa, 1999). Biological activity under *F. albida*, which sheds its leaves at a time when conditions for microorganisms are favorable, is two to three times higher than at open sites (Jung, 1970). A study from Malawi found that the available nitrogen in soil beneath canopies of *F. albida* was 7 times higher than beyond canopies during the first months of the rainy season and 1.5 to 3 times higher during the rest of the cropping season (Rhoades, 1995). The amount of nitrogen made available through nitrogen fixation might be limited since mostly *F.*

albida seedlings have been reported to nodulate naturally but mature trees less so (Dunham, 1991). The same observation has been made for roots of mature *Acacia senegal* trees (Bernhard-Reversat, 1982). Increased relative humidity and rainfall infiltration beneath *F. albida* trees were documented in West Africa (Dancette & Poulain, 1969; Jung, 1966). Dancette & Poulain (1969) found improved water conditions under tree crowns to a depth of 120 cm and attributed these findings to reduced evaporation under the trees affecting the upper soil and water uptake from lower depths. Rhoades (1995) showed that soil moisture in the surface 15 cm was higher beneath tree canopies than in the open and that tree canopies moderated soil moisture shifts so that they fluctuated less under canopies. In order to attain maximal crop production under *F.albida,* canopy cover should be about 20% and the return of all organic matter to the soil (except for cereal grain yields) has to be assured. The maximal increase in crop yield of 300 kg / ha that was observed for well-managed *F. albida* parklands in the Sahel is nowadays seldom reached (Breman & Kessler, 1997). *F. albida* parklands store significant amounts of carbon in their biomass. But as the Kyoto protocol only admits carbon sequestered as a result of newly implemented mitigation projects, they are not likely to be considered as carbon sequestration projects in the near future (Takimoto et al., 2008).

Besides *F. albida, Vitellaria paradoxa* and *Parkia biglobosa* are the most widespread parkland species in the Sahel and Sudan zones of Africa. They are not common in parklands in Senegal though. Species that are often found, however, are *Adansonia digitata*, *Acacia senegal*, *Acacia raddiana*, *Sclerocarya birrea*, *Hyphaene thebaica* and others (Boffa, 1999). *Figure 2* shows parkland with *A. digitata* in western Senegal and with *V. paradoxa* and *F. albida* in Mali.

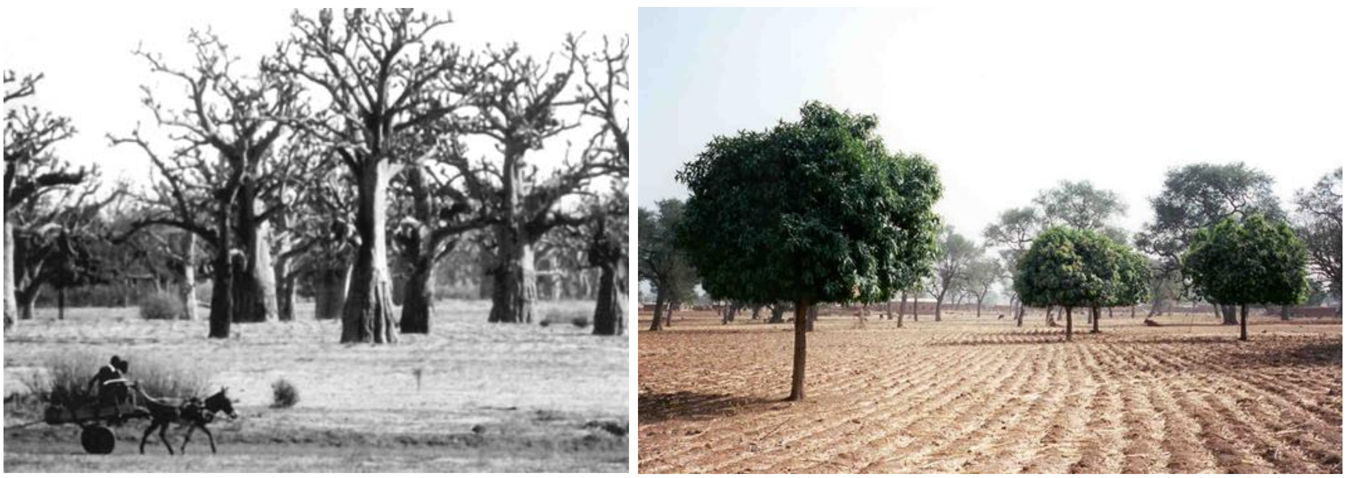


Figure 2. Parkland with *A. digitata* in Senegal (left) and with *V. paradoxa* and *F. albida* in Mali (right); sources: Boffa (1999) and Gillison (2000)

2.5.2.2. Live hedges

Live hedges are usually established by planting relatively fast-growing trees with very high density around field plots, orchards or cultivated land to prevent roaming animals from entering (Takimoto et al., 2008). The installation of live hedges as a promising agroforestry technique has been promoted widely in the Sahel. Between 1995 and 1996 a network of *Euphorbia balsamifera* live hedges was planted on almost 5,000 ha throughout the Senegalese peanut basin. Other species often used for live hedges in Senegal are *Balanites aegyptiaca*, *Bauhinia rufescens*, *Prosopis sp.*, *Ziziphus mauritiana* and different species of the genus *Acacia*. Farmers from 12 villages in the South of Senegal adopted live hedges for the following reasons: to fight wind erosion, to keep roaming animals out of fields, as a general protection of the field, for regeneration of soil fertility and to fight against water erosion. Where live hedges were not established it was attributed to limited workforce availability, seeds or seedlings, time, knowledge about the technology etc. (Sanogo et al., 2000).

Although a study in Mali found that traditional agroforestry parkland systems stored more carbon in their biomass than improved agroforestry systems such as live hedges, the introduction of live hedges is more feasible as they are usually established on treeless land and can therefore provide a net gain in sequestered biomass carbon (Takimoto et al., 2008).

2.5.2.3. Homegardens

The word "homegarden" refers to small agroforests, typically around 0.5 ha, with distinct boundaries, usually located near a house and intensively managed by family labor. The mix of diversified agricultural crops and multipurpose trees fulfils most of the fundamental needs of the local populations and the usually high species diversity avoids the environmental degradation associated with monocultural production systems. A majority of them is found in lowland humid tropics but an exception has been documented in semi-arid Burkina Faso in the form of Ka/Fuyo homegardens. The primary function of most, if not all, homegardens is food production. Therefore, there is a predominance of fruit-trees or other food-producing trees. Environmental protection is often caused by homegardens but is seldom a motivation for adopting this practice. Torquebiau (1992) suggested several indicators to measure whether a homegarden is sustainable or not, such as diversity of plants used by the local population, average level of indigenous knowledge present, number of horizontal layers, soil organic matter content, inputs from farm and off-farm sources, labor requirement and many more (Torquebiau, 1992). In general, homegardens have evolved under the influence of physical limitations, such as the long distance to markets, which compels farmers to produce something of everything they can use. As farmers rely mostly on their own perceptions regarding species selection, mixture and management, each of these system is a highly specialized entity (Fernandes & Nair, 1986). Homegardens have been considered the most biodiverse and complex of all agroecosystems (Scales & Marsden, 2008).

2.5.2.4. Improved fallows

Mineral fertilization is not sufficient to sustain crop yields in savanna soils and fallowing is therefore one of the few means available to subsistence farmers to maintain physical and chemical soil fertility (Priéri, 1989). However, fallow periods are shortening due to population pressure and the need for cultivable land and might therefore not allow trees to reach maturity within fallows. In Niger the fallow period has declined from 15 or more years to less than 5 years (Wezel & Boecker, 1998). Augusseau et al. (2006) found that the tree species richness was the largest at the end of a fallow phase and therefore recommended maintaining fallows as areas of recovery for tree species diversity.

An alternative to long natural fallows are improved fallows. In this technique, economically useful and fertility-improving trees are planted a few years before a field is left fallow in order to give the seedlings a competitive advantage over natural regeneration. In order to be accepted by farmers, improved fallows need to restore soil fertility in a shorter time than natural fallows (Boffa, 1999). Tree species planted in improved fallows are ideally fast-growing, N-fixing and efficient at nutrient capture and cycling. Once the fallow is cleared for cultivation, the fallow biomass is incorporated into the soil for subsequent cropping (Jama et al., 2006). *Acacia senegal* is a candidate for improved fallows, well adapted to the Sahelian ecosystem and generating an economically valuable product, gum arabic, after only four years (Boffa, 1999).

2.5.3. Multifunctionality of agroforestry systems

Soil improvement

The processes through which trees improve soil quality in agroforestry systems include increased nitrogen input through biological nitrogen fixation by nitrogen-fixing trees, enhanced availability of nutrients, resulting from decomposition of tree biomass and greater uptake of nutrients from deeper layers of soils. In reducing soil temperature and evapotranspiration, agroforestry can create a favorable microclimate for crop growth (Buck et al., 1999). For example *A. raddiana* and *A. digitata* were found to reduce soil temperatures by 5-12° C in a semi-arid savanna in Kenya (Belsky et al., 1993). Through soil conservation, agroforestry has the potential to reduce the negative impacts of land degradation such as erosion and it can help to rehabilitate degraded land. However, Breman and Kessler (1997) found that in spite of several processes through which woody plants can improve nutrient and water availability, the added values of woody plants in agroforestry systems are generally lower than expected due to the following reasons:

- the potential of agroforestry is highest in environments where production conditions are already most favorable
- the competition between woody plants and crops or pastures is strong
- conditions for optimal canopy cover, tree canopy structure and therefore a maximum return of soil organic matter to the soil are generally not given, mainly because of high exploitation levels and drought events

They see the potential benefit of agroforestry mainly in terms of the improved efficiency of nutrient inputs due to improved organic matter content, rather than as an alternative for fertilizers.

Provision of wood and non-wood products

Due to declining forest resources and increasing demand for certain forest products, people tend to rely more on obtaining these products from trees grown in fields. Products from agroforestry systems can be classified into several use categories such as food, fodder, fuelwood, construction materials, medicinal products and others. Many trees serve multiple purposes (Boffa, 1999).

The role of trees in agroforestry for food security is very important. In most of the southern Sahel and Sudan zones in West Africa, butter from *V. paradoxa* is the most extensively used fat and in non-pastoral areas sometimes the only available source. Seeds of *P. biglobosa* that are used for seasoning are equally important. Food trees supplement the nutritional value of basic cereals, diversify diets and enhance villagers' seasonal food balance. In West Africa the availability of food products from trees is especially important between the end of the dry season and the beginning of the rainy season when stocks from the previous season are exhausted and the current season's crops are yet to be harvested (Boffa, 1999). Trees in fields are also an important source of fodder for animals in the dry season and herders often lop branches to provide food for cattle (Petit, 2003).

Rural people in West Africa mainly rely on medicines based on plants to treat common illnesses (Boffa, 1999). As forest degradation has diminished the availability of widely used medicinal products there is a need for the cultivation of medicinal tree species in agroforestry systems. Many *Acacia* species found in Africa such as *A. senegal*, *A. seyal* or *A. nilotica* are highly esteemed because of their medicinal value. Most of the times the medicinal value is only exploited locally and medicinal products are seldom commercialized (except for the use of *Azadirachta indica* in malaria treatment) (Rao et al., 2004).

Wood production might not be a primary objective of agroforestry systems, but rather of forest plantations. However, because time constraints are a concern in wood collection, the proximity of fields and fallows facilitates gathering (Boffa, 1999). In the northern part of the Senegalese peanut basin 75% of firewood was provided by trees in fields and fallows, while the rest was collected in unexploited zones of the rural landscape (Seyler, 1993).

Biodiversity conservation

The importance of agroforestry for conservation is becoming increasingly recognized and has resulted in a number of studies comparing the biodiversity of primary forest to land under agroforestry use. A metastudy about biodiversity in small-scale tropical agroforests (Scales & Marsden, 2008) found that 8 out of 13 published studies reported reduced plant species richness in currently-used agroforests or <10 year fallows compared to intact forests. Only in an active agroforest in Sumatran jungle rubber a higher plant species richness was reported than in primary forest (Gillison et al., 2003). 21 studies compared plant biodiversity across different agroforestry systems. Many factors such as the increased prevalence of cash crops, increased holding size and increasing soil quality have been associated with both plant diversity gain and loss. In Nicaragua, homegardens used for cash crop and subsistence functions showed higher plant diversity than homegardens used only for subsistence functions. Several other factors, including management intensity, agricultural extensification, market proximity and shortening of fallow periods were found to have a negative impact on plant species diversity in agroforests (Scales & Marsden, 2008).

However, agroforestry is suited to provide solutions for landscape management strategies that successfully combine objectives for increased food security and biodiversity conservation gains (ecoagricultural strategies), especially by promoting better use of indigenous trees in agroforestry systems (Kindt et al., 2006a). In addition it represents a viable system for reducing pressure on remaining forests and helps to maintain high levels of biodiversity compared to monocultural cropping systems (Scales & Marsden, 2008). In landscapes mainly occupied by croplands, riparian forest buffers and field shelterbelts can be essential for maintaining plant and animal biodiversity. The cultivation of rare species such as medicinal plants and fruit-trees in tropical homegardens contributes to biodiversity conservation, even if primary motivations are linked to economic and social gains (Nair, 2007).

3. Research questions, hypotheses and methodology

3.1. Research questions

What are the characteristics of different sustainable SLM technologies in Senegal, where are they used and what impacts do they have?

Does the application of the given SLM technologies enhance soil vegetation cover and tree biodiversity?

Are the density and richness of species which are useful for the local population higher at sites under one of the applied SLM technologies than at sites under conventional land management?

3.2. Hypotheses

The hypotheses in this chapter relate to the objectives 2 and 4 of this thesis. Hypotheses H1 to H4 were tested for trees with a DBH ≥ 2 cm.

H1: Sites under the documented SLM technologies have higher woody plant density, species richness and species diversity than sites under conventional land management

H2: Sites under the documented SLM technologies show a higher percentage of woody canopy cover than sites under conventional land management and therefore protect the soil from degradation

H3: The number of woody individuals showing damages caused by human beings is higher at sites under conventional land management than at sites under the documented SLM technologies

H4: The density and richness of species which are useful for the local population is higher at sites under the documented SLM technologies compared to sites under conventional land management

H5: The density, species richness and species diversity of regeneration (DBH < 2 cm) is higher at sites under the documented SLM technologies than at sites under conventional land management

3.3. Methodology

3.3.1. Implementation of the Land Degradation Assessment (LADA)

3.3.1.1. Selection of geographical assessment areas (GAA's) and study areas

According to the LADA manual (McDonagh & Bunning, 2009a), geographical assessment areas are "areas of national priority concern and interest with respect to land degradation and / or SLM". They are also a sample of one or more nationally important land use systems. As GAA's are usually several hundred km^2 large, a few study areas are chosen within them for the field level assessments. The study areas should be representative of the land use systems.

In Senegal three GAA's were chosen and this thesis is concerned with two of them: Barkédji was chosen as a so-called "hot-spot", representing wide ranging land degradation and Lompoul as a "bright-spot" with a high percentage of land under sustainable management.

3.3.1.2. Study Areas in Barkédji

Three (3) study areas were chosen in the geographical assessment area (GAA) of Barkédji (see *Figure 3*), representing land use types consisting of predominantly extensive pasture, rainfed crop production, and different agroforestry systems including parkland and homegardens, and a natural grove (CSE, 2009a).

The three study areas were located:

1) Around the village of Diagaly, in the north-east of the Barkédji rural community (UTM coord: X: 1688653, Y: 535350)

2) Around the village of Touba Ndar Fall, in the south-west of the Barkédji rural community (UTM coord: X:1672355, Y: 504495)

3) Between the villages of Diabale and Niakha, in the north of the Barkédji rural community (UTM coord: X: 1692585, Y: 506610 and X: 1690994, Y: 510745 respectively)

Within each study area 7-9 sites were selected on transects of 5-6 km length for the LADA assessment, representing degraded land as well as land under sustainable management (CSE, 2009a). A site could for example be a pasture, an agroforestry system, an agricultural field etc. For the present thesis, sites representing sustainable land management were chosen for documentation with the WOCAT methodology and data from sites representing the conventional land use type was used for comparison.

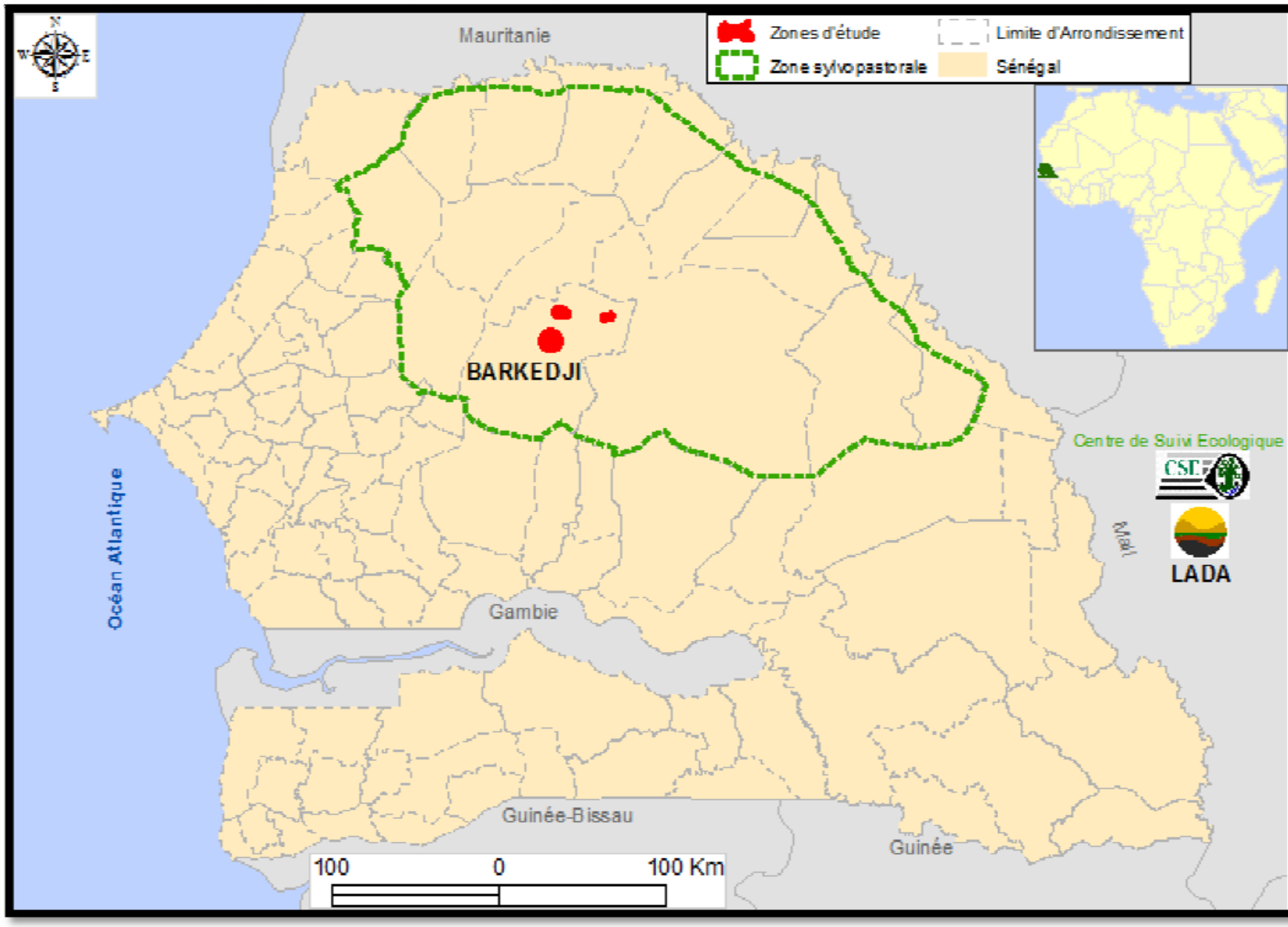


Figure 3. Map of Senegal with indication of the Ferlo silvopastoral zone (green) and the three study areas (red); source: (CSE, 2009a)

3.3.1.3. Study Areas in Lompoul

Two study areas were chosen in the GAA of Lompoul, which include all land use types common in the GAA. Major land use types were plantation forests of *Casuarina equisetifolia* (Bande de Filao) along the beach and *Eucalyptus camaldulensis* in the hinterland as well as vegetable fields in interdunal depressions (CSE, 2009b). Pasture land may cover a larger area but is not as important for the livelihoods of the local population as the vegetable plots (Touré Fall & Salam Fall, 2001). *Figure 4* shows the location of the GAA of Lompoul on the northern coast of Senegal.

The two study areas were located:

1) From the beach into the hinterland including the village of Lompoul-sur-Mer with the small hamlet Thioucougne (UTM coord: X: 1708576, Y: 314777)

2) Around the two villages of Mabouye Niayes and Khonkh Yoye in the hinterland of the “Bande de Filao” (UTM coord: X: 1704855, Y: 315497)

One transect of 2.2 to 2.6 km length was laid through each study area for the LADA assessment with 9 and 8 sites respectively that were placed in either degraded, conventionally or sustainably managed land (CSE, 2009b). For the connection between these sites and the present thesis see the explanation in the previous chapter (p. 16).

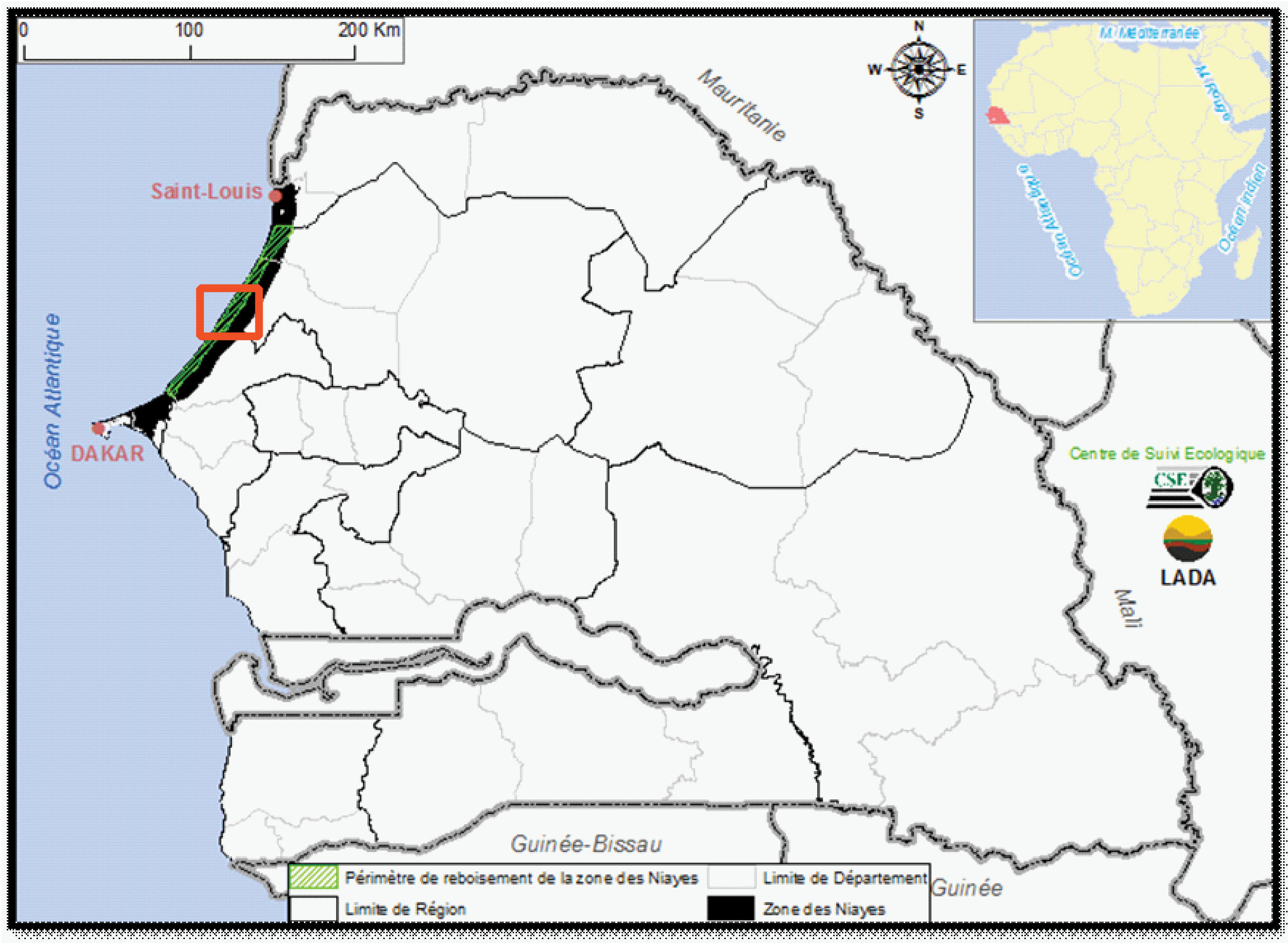


Figure 4. Map of Senegal with indication of the “Zone des Niayes” (black), the extent of dune fixation with *Casuarina equisetifolia* (green) and the GAA of Lompoul (orange); source: (CSE, 2009b)

3.3.2. Description of the GAAs: Barkédji and Lompoul

3.3.2.1. Overview

The following table shows the main characteristics of the two GAAs Barkédji and Lompoul:

Table 2. Comparison of the GAA's Barkédji in the Ferlo and Lompoul in the Niayes

	Barkédji (Ferlo)	**Lompoul (Niayes)**
Climate zone[1]	Sahelian zone	Sahelian zone but with cool, humid climate in the dry season
Mean annual rainfall[2,3]	400 mm	350 mm
Soil types[1,2,3]	• immature brown isohumic soils with loess (sols isohumiques bruns d'apport éolien peu évolués) • red tropical ferruginous not leached (sols ferrugineux tropicaux non lessivés) • hydromorph soils	• mineral soils with additions (sols minéraux bruts d'apport) - wandering sand dunes • immature soils with loess (sols peu evolués d'apport éolien) - yellow dunes • red tropical ferruginous soil not leached (sols ferrugineux tropicaux non lessivés) - red dunes • pseudogleys (sols minéraux à pseudo gley) - depressions
Vegetation characteristics[4]	thorny shrub savannah with mainly Sahelian woody species	thorny shrub savanna with Sudanian, Sub-Guinean and Guinean woody species in depressions
Population	mainly Peul pastoralists, few Wolof agriculturalists[5]	Peul and Wolof equally distributed, both engaged in horticulture[3]
Main land use[2,3]	silvopastoral	agropastoral
Degree of land degradation[2,3]	severe	mitigated through SLM
Main types of land degradation[2,3]	• wind- and water erosion • overgrazing • compaction • reduction of vegetation cover • bushfires	• wind erosion • reduction of vegetation cover • fertility decline • pasture degradation
Presence of SLM[2,3]	weak	abundant

[1] Mailly et al. (1994)
[2] CSE (2009a)
[3] CSE (2009b)
[4] Diouf & Lambin, (2001)
[5] Bradley & Grainger, (2004)

3.3.2.2. Barkédji in the Ferlo

Climate

Barkédji is a rural community situated in the Ferlo region which constitutes the heart of Senegal's silvopastoral zone. The Ferlo belongs to the Sahelian and South-Sahelian bioclimatic zones. Typical characteristics are short, irregular rainy seasons with mean annual rainfall oscillating around 400 mm (Diouf & Lambin, 2001). *Table 3* shows monthly and annual rainfall in the study area of Barkédji.

Table 3. Total monthly and annual rainfall for the year 2008 and means for the period from 1961-1990 in the study period (july-october)[1]

	June	July	August	September	October	Annual rainfall (mm)
Total 2008	33.1	118.3	192	137.3	14.8	495.5
Mean 1961-1990	26.1	92.6	138.1	106.7	34.4	397.9

[1] LADA (2009a)

Land cover

The community of Barkédji is dominated by a steppe with low tree and bush cover on sandy loam (CSE, 2009a). The effect of drought on woody cover in the 20th century has been tempered by deep, sandy soils with a large water storage capacity. However, the woody cover has shrunk over the past half century and become floristically poor. Analysis of a high resolution Corona satellite photograph from 1965 shows a woody cover that typically ranged from 10-15%. Analysis of aerial videography from 1994 found that the woody cover was reduced to less than 1-5%, except within small interdunal depressions where the density was often 10-40% (Tappan et al., 2004). A significant change in land use has occurred as rainfed crop production (which was limited to 1% of the area in 1965) expanded to over 16% in 1999. The trend of agricultural expansion in the Ferlo seems to be continuing as population pressure increases the demand for land in Senegal's other regions (Tappan et al., 2004).

Agriculture and pastoralism

The southern margin of the Ferlo coincides with the northern margin of rainfed agriculture in Senegal (Becker, 1983). Barkédji is located towards the southern margin and therefore crop cultivation is still practiced in parts. However, grazing is the main activity in this area. The population consists mainly of Peul, who are semi-sedentary herders practicing extensive pastoralism (this French term corresponds to the indigenous term of Fulbe, but as most people refer to themselves as Peul this is the term used here). Cattle rearing is complemented by the cultivation of cereal, such as millet (Bradley & Grainger, 2004). The Peul live in aggregations of 3-10 families most of the times linked by family bounds. The number of cattle that a family owns is difficult to determine, as tradition forbids a Peul to count what is precious to him, whether it be children or animals. Cattle constitute savings for Peul households and are therefore never consumed except in times of emergency (Pin-Diop, 2006). The largest ethnic group in Senegal, the Wolof, account for 8-20% of the population of Barkédji. They are mostly agriculturalists who have migrated from Senegal's "groundnut basin" in recent times. The rainfed cultivation of groundnut and cereal is at the base of their livelihoods. As many of them raise some livestock they also call themselves agropastoralists (Bradley & Grainger, 2004).

Plant diversity

The number of woody species is relatively limited with a predominance of the genus *Acacia*. The vegetation cover is very open and on the sandy soils consists mainly of shrubs like *Acacia raddiana, Acacia senegal, Boscia senegalensis, Balanites aegyptiaca, Combretum glutinosum, Sclerocarya birrea and grasses like Eragrostis tremula, Cenchrus bifloris, Schoenefeldia gracilis, Dactyloctenium aegyptium and Aristida adscensionis*. On the more lateritic soils, the following species can be found: *Pterocarpus lucens, Dalbergia melanoxylon, Acacia seyal* and different *Combreteaceas* as well as the grasses *Loudentia togoensis* and *Schoenefeldia gracilis* (Ndiaye, 2009).

Land degradation

Barkédji had been chosen as a geographical assessment area of the LADA local assessment because it represents one of Senegal's hotspots of severe land degradation. The silvopastoral system has undergone huge changes which brought different pressures on the ecosystem. In the 1980's boreholes were created and therefore the possible pasture area increased, attracting transhumants from elsewhere (UNDP & GEF, 2002). Transhumance is a particular form of semi-nomadism in which the main core of the population remains in a village and the herds are moved around according to the seasons (Advisory Committee on the Sahel Board on Science and Technology, 1984). The consequences are increased overgrazing around the boreholes and conflicts between the local population and newcomers. In the Ferlo, rangeland degradation has been estimated at 80,000 ha per year (UNDP & GEF, 2002). The greatest pressure on the land however stems from an increasing settlement and the influx of new farmers in search of arable soils. The conversion of pasture into cropland has led to an increased pressure (UNDP & GEF, 2002).

3.3.2.3. Lompoul in the Niayes

Characteristics

The second GAA, Lompoul, is situated at the Atlantic coast in the "Zone des Niayes". Senegal has an Atlantic coastline of 700 km^2 which is interspersed by very few rocky parts (Seck et al., 2005). The Niayes, located between Dakar and St.Louis, constitute a territory 5-30 km wide covering a surface of 4,200 km^2. The region accounts for two thirds of Senegal's vegetable production and allows 120,000 people to live on revenues from this sector (Mailly et al., 1994). Bovines and small ruminants are reared between the dunes in an extensive system (Seck et al., 2005). Sand dunes categorized as white or wandering dunes, yellow semi-fixed dunes and as a system of continental fixed red dunes cover the entire territory. The continental sand dunes support a shrub savanna which has been used as a grazing ground by Peul pastoralists for centuries. Today the dunes suffer increasingly from overgrazing (Tappan et al., 2004).

Climate

The Niayes profit from a cool, humid climate, caused by northern maritime trade winds during the dry season, while the rest of Senegal experiences dry and hot Harmattan winds from the East. This results in favorable conditions for vegetable production during the dry season. *Figure 5* shows the amount of rainfall in the rainy season during the year of this study.

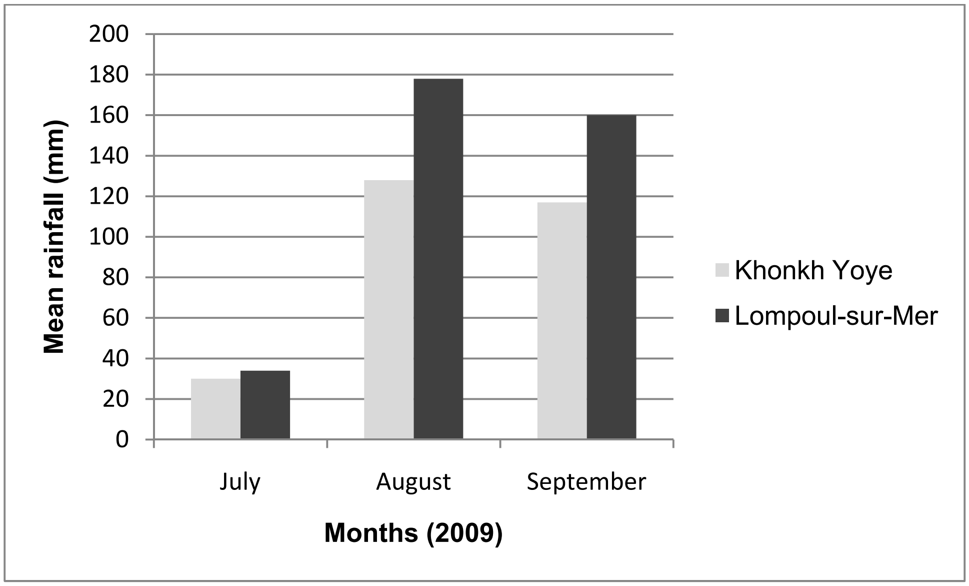


Figure 5. Mean rainfall in the months of July, August and September during the study year 2009 in the villages of Khonkh Yoye and Lompoul-sur-Mer; source: (CSE, 2009b)

Plant diversity

Humid and very fertile interdunal depressions can be found in between the dunes. These interdunal depressions, called Niayes, are special microenvironments. A vegetable culture developed around those depressions. They harbor a complex and rich flora with many relic species of the more southern Sudanian and Guinean regions which are able to survive by tapping into the near-surface ground-water. A typical Sub-Guinean species, common in the Niayes, is the oil palm (*Elaeis guineensis*). Thirteen (13) plant species in the Niayes are endemics, and 10 are threatened (UNDP & GEF, 2002).

Land degradation

The most important factor for successful production in the zone is the water resources. The near-surface groundwater is the key that allows for cultivation of the zone. However, considering the decline in rainfall during the last 60 years, the future of this water source is uncertain. Lack of rainfall was one of the causes that led to the retreat of natural vegetation which was then unable to stabilize the dunes any longer. Up to then, abundant vegetation consisting of herbs and shrubs fixed the dunes throughout the zone (including the hinterland). Migration of sand dunes could attain up to 10-12 m a year (Mailly et al., 1994). However, deforestation at the beginning of the 19^{th} century as well as overgrazing were also important factors causing gradual desertification in this system. Droughts have caused a decline of the groundwater level and gradual salinization (Seck et al., 2005). The main consequences resulting from the accelerated encroachment of sand dunes were degradation of arable land and of important water sources as well as natural vegetation (Mailly et al., 1994). Another constraint for land use is mixing of fresh- and saltwater in the underground (Touré Fall & Salam Fall, 2001).

3.3.3. Documentation of SLM technologies with WOCAT

3.3.3.1. Questionnaires

In order to collect data on SLM technologies to enter into the WOCAT database, three questionnaires have been developed by the WOCAT team. Of these three questionnaires, two have been used in this thesis (Liniger et al., 2008):

- Questionnaire on SLM technologies (QT)
- Questionnaire on SLM approaches (QA)

The QT addresses the questions on technology specifications, where it is being implemented (natural and human environment) and what is its impact. It consists of three parts (Liniger et al., 2008):

1. General information
2. Specification of SLM technology
3. Analysis of SLM technology

An SLM technology consists of one or more conservation measures in the following categories (Liniger et al., 2008):

- agronomic (e.g. intercropping, contour cultivation, mulching)
- vegetative (e.g. tree planting, agroforestry, wind breaks)
- structural (e.g. graded banks, level bench terrace)
- management (e.g. land use change, area closure)

The QA addresses questions regarding how and by whom implementation was achieved. It consists of the three main parts of (Liniger et al., 2008):

1. General information
2. Specification of SLM approach
3. Analysis of SLM approach

WOCAT defines an SLM approach by the ways and means used to promote and implement a SLM technology. The approach should support the technology used in achieving more sustainable soil and water use. It refers to a particular land conservation activity such as an official program / project, an indigenous system or changes in a land use system aimed towards achieving more sustainable soil and water conservation (Liniger et al., 2008).

All information collected with the help of the QT and QA questionnaires was entered into the designated WOCAT online database (see www.wocat.net). At the same time the information collected is presented and analyzed in a more detailed way in chapters “4.1. Case study Barkédji” and “4.2. Case study Lompoul” of this thesis. An example of a so-called 4-page case study (summary of the questionnaire) from the database can be found in Appendix 7 (see p. 161) together with the QT and QA questionnaires.

Throughout this work, the general term “SLM technologies” will be used for the documented sustainable land use types, although all of them are forestry or agroforestry technologies.

3.3.3.2. Documented technologies

Barkédji

The following sustainable land management technologies that were encountered within the three LADA study areas were documented:

- Agroforestry with *Acacia senegal*
- Agroforestry homegarden
- Agroforestry homegarden, project GPF
- Agroforestry parkland
- Natural grove with *Acacia seyal*

For each of these technologies, the respective land user was interviewed to obtain the information required to fill in the WOCAT QT questionnaire. The Senegalese researchers that worked on the LADA local assessment were asked for advice in their respective areas (soil, water, socio-economy and vegetation) to complete some of the biophysical and socio-economic information.

One area of a pasture reserve was not documented with WOCAT since it included the technology "natural grove" as well as degraded extensive pasture where people had illegally built a small settlement. For the vegetation assessment, 5 plots were established in the part of the pasture reserve that could be regarded as having a positive impact on the sustainability of the land use system. Remnants of a gallery forest around the temporary ponds of Niakha were not chosen for the assessment because the water level was already high after the first rains of the beginning wet season and did not allow for the establishment of vegetation sampling plots.

Two reference systems of the conventional land uses in this area (extensive pasture and cropland) were documented using the same methods for comparison. Although fields under crop production contained trees as well, they were not considered as SLM. This decision was made because (according to the focus group discussions in the LADA local assessment), land users did not actively try or at least wish to maintain trees in their fields. This is because they do not seem to perceive them as beneficial (CSE, 2009a).

For the SLM technology of "Agroforestry homegarden, projet GPF" the approach "promotion des femmes" was documented with the WOCAT QA questionnaire.

Lompoul

In Lompoul, all sustainable land management technologies that were encountered within the two LADA study areas were documented for the WOCAT database apart from a small natural grove with *Acacia raddiana,* because the main reason for its conservation was its inaccessibility.

The documented SLM technologies were:

- Dune fixation with *Casuarina equisetifolia* ("Bande de Filao")
- Dune fixation with *Eucalyptus camaldulensis*
- Agroforestry (mainly with *Neocarya macrophylla* and *Faidherbia albida*)
- Fruit orchard

Additionally, one technology was documented although it did not consist of vegetative measures and could therefore not be included in the vegetation assessment. It was, however, linked to the technology "dune fixation with *Casuarina equisetifolia*":

- Composting with litter from *Casuarina equisetifolia*

The reference system of conventional land use in the area was pasture land.

3.3.4. Assessment of biophysical characteristics

General information

Depending on the surface of the land use system, the tree density on site, and the shape of the land use system, number, size and shape of vegetation plots, respectively, varied for the different assessed sites (see *Table 4* and *Table 5*). The methodology had to follow the one used for the LADA local assessment (CSE, 2009a, 2009b).

Stratified-random sampling was not applicable as no maps indicating the boundaries of major land use types were available yet. Unless the entire surface was sampled, plots were randomly placed by selecting around ten points in each site on a random walk, marking them with a GPS and selecting three of them in a random drawing.

In each plot, all trees (defined as woody perennial species) with a circumference at breast height CBH ≥ 6 cm (= diameter at breast height DBH ≥ 2 cm) were counted and measured, including stumps and dead trees. Those trees with a DBH ≥ 2 cm were denominated mature trees throughout this work. The species identity of each tree was determined in the field by a local forestry specialist and the scientific names followed Arbonnier (2004). One species with a single individual present could not be determined and is referred to throughout this work as "Mindioli", its local Pulaar name. Species were considered "indigenous" if their origin is in the Sahelian, Sudanian or Guinean ecozone and else were considered "exotic". For every individual, tree circumference at breast height and height were measured and estimated respectively[2]. At some sites with large stands of trees of the same age, tree circumference was only measured for a few individuals and estimated for the rest. Human induced alterations of trees, such as lopping of branches to provide fodder for cattle or cutting whole stems for a variety of household uses, were recorded as well as the condition of the tree (dead or alive). Crown diameter was estimated in two directions to allow for calculation of canopy surface area. For regeneration with a CBH < 6 cm (= DBH < 2 cm) the numbers of individuals per species was recorded separately

Information about species valuable to the local community was gathered from interviews conducted at each site of the LADA local assessment (McDonagh & Bunning, 2009b) and from the literature (see p. 30).

The assessment of soil properties within the LADA assessment was not part of the present thesis. However, some of the results from the rapid assessment of soil properties in the field, presented in the LADA project reports (CSE, 2009a, 2009b), were used for the documentation of the WOCAT case studies. While most soil chemical laboratories provide a determination of total soil organic matter or soil organic carbon (SOM and SOC), this is not applicable in field tests. A technique of fractionating carbon on the basis of lability was used instead. Therefore, carbon values presented in this thesis are not measures of total soil organic matter but only of the labile or "active" organic carbon (see p. 8 for more information about "active" organic carbon) (McDonagh & Bunning, 2009b). Detailed information on the methods for the measurement of soil properties in the LADA assessment can be found in the LADA field manual (McDonagh & Bunning, 2009b) in Appendix 7, p. 161.

[2] An exception was the fruit orchard in Lompoul, where DBH and height were not measured

Barkédji

In each of the sustainable land management sites documented with WOCAT as well as in a pasture reserve, and in the two reference systems of conventional land use, a detailed assessment of vegetation cover and composition was conducted. The sample size for SLM was 17 plots with a total surface of 8.4 ha and 23 plots for conventional LM with a total surface of 15.3 ha (*Table 4*).

The largest sample size was for the conventional land use system of extensive pasture which represents the most common system in the area. If size allowed for it, the entire surface was sampled for fields under crop production with distinct boundaries instead of taking sub-samples. This resulted in rectangular plots of different sizes. Exact sizes were measured with GPS in order to calculate densities per ha. If fields were too large to be assessed entirely, two plots of one ha surface each were established. The small surface of homegardens did not allow for subdivision. Therefore in both cases the entire system was sampled. As homegardens were rare in the area of Barkédji and only two were found along the three transects chosen for the LADA Assessment, the sample size of this system was very low. For plots with savanna vegetation, circular plots of 20 m radii (1,257 m^2) were established as this is the common size used for vegetation assessments by the "Centre de Suivi Ecologique" in Senegal[3]. Circular plots with radii of 10 m (314 m^2) were established for dense stands in natural groves. *Table 4* presents detailed information on the land use systems sampled in Barkédji.

Since the herbaceous cover was not yet sufficiently developed at the time of the study, the percentage of covered and bare soil was roughly estimated in the different plots and recognized herbaceous species were noted.

Table 4. Number, shape, size of plots as well as the total area sampled for different land management types in Barkédji, Senegal

	No.	Land use	No. of plots	Plot shape	Plot size	Tot. surface (ha)	Comment
CLM	1	Extensive pasture	20	circular	1,257 m^2	2.5	
	2	Cropland	3	rectangular	7.3; 4.0, 1.5 ha	12.8	
	total		**23**			**15.3**	
SLM	3	Agroforestry *A. senegal* with fallow	5	circular (fallow), rectangular (cultivated part)	3 plots of 1,257 m^2 + 2 fields of about 2.4 and 1.8 ha	4.6	Documented as two different technologies for WOCAT
	4	Homegarden	2	rectangular	0.5 + 0.6 ha	1.1	
	5	Parkland	2	rectangular	1 ha	2	
	6	Natural grove	3	circular	314 m^2	0.1	
	7	Pasture reserve	5	circular	1,257 m^2	0.6	not documented with WOCAT
	total		**17**			**8.4**	

3 Oral personnal communication: Wélé, A. Ingénieur des Eaux et Forêts. In Barkédji, 30.07.2009.

Lompoul

In each of the sustainable land management sites documented with WOCAT, as well as in a small natural grove and the reference systems of conventional land use a detailed assessment of vegetation cover and composition was conducted. The sample size for SLM was 23 plots with a total surface of 6.3 ha and 3 plots for CLM with a total surface of 0.4 ha (*Table 5*).

The SLM technology of "dune fixation with *Casuarina equisetifolia*" had the largest sample size in the GAA of Lompoul as it is part of a large system (9,700 ha). For the SLM technology "agroforestry with *Neocarya macrophylla* and *Faidherbia albida"* five fields with distinct boundaries were taken as samples of which the entire surface was sampled. This resulted in rectangular plots of different sizes. Exact sizes were measured with GPS to allow for the calculation of densities per ha. As only one fruit orchard was encountered in the two study areas chosen by LADA, its surface was subdivided into three subplots. In the case of savanna vegetation in the CLM of pasture, circular plots with 20 m radii (1,257 m^2) were established as this is the common size used for vegetation assessments by the "Centre de Suivi Ecologique" in Senegal[4]. For the small and dense stand in the grove with *A. raddiana* and the rather uniform *Eucalyptus* plantations, circular plots with radii of 10 m (314 m^2) were established. For plantations with *Casuarina*, the number of individuals per species was counted in a plot with a radius of 20 m whereas tree measurements were only taken on individuals that were located within 10 m distance from the central tree.

In plantations and fields, the percentage of herbaceous cover and bare soil was roughly estimated. In the 3 plots of pasture, four subsamples of one m^2 were taken per plot with the help of a metallic frame. The frame was positioned at two m distance from the trunk of a tree and samples were taken to the North, South, East and West of the trunk. The percentage of soil cover of each herbaceous species present was estimated.

Table 5. Number, shape, size of plots as well as the total area sampled for different land management types in Lompoul, Senegal

	No.	Land use type	No. of plots	Plot shape	Plot size	Tot. surface (ha)	Comment
CLM	1	Pasture	3	circular	1,257 m^2	0.4	
	total		**3**			**0.4**	
SLM	2	Dune fixation with *Casuarina equisetifolia*	8	circular	1,257 m^2	1	
	3	*Eucalyptus* plantation	5	circular	314 m^2	0.2	
	4	Agroforestry (mainly with *Neocarya macrophylla* and *Faidherbia albida)*	5	rectangular	0.4; 0.8; 0.8; 1.5; 0.8 ha	4.3	the 5 samples are different plots of which the whole area was assessed
	5	Fruit orchard	3 subplots	rectangular	0.1; 0.2; 0.2 ha	0.5	the 3 samples are subplots in 1 enclosured system

[4] Oral personnal communication of Wélé, A. Ingénieur des Eaux et Forêts. In Barkédji, 30.07.2009.

No.	Land use type	No. of plots	Plot shape	Plot size	Tot. surface (ha)	Comment
6	Small grove of *Acacia raddiana*	2	circular	1,257 m^2	0.3	not documented with WOCAT
total		**23**			**6.3**	

3.3.5. Analysis and presentation of results

The documentation of the SLM technologies as well as the results and the discussion of the vegetation assessment are presented in the form of two case studies, one for the GAA of Barkédji and one for the GAA of Lompoul. The results of the vegetation assessment in the two GAA's are generally not compared with each other due to the different environmental and socio-economic conditions in the two regions.

3.3.5.1. Tree diversity

The freely available BiodiversityR statistical software (Kindt & Coe, 2005), developed for the R.2.1.1. statistical language and environment (R Development Core Team, 2005) combined with the vegan community ecology package (Oksanen et al., 2005), was used to analyze coupled datasets containing information on tree communities and environmental descriptors.

Data on species richness, density and diversity was summarized using descriptive statistical analysis procedures.

- *Species richness* was calculated by counting the number of species in a given sampling unit (plot).
- Sample-based exact *species accumulation curves* were calculated to compare species richness of land management types with different sample sizes following Kindt & Coe (2005). These curves show the trend with which additional species are encountered when large numbers of plots are sampled.
- *Tree density* is the total number of individuals recorded in a certain area.
- The *Shannon diversity index* (*H'*) was used as a diversity indicator of trees in sites under different land management. A value of zero means that there is only one species in a certain area whereas a maximum value is obtained when all species are present in equal abundance. It was calculated as (Magurran, 1988):

  $$H' = -\sum Pi \times \ln Pi$$

  where *H'* = Shannon Diversity Index; *Pi* = proportion of individuals found in the i^{th} species; *ln* = is the natural logarithm of this proportion.

- *Evenness* is the ratio of observed diversity to maximum diversity (Pielou, 1969):

  $$E = \frac{H'}{\ln S}$$

  where *H'* = Shannon diversity index; *S* = species richness

- The *mean species richness* was either calculated for all plots of a land use type e.g. "Agroforestry with *A. senegal*" or calculated for all plots under either sustainable or conventional land management. The same applies to *mean plant density* and *mean Shannon diversity index*.

For the *analysis of diameter classes*, all trees for which DBH was measured were assigned to one of the following diameter classes: 2-9.9 cm, 10-19.9 cm, 20-39.9 cm, 40-79.9 cm, ≥ 80 cm. Species that were found as regeneration were assigned to the diameter class < 2 cm. Tree stumps were excluded from the analysis of DBH and height.

All statistical tests were carried out using the Statistical Package for Social Sciences SPSS 17.0.0. (SPSS, 2009). For all statistical tests, the two SLM technologies of “agroforestry homegarden” and “agroforestry homegarden, project GPF” (in the case study of Barkédji) were grouped together and regarded as two samples of one system, called “homegarden”.

Data was tested for normal distribution using a Kolmogorov-Smirnov test. If the assumption of normal distribution was accepted, a one-way ANOVA was carried out to check for differences between the two groups of sustainable and conventional land management. A least significant difference (LSD) posthoc test was computed to see which land use types were different from each other. If normal distribution could not be assumed or the ANOVA did not show homogeneity of variances, a non-parametric Mann-Whitney U test was used to test for differences between SLM and CLM. Where significant differences were found, pairwise Mann-Whitney U tests were carried out to see which of the land use types were different from which. A level of $p < 0.05$ was chosen as the minimum for significance.

Results were presented as follows:

- *Rank-abundance curves* were computed using BiodiversityR (Kindt & Coe, 2005) to visualize parameters of tree diversity. First, the total number of individuals is calculated for each species and then the species are ranked from the most abundant to the least abundant. A plot shows the rank number on the horizontal axis and the proportion (percentage of each species of total number of trees encountered) on the vertical axis. The interpretation of a rank-abundance curve is as follows. The more species rich a site the wider is the curve on the horizontal axis (number of species = number of ranks). Evenness is indicated by the shape of the curve: the steeper a curve the less evenly species are distributed. A horizontal curve would mean that species are completely evenly distributed (Kindt & Coe, 2005).

- *Rényi diversity profiles* are a diversity ordering technique, which, apart from providing information on species richness and evenness (like rank-abundance curves do), offers a chance of ordering communities in diversity (Tothmeresz, 1995). They were calculated following Kindt & Coe (2005) as:

  $$H\alpha = \frac{\ln(\sum Pi\alpha)}{1-\alpha}$$

  where Hα = Rényi diversity profile; Pi = proportional abundance of a species; α = scale parameter with values 0, 0.25, 0.5, 1, 2, 4, 8, and ∞. In such profiles, a site with higher diversity than a second site will have a diversity profile that is above the profile of the second site at all points (Tothmeresz, 1995).

- *Box plots* were computed using SigmaPlot for Windows version 10.0 (Systat Software Inc., 2006). The lower boundary of the box indicates the 25^{th} percentile and the upper boundary the 75^{th} percentile. The thin line within the box marks the median and the thick line the mean. Whiskers (error bars) above and below the box indicate the 90^{th} and 10^{th} percentiles. SigmaPlot needs a minimum number of data points to compute each set of percentiles: 3 points are required to compute the 25^{th} and 75^{th} percentile and at least 9 data points are required for the 10^{th} and 90^{th} percentiles. If SigmaPlot is unable to compute a percentile point, the related graph element is not drawn (Systat Software Inc., 2006). For some box plots presenting tree density a base 10 logarithmic vertical scale was used. Abbreviations used for land use types in box plots are presented in the following table:

Table 6. Abbreviations used for land use types in box plots for Barkédji and Lompoul

Barkédji			Lompoul		
	Abbreviation	Land use type		Abbreviation	Land use type
SLM	Agrof	Agroforestry with *A. senegal*	SLM	DuneF	Dune fixation
SLM	Grove	Natural grove	SLM	EucP	*Eucalyptus* plantation
SLM	Parkl	Parkland	SLM	SmallG	Small grove
SLM	PastR	Pasture reserve	SLM	AgroF	Agroforestry
SLM	Homeg	Homegarden			
CLM	Past	Extensive pasture	CLM	Past	Conventional pasture
CLM	Crop	Cropland			

3.3.5.2. Species useful to the local population

A review of existing literature on plant use in the semi-arid regions of West Africa (mainly Senegal, Burkina Faso, Mali and Niger) was conducted and the tree species that were encountered during the vegetation assessment were assigned to one or several of the following five categories: food, firewood, construction material (including fences, domestic tools, furniture etc.), fodder and medicine. These are only a selection of many use-categories of trees in the West African Sahel (Gakou et al., 1994; Kristensen & Balslev, 2003; Lykke et al., 2004).

For the case study of Barkédji, trees were assigned to one of the five categories if they fulfilled one of the following criteria: they were mentioned in the study by Von Maydell et al. (1983) that concentrated on the Ferlo or they were mentioned during the interviews that had been conducted with land users for the documentation of the WOCAT case studies. If a species was considered in the study by Von Maydell et al. but not mentioned to be used by the local population, the same was assumed for the present work, even if other studies had mentioned a use of this species (this was the case for *E. camaldulensis* for example). For species that were not discussed in Von Maydell et al. (1983), information was gained from the study by Lykke et al. (2004), covering most woody species occurring in the Sahelian zone of Burkina Faso. For species that were not covered by the study of Lykke et al. (2004), the newest edition of Arbonnier's "Trees, shrubs and lianas of West African dry zones" (Arbonnier, 2004) was consulted for information. For the category of fodder, the two species of *Moringa oleifera* and *Sterculia setigera* were assigned to this category because of information gained from a native (to the country) forestry engineer[5] and *Pterocarpus erinaceus* was assigned to this category because it was mentioned to be a preferred fodder species in the studies of Diédhiou & Diatta (2004), Gakou et al. (1994) and Lykke et al. (2004). It has to be kept in mind that species that did not fall in any of these categories will most probably still have a use value for the local populations in some ways.

For the GAA of Lompoul in the Niayes no specific study of plant use could be found as it was the case for the Ferlo with Von Maydell et al. (1983). Trees were therefore assigned to one of the use-categories if any of the abovementioned sources mentioned their importance in the respective use-category, without giving a higher priority to any of the sources. Therefore, some species were assigned to a certain category in the

[5] Oral personnal communication of Wélé, A. Ingénieur des Eaux et Forêts. In Barkédji, 01.08.2009.

case study of Lompoul but not in the case study of Barkédji. The category of medicine was excluded, as according to Arbonnier (2004), all of the encountered species have a medicinal value.

4. Results

4.1. Case study Barkédji

4.1.1. Analysis of SLM technologies and the conventional land management (CLM)

In this chapter, each of the SLM technologies documented for the WOCAT database will be presented and analyzed separately. The two CLM systems are described in the same way to have a base for comparison. For the SLM technologies, a short description of the respective study area (see p. 16) is given before the description of the technology. For the CLM systems this is not the case as they include plots from several of the three study areas. For the SLM of "pasture reserve" which was not included in the WOCAT database, information on biophysical characteristics can be found in Appendix 3 (see p. 150). Results of the statistical analysis of vegetation data collected in SLM and CLM systems are presented in chapter 4.1.2., p. 61.

4.1.1.1. Conventional land use systems in the geographical assessment area (GAA) of Barkédji

CLM 1: Extensive pasture

<u>Key characteristics</u>

Semi nomadic pastoralism is the dominant land use in the Ferlo which constitutes Senegal's main pastoral region with an area of about 24,763 km^2. Most abundant are zebu cows of the Gobra race (see *Figure 6*). In addition, Peul pastoralists own herds of Peul-Peul sheep and Sahel goats for milk- and food production and a few horses, camels and donkeys as means for transport. The seasonal rhythm in the Sahel is determined by resource availability. In the dry season animals and their owners depend on boreholes and wells for their water supply. The animals move for kilometers to find herbs whereas the small ruminants feed on bushes. Sometimes usually sedentary herders embark on transhumance either because climatic conditions force them to do so or of their own will. When resources become too scarce, the men of the family leave with the cattle to more accommodating regions in the Senegal River valley or to the south of the country (Pin-Diop, 2006). Moor herders from Mauritania, mainly with herds of dromedaries, also move to the Ferlo for the rainy season.

Figure 6. Extensive pasture with zebu cattle in Barkédji, Senegal

Constraints

The biggest constraint for pastoralism in the Ferlo is the erratic rainfall regime which influences the availability of fodder and water sources. Competition for fodder is high between the Peul herders and Moor nomads and an important source of conflicts (Pin-Diop, 2006). Dromedaries consume large quantities of biomass and, because of the shape of their hooves, contribute a lot to soil compaction. Besides, their urine is perceived as detrimental to the growth of herbs by the local population (CSE, 2009a). Another constraint is the occurrence of bush fires which mostly spread due to the negligence of fires lit in homesteads for cooking or to keep roaming animals away. They often destroy tree regeneration and therefore have a detrimental impact on the provision of arboreal fodder resources. Trenches for fire prevention have already been established but need to be extended and the maintenance has to be assured (CSE, 2009a).

Biophysical characteristics

According to the LADA rapid assessment soil conditions in different sites of the CLM “extensive pasture” were moderate with low “active” soil organic matter content (< 1 g C / kg soil). They were generally not very stable and often characterized by soil crusts (CSE, 2009a).

At the assessed plots of extensive pastureland the percentage of canopy cover, tree density and density of regeneration were low. On average, trees were short, which is typical for this thorny shrub savanna and their diameter at breast height (DBH) was small. Some trees showed damages, mostly because of lopping by herders for animal fodder and almost 10% of encountered trees were dead (see *Table 7*). The herbaceous cover consisted of *Ipomoea vagans*, *Waltheria indica*, *Spermacoce stachydea*, *Zornia glochidiata* and *Tribulus terrestris.*

Table 7. Characteristics of vegetation at the CLM site “extensive pasture” in Barkédji, Senegal[1]

Canopy cover (%)	3 [0.5]
Herbaceous cover (%)	56 [5.5]
Tree height (m)	3 [0.2]
Tree DBH (cm)	10 [1.3]
Percent trees damaged	11 [3.4]
Percent dead trees	9 [3.4]
Number of trees ha^{-1}	52 [9.4]
Number of regenerating trees ha^{-1}	31 [8.9]
Shannon diversity index	0.45 [0.11]

[1] Standard errors are given in parenthesis. Sample size was n=20.

Balanites aegyptiaca was the most abundant tree species in the pasture land, as well for mature trees and regeneration, followed by *Combretum glutinosum*. All encountered mature species were also present as regeneration in this land use type, but mostly in lower numbers. Of *Combretum aculeatum* and *Adenium obesum* only one individual was found regenerating. The densities of all species that were encountered in extensive pastureland are presented in *Table 8*.

Table 8. Density of mature and regenerating woody species per ha and their origin (ind: indigenous, ex: exotic) at the CLM site "extensive pasture" in Barkédji, Senegal[1]

Species	Origin	No. of trees ha^{-1}	No. of regeneration ha^{-1}
Balanites aegyptiaca	ind	30.3 [8.5]	14.8 [4.7]
Combretum glutinosum	ind	6.4 [4.0]	4.4 [3.2]
Acacia raddiana	ex	4.4 [2.4]	1.2 [0.9]
Pterocarpus lucens	ind	4.0 [1.9]	0.4 [0.4]
Guiera senegalensis	ind	3.6 [2.4]	3.6 [3.2]
Commiphora africana	ind	1.6 [1.2]	0.8 [0.8]
Acacia senegal	ind	1.2 [0.6]	2.4 [1.7]
Grewia bicolor	ind	0.8 [0.5]	2.8 [2.1]
Combretum aculeatum	ind	0	0.4 [0.4]
Adenium obesum	ind	0	0.4 [0.4]
Total		**52.3 [9.4]**	**31.2 [8.9]**

[1] Standard errors are given in parenthesis. Sample size was n=20.

<u>Impacts</u>

Overgrazing is a big threat to those pastures since it not only reduces the quantity of available fodder but also alters the composition and quality of fodder (Zhang et al., 2004). Reduced herb cover renders the soil prone to wind and water erosion. Natural vegetation often shows damage as herders lop off branches to provide fodder for their animals. All of the investigated pasture plots were located in the proximity of boreholes where the semi nomadic herders bring their cattle to drink. The constant stamping of hooves compacts the soil and a denuded soil with a low water infiltration capacity is what remains (CSE, 2009a).

CLM 2: Crop production

<u>Key characteristics</u>

Crop production in the assessment area of Barkédji is exclusively rainfed as water is a scarce resource in the Ferlo. Therefore, cultivation only takes place during the rainy season from July to October. It is an extensive production system, mostly without the application of inorganic fertilizers as those are rarely accessible and not affordable for the majority of the local population. Although farmers prefer the more humid depressions to establish fields, all soil types are being used for crop production. Fallows to restore soil fertility are not common. While the Peul mainly practice crop production for subsistence, the Wolof produce cash crops for sale. The main crops are millet (*Pennisetum typhoides*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), watermelon (*Citrullus lanatus*) and maize (*Zea mays*). Other species commonly planted are roselle (*Hibiscus sabdariffa*, "Bissap" in Senegal) and okra (*Abelmoschus esculentus*) (CSE, 2009a). *Figure 7* shows a field being prepared for crop production in Barkédji.

Figure 7. Man and child working a field with a horsedrawn plough in Barkédji, Senegal

Constraints

The main constraint for crop production is certainly the dependence on sufficient rainfall during the rainy season. With recurring droughts and the decline in annual rainfall during the last decades the situation has been aggravated. Although in some areas boreholes have been established that access deep water, those sometimes break down and are not being repaired or the transport of water from the borehole to the field is not guaranteed. Wind erosion has led to a decline in soil fertility which is now a severe problem. As mentioned before, access to fertilizers is restricted. Other constraints are the presence of ravaging insects, birds or wild mammals (CSE, 2009a).

Biophysical characteristics

The soil texture in the assessed fields was sandy and sandy loam. The amount of “active” organic carbon in this land use system ranged from 0.04 to 0.1 g C / kg soil (CSE, 2009a). This is considered a poor value for both types of textures (Moody et al., 2008). The distribution of aggregates was moderate to good with a presence of both coarse clods and fine aggregates (CSE, 2009a).

The canopy cover in this system of crop production was very low. On average, trees had a medium diameter and low height. More than half of all trees were damaged by humans, mainly to improve light conditions for crops and a relatively high percentage of all trees were dead.

Table 9 presents the characteristics of vegetation at the CLM system of cropland.

Table 9. Characteristics of vegetation at the CLM site "cropland" in Barkédji, Senegal[1]

Canopy cover (%)	2 [0.5]
Herbaceous cover (%)	0
Tree height (m)	4 [0.5]
Tree DBH (cm)	21 [4.5]
Percent trees damaged	51 [12.4]
Percent dead trees	16 [9.9]
Number of trees ha^{-1}	20 [6.4]
Number of regenerating trees ha^{-1}	14 [8.1]
Shannon diversity index	1.36 [0.33]

[1] Standard errors are given in parenthesis. Sample size was n=3.

The only tree species common to "crop production" was *Balanites aegyptiaca* with another 15 species sparsely distributed in the fields. Only six species were found regenerating but the density was very low. Although the analyzed agricultural fields contain trees of a wide range of species, this land use system was not considered sustainable but chosen as a conventional land use system. This is because the cultivators of these fields stated that they do not have a special interest in those trees and might cut them down sooner or later in order to gain more space for cultivation. *Table 10* presents the density of mature trees and regeneration at this CLM site.

Table 10. Density of mature and regenerating woody species per ha and their origin (ind: indigenous, ex: exotic) at the CLM site "cropland" in Barkédji, Senegal[1]

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Balanites aegyptiaca	ind	15.0 [8.6]	9.4 [3.7]
Acacia raddiana	ex	1.7 [1.0]	0.6 [0.4]
Acacia seyal	ind	1.1 [0.6]	3.1 [3.1]
Ziziphus mauritiana	ind	0.7 [0.4]	0.2 [0.2]
Combretum glutinosum	ind	0.3 [0.2]	0
Acacia nilotica	ind	0.3 [0.2]	0.2 [0.2]
Adansonia digitata	ind	0.2 [0.1]	0
Grewia bicolor	ind	0.2 [0.1]	0
Faidherbia albida	ind	0.2 [0.1]	0
Acacia senegal	ind	0.2 [0.1]	0
Azadirachta indica	ex	0.1 [0.1]	0

Species	Origin	No. of trees ha^{-1}	No. of regeneration ha^{-1}
Prosopis juliflora	ex	0.1 [0.1]	0
Acacia ataxacantha	ind	0.1 [0.1]	0
Feretia apodanthera	ind	< 0.1	0
Combretum micranthum	ind	< 0.1	0
Guiera senegalensis	ind	0	0.5 [0.4]
Total		**20.2 [6.4]**	**14 [8.1]**

[1] Standard errors are given in parenthesis. Sample size was n=3.

Impacts

The continuous cultivation of fields without the application of fallows leads to a decline in soil fertility. The natural vegetation cover is degraded as in most cases trees are cut down completely or partially to gain space for crops or to increase light availability. The decreasing soil productivity forces the farmers to extend the area under crop production and to clear more land for cultivation, which leads to further degradation of vegetation cover in the area and therefore reduced availability of fodder for cattle (CSE, 2009a).

4.1.1.2. SLM technologies in Touba Ndar Fall

Characteristics of Touba Ndar Fall

The village of Touba Ndar Fall and its surroundings were chosen as one of three study areas within the GAA of Barkédji. The main land use type in the area is rainfed crop production under agroforestry parkland. It is located in a belt around the main village. In a second circle extensive pastoralism is practiced and forest resources are being exploited. The main constraints mentioned by land users in the area are the presence of insects and wild animals (monkeys, warthogs) which damage cultures and the lack of sufficient rainfall. During 2002 and 2003, Touba Ndar Fall suffered from a long drought. Land users try to cope by diversifying their income, notably through exploitation of forest products such as gum arabic, breadfruit and jujube (*Ziziphus mauritiana*). However, because of ongoing deforestation, those products are becoming rare and some species like *Cordyla pinnata* have completely disappeared from the area. The bare soil is prone to wind erosion which is a common phenomenon in the area. Winds carry away the arable soil horizon and cause a decline in soil fertility. In general, the local population has slowed the decline of land degradation due to the widely practiced tradition of SLM technologies (CSE, 2009a).

SLM technology 1: Traditional agroforestry parkland system

Key characteristics

Millet (*Pennisetum typhoides*), groundnut (*Arachis hypogaea*) or watermelon (*Citrullus lanatus*), are grown in rotation between scattered large trees. The encountered tree species in this parkland were *Faidherbia albida* (syn. *Acacia albida*), *Sclerocarya birrea*, *Sterculia setigera*, *Combretum glutinosum, Balanites aegyptiaca* and *Piliostigma reticulatum*. The tree species were carefully selected by farmers for improvement of soil properties, fruit and fodder production or medicinal purposes. Some of the species were introduced from more southern parts of Senegal and planted by land users when they migrated and settled in this area. Other species regenerated naturally in the fields and were protected till they reached a mature age. Mulching and the application of manure are common means to improve soil organic matter and nutrient content. *Figure 8* shows *F. albida* in parkland in Touba Ndar Fall.

Figure 8. *F. albida* in agroforestry parkland in Barkédji, Senegal

Technology origin

Traditional parkland systems, often with *F. albida* as the main tree component, have existed for a long time in the more southern parts of Senegal where intensive agriculture is practiced. When Wolof farmers migrated north from the overpopulated peanut basin in search of new land to establish a Koran school, they brought the traditional knowledge of combining crop cultivation with beneficial trees with them. Local unwritten codes that extend protection to field trees exist among Wolof communities in the peanut basin (Tschakert & Tappan, 2004). Knowledge is transferred from older to younger people and no kind of external training or formation was received by the land users.

Objectives of land users applying the technology

According to the interviewed land user, the main objectives of this parkland system are to enhance crop production through improvement of soil properties with the help of trees, the provision of supplementary food for cattle in the form of fruits and the availability of plants (or parts of them) for traditional medicine.

Benefits and disadvantages of the technology

Several tree species of this parkland are beneficial for soil properties or food production. *F. albida* greatly increases soil nutrient content through litter fall, root decomposition and increase of microbial activities (Boffa, 2000; Jung, 1970; Rhoades, 1995) (see chapter 2.5.2.1. Parkland systems). *S. birrea* is an indigenous tree, whose fruits are rich in vitamin C and have been consumed by humans since 10,000-9,000 BC (ICRAF, 2009). They are much liked by cattle (Arbonnier, 2004), whereas *B. aegyptiaca* is a preferred fruit tree for humans (Becker, 1983). The leaves of *C. glutinosum* are known to be made into a tea for medical purposes in the Ferlo (Becker, 1983). *S. setigera* is a gum producing tree and provides leaves used as fodder for cattle in the dry season (Arbonnier, 2004). In a study about the perceptions of farmers regarding trees in the agricultural landscape of the Sudanian zone of Senegal (Diédhiou & Diatta, 2004), *S. setigera* was mentioned as a tree that was appreciated in fields because of food production. However, some of the farmers disliked the presence of the species because its superficial rooting systems makes it hard to cultivate the field. In southern Mali *S. setigera* is a sacred tree and people say: "tu ne connaîtras jamais la famine si tu laisses un kongosirani (*S. setigera*) dans ton champ..." (Bagnoud, 1992). *P. reticulatum* is known for its leaves and its fruits which are highly esteemed as fodder and provide dye (Arbonnier, 2004).

Table 11 presents benefits and disadvantages of this SLM technology using the WOCAT criterias. Since tree density in this parkland was low (see "Evaluation and Outlook", further down), the degree of the different benefits was never estimated as high.

Table 11. Benefits and disadvantages of the SLM technology "agroforestry parkland" according to the WOCAT criterias, Barkédji, Senegal

	Benefits		Disadvantages	
	Type	Degree	Type	Degree
Production and socio-economy	Increased crop yield	medium	Decreased production area	little
	Increased fodder production	medium	Hindered farm operations (due to tree roots)	little
	Increased product diversification	medium		
	Reduced expenses on agricultural inputs	negligible		
Socio-cultural	Improved food security / self-sufficiency	medium		
	Improved health (due to medicinal trees available)	little		
Ecological	Increased plant diversity	medium	Increased niches for pests (beetles in the *Cantharidae* family)	unknow n
	Increased biomass	medium	Increased competition (water, sunlight, nutrients)	little
	Increased soil cover (due to mulching)	medium		
	Increased soil moisture (due to mulching)	medium		
	Increased soil organic matter	medium		
	Reduced evaporation (due to mulching)	medium		
	Increased nutrient cycling	medium		
	Provision of shade for cattle and humans	medium		
	Reduced emission of carbon and greenhouse gases due to maintenance of trees	negligible		

Biophysical characteristics

The brown soils in this parkland had a sandy texture with a presence of both coarse and fine aggregates. Measurements of "active" organic carbon were taken in two sites within the parkland. In the part with a presence of *F. albida*, an amount of 0.14 g C / kg soil was measured, indicating moderate soil condition. For the part with *S. birrea*, *S. setigera* and *C. glutinosum,* however, labile organic matter was almost absent. As the species is known to improve soil properties, it is possible that this is reflected in the higher amount of "active" C in the part of the parkland with *F. albida*, compared to the second soil measurement site. However, it could also be related to uneven application of organic manure or other factors. The overall rating of soil condition by the LADA local assessment still assigned these soils moderate to good conditions, taking into consideration a variety of different factors (CSE, 2009a).

Trees were few and scattered in the parkland and canopy cover was therefore low. However, the mean DBH and height were comparatively high for this bush savanna ecosystem and indicate that the trees have been maintained in this system for some time. All individuals were alive and none of them showed signs of damage caused by human impact (see *Table 12*).

Table 12. Characteristics of vegetation at the SLM technology site "agroforestry parkland" in Barkédji, Senegal

Canopy cover (%)	4 [1.0]
Herbaceous cover (%)	4 [0.0]
Tree height (m)	10 [0.3]
Tree DBH (cm)	38 [8.0]
Percent trees damaged	0
Percent dead trees	0
Number of trees ha^{-1}	8 [0.5]
Number of regenerating trees ha^{-1}	3 [0.5]
Shannon diversity index	1.16 [0.19]

[1] Standard errors are given in parenthesis. Sample size was n=2.

The tree species were very evenly distributed in this system. Regeneration was almost absent, probably due to the continuous cultivation of the fields. For two of the preferred species in parklands, *F. albida* and *P. reticulatum*, no regeneration was present at all (see *Table 13*).

Table 13. Density of mature and regenerating woody species per ha and their origin (ind: indigenous, ex: exotic) at the SLM technology site "agroforestry parkland" in Barkédji, Senegal[1]

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Combretum glutinosum	ind	2.0 [2.0]	1.0 [1.0]
Sclerocarya birrea	ind	1.5 [1.5]	0
Sterculia setigera	ind	1.5 [0.5]	1.5 [1.5]
Piliostigma reticulatum	ind	1.0 [1.0]	0
Faidherbia albida	ind	1.0 [1.0]	0
Balanites aegyptiaca	ind	0.5 [0.5]	0
Total		**7.5 [0.5]**	**2.5 [0.5]**

[1] Standard errors are given in parenthesis. Sample size was n=2.

Evaluation and Outlook

Compared to other parkland systems in the West African Sahel, the density of trees in this case was low with only eight trees per ha (Boffa, 1999). The tree density in farmed parklands in Burkina for example is usually between 15 and 30 trees per ha (Gijsbers et al., 1994). A study of *Parkia biglobosa* and *Vitellaria paradoxa* parklands in southern Mali found average densities between 8 and 28 trees per ha, declining with increasing years of cultivation (Bagnoud, 1992). As the positive effects of trees have generally been associated with savannas that have low tree densities (Grouzis & Akpo, 1997), this fact might even prove beneficial for crop production in this system. However, the beneficial effects of *F. albida* on soil properties (see p.10) might be limited due to the weak presence of the species. Kaisin (1994) recommended reconstituting *F. albida* parklands in the Sahel with a density of 40 trees per ha.

The application of manure consisting only of cattle feces does not return all the nutrients removed by the crops to the soil and might therefore be insufficient. Composted manure would provide a possibility to improve organic soil fertilization but the limited access to water in the area is a big constraint to its implication (Ganry et al., 2001).

Given the long generation time of trees, the fact that regeneration and small diameter classes were almost absent in this parkland is a sign for the degradation of the system. An absence of fallows and continuous cultivation of the system hinders the germination of tree seeds or the resprouting of stumps. Contrary to popular belief, livestock has been found to reduce the number of viable seeds of the parkland species considerably by ingestion in different studies (Boffa, 1999). Pests can be another cause of declining tree densities in parklands. Insects of the *Bruchidae* family, for example, were found to destroy *F. albida* seed viability by feeding on the seed embryo and birds of the *Lamprocolius spp.* remove seeds from *F. albida* pods (Boffa, 1999). A trend towards declining tree densities in parklands has been reported in other Sahelian systems as well. For example, in Petit Samba (Burkina Faso) (Gijsbers et al., 1994) and in Sob (Senegal) (Lericollais, 1989) the same phenomenon has been observed. Species in the investigated parkland are predominantly Sudanian or Sahelo-Sudanian taxa as defined by Arbonnier (2004), which is characteristic for all West African parkland systems. Since these species are at their northern distribution limit in Barkédji, the ecologically critical rainfall shifts of the 20th century could be responsible for the decline of these parkland species. Acute moisture and heat stresses might not necessarily have an immediate effect on mature trees, but stand rejuvenation could be greatly affected (Maranz, 2009). Appropriate tree densities (according to the farmer's objectives) will only be maintained in the long term if farmers compensate for trees senescence and natural mortality with protected natural or planted regeneration.

SLM technology 2: Natural grove with *Acacia seyal*

Key characteristics

The grove, dominated by *Acacia seyal,* is located within the silvopastoral reserve of Lindé. As vegetation in the reserve around the forest is widely degraded despite the rules of the reserve, this cannot be the factor explaining the preservation of this grove. An informal protection of the grove by the local population is practiced. The small forest is a habitat for a variety of animal and plant species and provides a number of services to the local community. These include wood for construction, firewood, products for traditional medicine, fodder for cattle and shelter for human basic needs. *Figure 9* shows the SLM site "natural grove" in Touba Ndar Fall.

Figure 9. Natural grove with *A. seyal* in Barkédji, Senegal

Objectives of land users applying the technology

As droughts are common in the area and several pests endanger food security, the population tends to look for diversification of products. Exploitation of forest products is an important second pillar of livelihood generation, in which trees provide food, timber, fodder, medicine and more. The objective is therefore to maintain natural vegetation as a spare resource in the grove e.g. for times of food scarcity.

Benefits and disadvantages

The dominant tree species in the grove, *A. seyal*, has several properties beneficial for humans and the environment. *A. seyal* is considered the best fodder plant in the Sahelian savanna with highly palatable and nutritious leaves and pods. Sheep, goats and cattle are extensively fed with bark during the dry season. In times of fodder scarcity, branches or the whole crown can be lopped off (ICRAF, 2009). *A. seyal* is known for being associated with nitrogen fixing bacteria and its levels of biological nitrogen fixation are higher than, for example, in *F. albida* (Ganry et al., 2001). An important ecological benefit of the grove is therefore the increase of soil nitrogen.

Table 14 presents more benefits and disadvantages of this SLM technology.

Table 14. Benefits and disadvantages of the SLM technology “natural grove” according to the WOCAT criterias, Barkédji, Senegal

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased wood production	high	Decreased production area	little
	Increased fodder production	high		
	Increased product diversification	medium		
Socio-cultural	Improved food security / self-sufficiency	medium		

	Benefits		Disadvantages	
	Type	Degree	Type	Degree
	Improved health (due to medicinal trees available)	little		
Ecological	Increased nutrient cycling	high	Increased niches for pests	unknown
	Increased soil cover	high		
	Increased soil organic matter	high		
	Increased plant diversity	high		
	Increased biomass	high		
	Increased soil moisture	medium		
	Reduced evaporation	medium		
	Maintained habitat diversity	medium		
	Reduced emission of carbon and greenhouse gases due to maintenance of trees	little		
	Increased animal diversity	unknown		
	Increased beneficial species (e.g. pollinators)	unknown		
Others	Provision of shelter for humans to relieve themselves during work in the fields			

Biophysical characteristics

The soil type under this vegetation was hydromorph and generally in a good condition. The distribution of aggregates indicated that there was no degradation present. Soil organic matter content was relatively high with 0.46 g C / kg soil in the labile fraction. The pH was around 5.5 and infiltration rate was moderate. These are all signs of a productive soil (CSE, 2009a).

The canopy cover in this dense stand dominated by *A. seyal* was high and the estimated herbaceous cover was low. The latter might be a consequence of limited sunlight reaching the understory. Tree height was medium and DBH low with little variation between trees. The percentage of damaged trees was rather high and concentrated in some areas, reaching up to 23 % damaged trees in one of the three plots. This shows that the grove is only weakly protected and above all, serves as a wood source for different purposes. High tree mortality is probably a consequence. *Table 15* presents characteristics of vegetation in this SLM technology.

Table 15. Characteristics of vegetation at the SLM technology site "natural grove" in Barkédji, Senegal[1]

Canopy cover (%)	47 [5.2]
Herbaceous cover (%)	15 [0.0]
Tree height (m)	5 [0.3]
Tree DBH (cm)	10 [0.8]
Percent trees damaged	12 [5.6]
Percent dead trees	9 [4.9]
Number of trees ha^{-1}	902 [53]
Number of regenerating trees ha^{-1}	350 [66]
Shannon diversity index	1.56 [0.34]

[1] Standard errors are given in parenthesis. Sample size was n=3.

The dominating tree species in this grove was *A. seyal*, followed by *A. macrostachya*, *F. apodanthera*, and *G. bicolor*. For many of the other species, only one individual was detected during the survey of the three plots, therefore standard errors are very high. Regeneration, mainly of *A. seyal*, was abundant and even comprising two species that were not found as mature trees (*A. leiocarpus* and *C. africana*) (see *Table 16*).

Table 16. Density of mature and regenerating woody species and their origin (ind: indigenous, ex: exotic) at the SLM technology site "natural grove" in Barkédji, Senegal[1]

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Acacia seyal	ind	424.4 [142.7]	52.9 [27.9]
Acacia macrostachya	ind	116.7 [46.2]	10.7 [10.7]
Grewia bicolor	ind	74.1 [38.2]	85.0 [21.2]
Feretia apodanthera	ind	73.9 [21.1]	52.9 [21.0]
Combretum glutinosum	ind	63.9 [0.1]	42.3 [27.9]
Pterocarpus erinaceus	ind	53.1 [53.1]	0
Guiera senegalensis	ind	31.9 [18.4]	10.7 [10.7]
Acacia ataxacantha	ind	21.2 [21.2]	0
Stereospermum kunthianum	ind	10.7 [10.7]	10.7 [10.7]
Lannea acida	ind	10.7 [10.7]	0
Combretum nigricans	ind	10.7 [10.7]	10.7 [10.7]
Combretum micranthum	ind	10.7 [10.7]	21.3 [21.3]
Anogeissus leiocarpus	ind	0	42.3 [42.3]
Commiphora africana	ind	0	10.7 [10.7]
Total		**901.9 [53.2]**	**350.2 [66.3]**

[1] Standard errors are given in parenthesis. Sample size was n=3.

Evaluation and Outlook

This small forest represents one of the few remaining islands of dense vegetation in the otherwise open shrub savanna of the area. Canopy cover was high at about 47% compared to other forest reserves in the country e.g. Welor Forest Reserve in west-central Senegal with 8.5-15.9% woody vegetation cover (Sambou et al., 2008) or Fathala forest in the same region with 10-40% cover (Lykke, 2000).

As the grove is not officially protected, its' future remains unclear. If population grows further and the need for cultivable area increases, pressure on the natural forest will increase. A drastic response would be that the surface will be cleared for cultivation apart from a few beneficial trees. On the other hand if the need for a continuing supply of forest products and that for arable land form a balance, this might prevent the forest from being cut. Its location which is not far from the main village makes it an easily accessible site for firewood collection and as the rest of vegetation around the village is already being degraded, pressure on this site might rise as well.

The fact that decisions in the village ar taken by the "marabou" and that the disciples of Mouridism[6] follow a strict discipline would largely ensure an effective protection of the grove once the "marabou" agrees to it.

4.1.1.3. SLM technologies in Diagaly

Characteristics of Diagaly

The village of Diagaly was founded more than 100 years ago by members of the Peul ethnicity, who are West Africa's pastoralists. At this time the vegetation around the village was very dense and even harbored a group of lions because of which the village came to its name. The main land use type in the area is extensive pastoralism followed by rainfed crop production. Vegetation cover in the area has largely been degraded due to exploitation for domestic uses and cattle feeding, bushfires and overgrazing. The soil is exposed to wind erosion which carries away nutrients in the topsoil and therefore decreases soil fertility. During intense rains in the rainy season, surface runoff is accelerated and leads to the formation of gullies and ravines. The quality of water sources has declined as they are used by the local population for the purpose of body hygiene and laundry. Despite these various types of degradation, pastoralism and rainfed crop production guarantee a certain food security for the local population as they experience famines very rarely (CSE, 2009a).

SLM technology 1: Traditional agroforestry system with *Acacia senegal*

Key characteristics

This agroforestry system, dominated by *Acacia senegal,* has been developed through assisted tree regeneration. Trees naturally growing in the fields are protected from tillage until they reach a mature age. To improve soil properties and crop production, organic manure is applied and a fallow system is practiced. Part of the field is under cultivation with millet (*Pennisetum typhoides*), cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) whereas the other part is left fallow for two years before a rotation (see *Figure 10*). This SLM technology is managed by family labor and occupies an area of about 35 ha.

[6] A marabout is an Islamic religious leader and teacher in West Africa. In this context it is a leader of the Mouride brotherhood, an Islamic Sufi brotherhood, most prominent in Senegal and Gambia, with its headquarters in the city of Touba, Senegal (Thiam, 2005).


Figure 10. Agroforestry with *A. senegal* (left: fallow part, right: cultivated field), Barkédji, Senegal

Technology origin

The land users applying this agroforestry practice believe that any tree in their fields is useful and should be protected, because of knowledge that their fathers have passed down to them. This is a concept they have been applying ever since they started cultivating their own fields.

Objectives of land users applying the technology

Initially, the main objective of the land users was to improve soil properties and crop production in the fields by maintaining any tree and protecting natural regeneration when preparing the land for cultivation. With the start of the exploitation of *A. senegal* for its' exudates (gum arabic), the potential revenue increase through gum exploitation became evident to land users and the objective shifted from soil protection to gum exploitation.

Benefits and disadvantages

Table 17 presents benefits and disadvantages of this SLM technology. While the benefit of increased plant diversity mainly applies to the part of the system under cultivation, all other ecological benefits mainly apply to the fallow part where tree density is high.

Table 17. Benefits and disadvantages of the SLM technology “agroforestry with *A. senegal*” according to the WOCAT criterias, Barkédji, Senegal

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased farm income	high	Increased labor constraints (protection of *A.senegal* trees from illegal exploitation)[7]	high
	Diversification of income sources	high	Decreased production area	medium
	Increased product diversification	medium		
	Increased crop yield	medium		
	Increased fodder production	medium		
Socio-cultural	Improved food security / self-sufficiency	medium		
	Improved health (due to medicinal trees available)	negligible		
Ecological	Increased plant diversity	medium	Increased niches for pests (birds)	unknown
	Increased biomass	medium	Increased competition for water, sunlight and nutrients (cultivated part)	little
	Increased soil organic matter	medium		
	Increased nutrient cycling	medium		
	Increased soil cover	medium		
	Reduced wind velocity (fallow part)	medium		
	Reduced soil loss (fallow part)	medium		
	Reduced emission of carbon and greenhouse gases due to maintenance of trees	little		
	Increased soil moisture	little		
	Reduced evaporation	little		
Offsite	Reduced wind transported sediments	little		
Others	Provision of shade for cattle, therefore increased availability of manure	medium		

[7] This is the case during the exploitation season for gum Arabic from November-May

Regarding inputs required for the maintenance of the system, the technique of assisted tree regeneration is technically easy to apply and in this case does not require any financial input as trees only need to be protected from tillage. Roaming cattle is less of a problem in this case than in other regions, as herds are always accompanied by a Peul herder who has an interest to prevent his herd from ravaging fields to avoid conflicts with cultivators of the same or of the Wolof ethnicity[8].

Biophysical characteristics

For the part under cultivation, soil texture was sandy to loamy consisting of coarse as well as fine aggregates, which is suboptimal (Shepherd, 2000). The amount of organic carbon in the labile fraction was very low with 0.05 g C / kg soil, a value considered as poor for sandy soils (Moody et al., 2008). In the fallow part, soil conditions were only little improved with an amount of active organic carbon of 0.09 g C / kg soil and signs of a biological crust (CSE, 2009a). According to these measurements, the described SLM technology can therefore not be considered as having improved soil properties in general. However, the availability of soil nutrients has not been investigated and according to the land user's opinion, the presence of trees is beneficial for his crop production.

Canopy cover in the cultivated part was very low but higher in the fallow part. In the fallow part, herbaceous cover was estimated at 70%, whereas in the cultivated part herbs were exclusively present under the canopy of trees since the rest had been removed to minimize competition with crops. At the entire technology site trees were alive and in good condition, except for one individual of *B. aegyptiaca* showing signs of cutting. Trees in the cultivated part were likely to be older than in the fallow part, regarding height and DBH. Trees in the almost monospecific stand of *A. senegal* in the fallow part seemed to be of the same age (see *Table 18*).

Table 18. Characteristics of vegetation in fields under cultivation and left fallow at the SLM technology site "agroforestry with *A. senegal*" in Barkédji, Senegal[1]

	Part under cultivation	Part left fallow
Canopy cover (%)	1 [0.1]	11 [7.3]
Herbaceous cover (%)	1 [0.0]	70 [0.0]
Tree height (m)	4 [0.9]	2 [0.2]
Tree DBH (cm)	15 [4.4]	5 [0.7]
Percent trees damaged	2 [1.5]	0
Percent dead trees	0	0
Number of trees ha^{-1}	13 [4.8]	343 [201.9]
Number of regenerating trees ha^{-1}	35 [25.7]	88 [33.3]
Shannon diversity index	1.29 [0.1]	0.29 [0.16]

[1] Standard errors are given in parenthesis. Sample size was n=2 for "cultivation" and n=3 for "fallow".

The part left fallow was covered by a dense stand of *A. senegal* with only few individuals of other species. As expected, regeneration was higher in the fallow part than in the part under cultivation and consisted mainly of almost equal proportions of *A. senegal* and *B. aegyptiaca*. In the part under cultivation tree density was low but species richness higher than in the fallow part. Regeneration consisted mainly of *B. aegyptiaca* (see *Table 19*).

[8] Oral personnal communication of Wélé, A. Ingénieur des Eaux et Forêts. In Barkédji, 01.08.2009.

Table 19. Density of mature and regenerating woody species (ordered alphabetically) in fields under cultivation and fallow at the SLM technology site "agroforestry with *A. senegal*" in Barkédji, Senegal[1]

	Part under cultivation		Part left fallow	
Species	**No. ind. ha^{-1}**	**No. ind. of reg. ha^{-1}**	**No. ind. ha^{-1}**	**No. ind. of reg. ha^{-1}**
Acacia raddiana	0	2.3 [2.3]	0	2.7 [2.7]
Acacia senegal	4.3 [4.3]	3.7 [3.7]	329.1 [201.3]	32.0 [21.2]
Balanites aegyptiaca	5.1 [1.1]	12.9 [10.9]	8.0 [4.6]	26.7 [14.1]
Bauhinia rufescens	0	0	2.7 [2.7]	5.3 [5.3]
Combretum glutinosum	0.4 [0.4]	3.9 [0.1]	0	2.7 [2.7]
Faidherbia albida	0.5 [0.5]	0	0	0
Grewia bicolor	1.0 [0.0]	0.5 [0.5]	0	2.7 [2.7]
Guiera senegalensis	0	5.4 [4.4]	2.7 [2.7]	8.0 [4.6]
Piliostigma reticulatum	0.5 [0.5]	0.9 [0.1]	0	5.3 [5.3]
Ziziphus mauritiana	1.0 [0.0]	5.1 [5.1]	0	2.7 [2.7]
Total	**12.8 [4.8]**	**34.7 [25.7]**	**342.5 [201.9]**	**88.1 [33.3]**

[1] Standard errors are given in parenthesis. Sample size was n=2 for "cultivation" and n=3 for "fallow".

Evaluation and Outlook

In the part of the system under cultivation at the time of this study, species richness and diversity were higher than in the part left fallow. Regeneration was common for *B. aegyptiaca* and if all of the seedlings would reach mature age, competition with crops for light, water and nutrients might occur. At present, the land users seem primarily interested in the profit they could derive from *A. senegal* and they might be tempted to abandon the concept of assisted natural regeneration and only support the establishment of further *A. senegal* trees to outweigh the loss of cultivable area with income from gum production.

In the fallow part, density of *A. senegal* was intermediate with 329 trees ha^{-1} compared to tree densities used in an experimental setup to study the effect of tree density on water use, gum production and crop yield in Sudan (high density: 433 trees ha^{-1}, low density: 266 trees ha^{-1}) (Gaafar et al., 2006). Although contradictory to the land users' statement, it is likely that they have influenced species composition by carefully selecting for *A. senegal*. Gaafar et al. (2006) found that the highest gum production per tree occurred when trees of high densities were intercropped with sorghum (115 kg ha^{-1}) whereas the same tree density without intercropping yielded only 81 kg of gum ha^{-1}. On the other hand, crop yields (sorghum and roselle) were significantly lower when grown in association with *A. senegal* than in monocultures. For the family of land users managing this technology in the Ferlo, this knowledge is not available as services of education and training in agriculture (and especially agroforestry) are non existent. Since crop cultivation in this environmental and socioeconomic setting is very strenuous labor, and as the revenues from selling gum arabic are higher than the income generated by the low amount of crops available for commercialization, it is likely that crop cultivation in this field will not be retained. Assuming that the cultivation of millet has similar effects on gum production as sorghum, it could be favorable to test this intercropping regime in the Ferlo.

The woody plant density was much higher in the fallow part of this SLM system and therefore the positive impacts on soil properties should be higher compared to the one under cultivation. If cultivation was abandoned in this part of the system in favor of a monospecific stand of *A. senegal,* biodiversity would decrease but on the other hand soil cover and plant biomass would increase, improving soil properties and augmenting the carbon sequestration potential of this technology. An expansion of the *A. senegal* agroforestry system in the region might have an important potential for improving the livelihoods of small scale farmers and at the same time reducing land degradation.

SLM technology 2: Agroforestry homegarden

<u>Key characteristics</u>

This agroforestry plot, located in the village of Diagaly, represents a typical tropical homegarden system (see p. 12): The piece of land with a size of 0.5 ha, under the management of family labor, contains a variety of multipurpose trees and shrubs in association with annual and perennial crops and vegetables (see *Figure 11*). Irrigation is practiced during the dry season with water from the borehole.

The garden is subdivided into several micro-zones under different management. One part is dedicated to vegetable production during the dry season which is replaced by the cultivation of maize (*Zea mais*) in the rainy season. In a second zone, cassava (*Manihota esculenta*) is grown, a perennial plant that can be harvested all year round. These two zones of crop cultivation are separated by a small and dense grove of lemon (*Citrus limon*) trees, under which herbaceous cover is absent. *Prosopis juliflora*, as well as a variety of less abundant indigenous and exotic tree species (see *Table 22*) are scattered throughout the garden. The combination of those micro-management zones result in a three-layered architecture. Since tree density is relatively low, the three layers rarely overlap. In the lowest level, sweet potatoes (*Ipomoea batatas*), egg plants (*Solanum melongena*), cabbage (*Brassica oleracea*) and roselle (*Hibiscus sabdariffa*) are grown, whereas vegetables such as tomatoes (*Lycopersicon esculentum*), chili (*Capsicum sp.*), beans (*Phaseolus vulgaris*) and okra (*Abelmoschus esculentus*) make up the intermediate and the multipurpose tree species make up the top level. Trees are mainly raised and maintained for food production and for their medicinal value. However, homegarden production is supplementary to staple food production in the bushfields cultivated by the owner of this homegarden. A hedge of mainly dead wood, some *Euphorbia balsamifera* shrubs and few *Eucalyptus camaldulensis* trees protects the homegarden from roaming animals. The system is aimed at a mixed subsistence / cash crop production though the level of commercialization is still very low. Organic manure obtained from cattle feces is used as a natural fertilizer.

Figure 11. Agroforestry homegarden, Barkédji, Senegal

Technology origin and objectives

The homegarden was established in 1991 and belongs to a single land user who was looking for an opportunity to improve his livelihood by diversifying agricultural production in this remote village. According to his statement this plot of land was bare when it was assigned to him by the village chief and he started the garden by planting *P. juliflora* and Neem (*Azadirachta indica*) trees.

The main objectives of the land user were to increase food security for his family, to make a wide range of fruits and vegetables available in this remote zone and to improve his household income through diversification of products. As the plot is situated on a slope of 7 % and is prone to water erosion during heavy rains, a further objective was to prevent the formation of gullies and ravines through improved soil stabilization.

Benefits, disadvantages and constraints

Having a wide range of food products available, was the main advantage of this SLM technology mentioned by the land user. The majority of trees in the homegarden provide non-timber products e.g. dye in the case of Henna (*Lawsonia inermis*) or medicine. The hedge of dead wood and live trees has the positive off-site effect of preventing the temporary pond beneath the plot from being filled up with sediments due to wind erosion. More benefits of this SLM technology as well as the disadvantages are presented in *Table 20*.

An important constraint for the well-functioning of this technology is the scarcity of water for irrigation. Although a small water basin in the plot is connected with the village's borehole through a pipe, the outflow of the borehole is very weak. The planting of 200 *E. camaldulensis* seedlings in a tree nursery, aimed at reinforcing the hedge, failed because of a lack of water. According to the land user, in the lower part of the plot none of the planted vegetables grow. He suspects soil macrofauna to be the cause and therefore applied a range of pesticides without any success. The life hedge is very weak and has already been destroyed in some parts by gully formation. Shading from mature trees can impede the growth of vegetables which makes it necessary to cut some of the branches from time to time.

Table 20. Benefits and disadvantages of the SLM technology "agroforestry homegarden" according to the WOCAT criterias, Barkédji, Senegal

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased farm income	medium	Increased demand for irrigation water	high
	Diversification of income sources	medium	Decreased production area	little
	Increased product diversification	medium		
	Increased fodder production	negligible		
Socio-cultural	Improved food security / self-sufficiency	high		
	Improved health (due to medicinal trees available)	little		
Ecological	Increased plant diversity	medium	Increased niches for pests	unknown
	Reduced soil loss through wind and water (due to hedge)	medium	Increased competition (water, sunlight, nutrients)	medium
	Increased soil organic matter (through trees and application of manure)	little		

	Benefits		Disadvantages	
	Type	Degree	Type	Degree
	Increased nutrient cycling	little		
	Increased soil cover	little		
	Increased biomass	little		
	Reduced evaporation	little		
	Increased soil moisture	little		
	Reduced emission of carbon and greenhouse gases due to maintenance of trees	negligible		
Offsite	Reduced wind and water transported sediments into the pond beneath the homegarden	little		

Biophysical characteristics

The sandy soil contained coarse as well as fine aggregates (CSE, 2009a), a sign of moderate soil condition (Shepherd, 2000). In the part of the plot described by the land user as unsuitable for cultivation, a pH of 4.5 was measured. As acidic soils have many negative characteristics such as aluminum toxicity, phosphorus deficiency or reduced nitrogen mineralization because of restricted microbial activity (FAO, 2007), the fact that crop growth was inhibited in this area might be related to pH. The cause of the acidic pH, however, remains unclear. The amount of “active” soil organic carbon was poor with 0.09 g C / kg soil (CSE, 2009a), possibly lowering the cation exchange capacity (Boffa, 1999). The infiltration capacity was moderate and therefore beneficial for crop production as neither waterlogging nor moisture unavailability should be a problem. The fact that in the above mentioned part of the homegarden cassava (*Manihota esculenta*) was grown as the major crop might have had a negative effect on soil productivity. Cassava extracts large amounts of nutrients from the soil and easily leads to K exhaustion if not replaced with appropriate amounts of fertilizer. As N accumulates mostly in leaves, it is returned to the soil after crop harvest through residues (Howeler, 1991). The land user mentioned problems with fertilizer application because of limited means to buy it and mostly relies on manure. However, cassava gives relatively good yields when soil fertility is poor (Fermont et al., 2008). Farmers in Ghana and Benin even use cassava as a “soil fertility regenerating strategy” (Adjei-Nsiah et al., 2007; Saidou et al., 2004). A different possible explanation of poor soil conditions is related to the perception of the problem by the land user. He suspected termites of being the cause of crop failure and therefore applied a range of chemical pesticides to the soil. Those probably destroyed all soil macro- and microfauna and might be held responsible for crop failure.

Canopy cover was intermediate and almost one third of all mature trees showed signs of cutting which has been explained by the land user as a measure to improve light conditions for crops. Herbaceous cover was present in the parts of the plot not yet prepared for cultivation but will subsequently be removed (see *Table 21*).

Table 21. Characteristics of vegetation at the SLM technology site "homegarden" in Barkédji, Senegal[1]

Canopy cover (%)	17
Herbaceous cover (%)	20
Tree height (m)	7 [0.4]
Tree DBH (cm)	17 [1.2]
Percent trees damaged	28
Percent dead trees	0
Number of trees ha^{-1}	156
Number of regenerating trees ha^{-1}	73
Shannon diversity index	1.83

[1] For this SLM technology the whole site (one homegarden) was assessed. Standard errors for the average tree height and DBH in the homegarden are given in parenthesis.

Common tree and shrub species were *P. juliflora*, *E. balsamifera*, *C. limon*, *E. camaldulensis* and *A. indica*. Of all other species, only one or two individuals were present in the plot. More than half of the present trees were of exotic origin. They had been planted for fencing of the plot (*E. balsamifera*, *E. camaldulensis* and *P. juliflora*), food production (*C. limon*, *T. indica, M. oleifera),* medicinal value (*A. indica*) or production of dye (*L. inermis*). Indigenous species were all present in low numbers. *Table 22* presents densities of trees and regeneration.

Natural regeneration was common for *Z. mauritiana* and *B. aegyptiaca* but absent for all other species (see *Table 22*).

Table 22. Density of mature and regenerating woody species and their origin (ind: indigenous, ex: exotic) at the SLM technology site "homegarden" in Barkédji, Senegal[1]

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Prosopis juliflora	ex	51.2	0
Euphorbia balsamifera	ex	37.4	0
Citrus limon	ex	27.6	0
Eucalyptus camaldulensis	ex	15.7	0
Azadirachta indica	ex	7.9	0
Tamarindus indica	ex	3.9	0
Ziziphus mauritiana	ind	2.0	41.3
Calotropis procera	ind	2.0	0
Combretum glutinosum	ind	2.0	0
Moringa oleifera	ex	2.0	0
Piliostigma reticulatum	ind	2.0	0

Species	Origin	No. of trees ha^{-1}	No. of regeneration ha^{-1}
Lawsonia inermis	ex	2.0	0
Balanites aegyptiaca	ind	-	31.5
Total		**155.7**	**72.8**

[1] For this SLM technology the whole site (one homegarden) was assessed

Evaluation and Outlook

The initiative to increase plant product diversity in a zone dominated by extensive pastoralism is promising but the goals are difficult to achieve. A lack of education and training in agricultural fields hinders the land user from taking appropriate decisions when selecting species to intercrop in his homegarden. The use of *E. camaldulensis* for reinforcement of the hedge is questionable as this species is known for its high water use. A study comparing water use of *A. indica*, *P. juliflora* and *E. camaldulensis* in western Senegal at the end of the rainy season found that *E. camaldulensis* used significantly more water per unit leaf area than the other two species (Deans & Munro, 2004). The competition for water between *E. camaldulensis* and vegetables as well as other trees might even intensify the already prevalent problematic of water scarcity in the homegarden. The description Kumar and Nair (2004) used for homegardeners as “perpetual experimenters” holds true for the land user cultivating this garden. A new species may be chosen because of its properties i.e., food, medicinal, wood etc. and based on self-instinct or information passed on by other villagers (Kumar & Nair, 2004).

Following the suggestions by Torquebiau (1992), a variety of indicators can be analyzed to decide if a homegarden is sustainable or not. The rate of soil erosion is one of these indicators. At the margins of the garden, water erosion has already caused small ravines and destroyed part of the hedge. However, in a different part of the garden, on the footslope, the hedge mitigates the loss of soil material towards the village’s temporary pond and main water source in the rainy season. Soil organic matter was low but measurements were only taken in one part of the plot, where few trees were present. As canopy and herbaceous cover were rather low, the positive effects of a multilayered system, such as interception of rainfall and therefore reduced impact of rain drops on the soil as well as an increase of water retention on the plants (Torquebiau, 1992) might be negligible. However, a high diversity of plants is used in this homegarden, providing food security and income for the land user. Few cash-demanding inputs are required: inorganic fertilizers and pesticides are only applied on rare occasions as they are hardly available in the zone and expensive. The only endogenous input is the use of organic manure. Labor requirements cannot be very high, as in addition to the homegarden the owner cultivates several bushfields and runs a small bakery business.

In the present state, the sustainability of this SLM technology is medium with a potential to be increased in the future. Natural regeneration of *Z. mauritiana* and *B. aegyptiaca*, the two most preferred fruit trees in the Ferlo (Becker, 1984), is abundant and will further increase food security for the land user if the seedlings reach maturity. Soil conservation measures, such as establishing terraces on the 7% slope and improving the hedge should be used to minimize the threat that water erosion poses to this homegarden. Endogenous inputs could be diversified and include mulching or composting. Soil fertility in the part where the measurements were taken probably has to be restored by fertilizer application. Training for better soil management would be needed in order to prevent similar degradation of soil properties in the future.

SLM technology 3: Homegarden with approach “Groupe de Promotion des Femmes”

Key characteristics

This homegarden with a surface of 0.55 ha is located in the village of Diagaly and has been established by the “Groupe de Promotion des Femmes (GPF)” (see *Figure 12*). During the dry season vegetables are intercropped with some scattered trees whereas during the rainy season millet (*Pennisetum typhoides*) is planted. The vegetables that are planted include okra (*Abelmoschus esculentus*), carrot (*Daucus carota)*, onion (*Allium cepa*), eggplant (*Solanum melongena*) and chili (*Capsicum sp.*). Irrigation is practiced for the vegetable cultures. A fence of dead wood and *P. juliflora* trees protects the plot against free ranging cattle.

A tree nursery incorporated in the plot contained seedlings of *E. camaldulensis*, *A. indica*, *A. senegal*, *Terminalia cattapa* and *F. albida.*

Figure 12. Homegarden "Groupe de Promotion des Femmes" with fence of dead wood in the background, Barkédji, Senegal

Characteristics of the approach

The initiative for this approach was taken by an agronomic technician who was willing to support women in this rural area by improving their livelihoods. Women in this area generally only have one opportunity to earn some money, by starting a so-called "petit-commerce", which involves buying a few products such as matchsticks etc. in a bigger village or town and then reselling them in the village. Through the approach "promotion des femmes" women should be given the opportunity to create income from the commercialization of agricultural products. A plot of land to establish vegetable cultures was borrowed from the village chief. Women from different social backgrounds and from four different villages in the area of Diagaly assembled to build the "Groupe de Promotion des Femmes (GPF)". They chose one woman as their representative, called "mère des femmes". The whole group, including the "mère des femmes", is presided by the "dirigeant", a man. Initially, this was the technician who had started the initiative but in the meantime he had been replaced by a village elder. In the beginning, a little funding was obtained from the national "Projet d'Appui à l'Elevage (PAPEL)", ENDA Tiers-Monde (an international NGO) and a local agricultural project (ADESA). After this initial support the GPF has been left to its own devices. Each woman then had to contribute to the establishment of the plot by either constructing two meters of the enclosure (dead fence) or by paying 1,000 FCFA (=USD 2.10)[9] compensation. The maintenance of the plot is now assured through voluntary contributions by the women. *Figure 13* presents the organogram of the GPF.

[9] Exchange rate FCFA to USD, 22.02.2010: 1 FCFA = 0.00207 USD (OANDA Corporation, 2010); the same is valid for all other conversions from FCFA to USD in this document

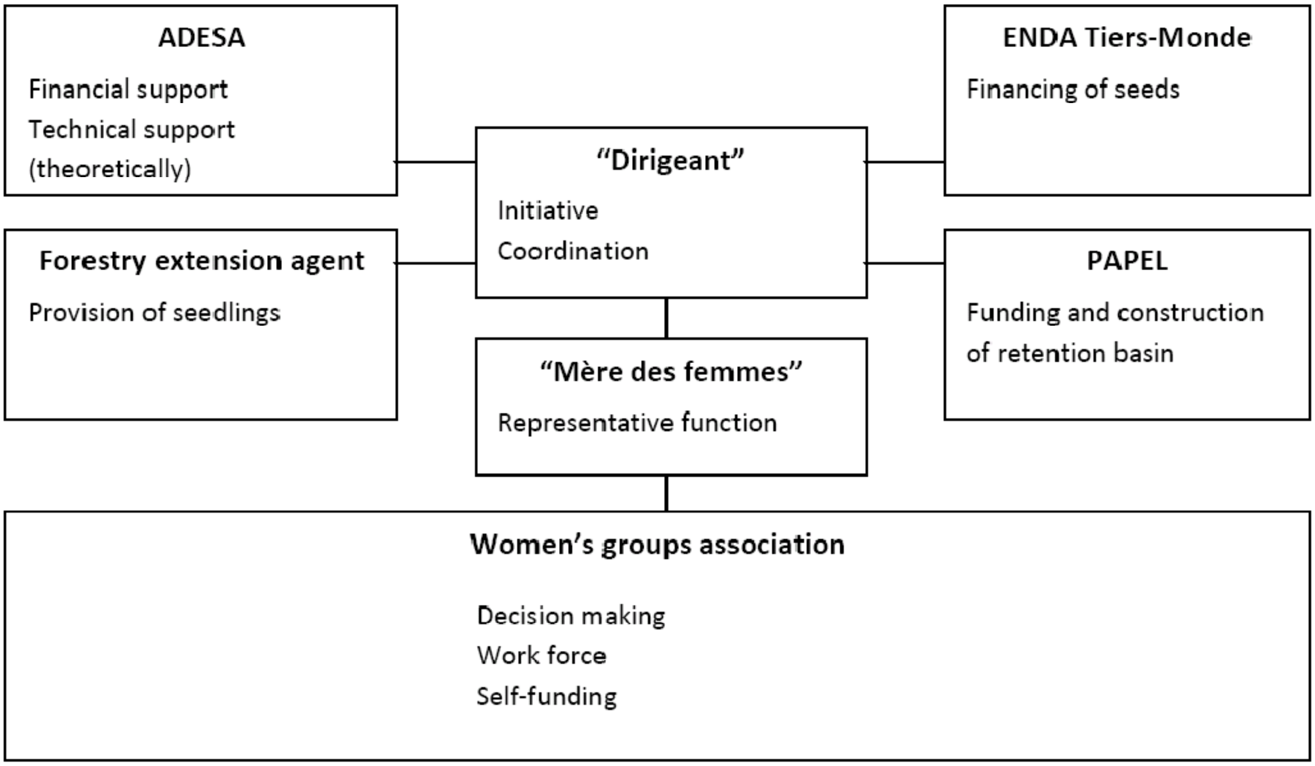


Figure 13. Organogram of the "Groupe de Promotion des Femmes", Barkédji, Senegal

Benefits, disadvantages and constraints

A big constraint for the success of this community project is the scarcity of water for irrigation purposes. Access to the village's borehole is restricted because cattle herders are always privileged and in the end there is no water left for the women's group to water their vegetable cultures. Access to construction materials for the fence was limited.

Cultural constraints were encountered during the initial phase of the approach. In the beginning the "dirigeant" and the "mère des femmes" were both members of the Wolof ethnicity even though the majority of participating women were Peul which led to protests by the latter. By discussion and reconciliation it was decided that at least one of the two head positions in the group ("dirigeant" and "mère des femmes") would have to be occupied by a Peul woman.

Table 23 presents the benefits and disadvantages of this SLM technology.

Table 23. Benefits and disadvantages of the SLM technology "homegarden GPF" according to the WOCAT criterias, Barkédji, Senegal

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased farm income	little	Increased demand for irrigation water	high
	Diversification of income sources	little		
	Increased product diversification	little		
Socio-cultural	Improved situation of socially and economically disadvantaged groups	medium		
	Improved food security / self-sufficiency	little		
Ecological	Increased plant diversity	medium		
	Increased soil organic matter	little		
	Increased biomass	little		
	Increased nutrient cycling	negligible		
	Increased soil cover	negligible		
	Reduced evaporation	negligible		
	Increased soil moisture	negligible		
	Reduced emission of carbon and greenhouse gases due to maintenance of trees	negligible		

Biophysical characteristics

The soil texture was sandy loam with a mixture of coarse and fine aggregates providing moderate conditions for crop growth. The pH was almost neutral and infiltration rates were medium which is favorable for vegetable production. The amount of soil organic carbon in the labile fraction was moderate with 0.24 g C / kg soil. Soil properties according to the LADA rapid assessment were moderate to good (CSE, 2009a).

Canopy cover was relatively low and herbaceous cover was absent due to cultivation of the soil. Around 65% of all trees in this homegarden showed damage through cutting. This high percentage was due to the cutting of all *P. juliflora* trees to improve light conditions for crops. One individual of *B. aegyptiaca* had branches cut to provide fodder for cattle. For the other trees the reason for cutting is unknown. The tree DBH was low indicating that the trees present might have been established only recently (see *Table 24*).

Table 24. Characteristics of vegetation at the SLM technology site “homegarden GPF” in Barkédji, Senegal[1]

Canopy cover (%)	10
Herbaceous cover (%)	0
Tree height (m)	6 [0.3]
Tree DBH (cm)	10 [0.6]
Percent trees damaged	65
Percent trees dead	0
Number of trees ha^{-1}	86
Number of regenerating trees ha^{-1}	2
Shannon diversity index	1.67

[1] For this SLM technology the whole site (one homegarden) was assessed. Standard errors for the average tree height and DBH in the homegarden are given in parenthesis.

Apart from *P. juliflora*, most species were present with only few individuals due to the high seedling mortality. Regeneration was practically absent for the same reason. Several species found were of exotic origin: *P. juliflora*, *A. indica*, *E. camaldulensis*, *L. leucocephala, L. inermis* and *M. oleifera*. *Table 25* presents density of mature trees and regeneration in the GPF homegarden.

Table 25. Density of mature and regenerating woody species and their origin (ind: indigenous, ex: exotic) at the SLM technology site “homegarden GPF” in Barkédji, Senegal[1]

Species	**Origin**	**No. trees ha^{-1}**	**No. regeneration ha^{-1}**
Prosopis juliflora	ex	51.4	1.8
Ziziphus mucronata	ind	7.3	-
Lawsonia inermis	ex	5.5	-
Ziziphus mauritiana	ind	3.7	-
Azadirachta indica	ex	3.7	-
Balanites aegyptiaca	ind	1.8	-

Species	Origin	No. trees ha^{-1}	No. regeneration ha^{-1}
Bauhinia rufescens	ind	1.8	-
Combretum glutinosum	ind	1.8	-
Eucalyptus camaldulensis	ex	1.8	-
Leucaena leucocephala	ex	1.8	-
Mindioli (local name)		1.8	-
Moringa oleifera	ex	1.8	-
Sclerocarya birrea	ind	1.8	-
Total		**86.3**	**1.8**

[1] For this SLM technology the whole site (one homegarden) was assessed.

Evaluation and Outlook

The outcome of this project in the form of an amelioration of the women's revenues has been disappointing. Despite the moderate soil properties that were measured, the land users complained that none of the seedlings of fruit trees planted in this plot ever survived. If the mortality is not caused by problems with soil productivity it might be related to water stress or the technique of transplanting the seedlings from the tree nursery into the field. The majority of group members are Peul, looking back on a tradition of successful cattle breeding but with little experience in agricultural techniques. This can be part of the reason why there has not been any success with the cultivation of vegetables and fruit trees in this site yet. Support from extension services is inadequate. Seedlings have been provided on several occasions but the cultivators have not received any advice on how to proceed or where to plant them. *P. juliflora* seedlings planted to reinforce the hedge have not established and therefore the fence remains weak. If reinforcement does not succeed, the protective function of the fence might be at risk and its few ecological benefits will cease. Despite the lack of success, the group members' motivation is still high to continue with the activities. The absence of monitoring and reporting is a weakness as it would have been important to note the changes that occurred in soil productivity, technical maintenance etc. during the course of the years. Unfortunately no research has been conducted yet to investigate the reasons for the poor soil properties reported by the group. Better technical support from the forestry extension service would be necessary to improve the outcome of this SLM technology.

The GPF approach has however improved the situation of a group of socially and economically disadvantaged people – the women. Even if revenue augmentation is negligible, the project empowered women to discuss and take decisions independently from their husbands.

4.1.2. Results from vegetation assessment in the GAA of Barkédji

4.1.2.1. Mature woody species

Species composition

Forty three (43) tree species were identified in 40 plots in the GAA of Barkédji covering a total surface of about 24 ha. On those 24 ha a total number of 901 trees were found. Nine of the encountered species were of exotic origin and the others indigenous (for definitions see chapter 3.3.4., p. 25). Of the 34 indigenous species, about half were Sahelian or Sahelo-Sudanian taxa and the rest mainly of Sudanian or Sudano-Guinean affinity (Arbonnier, 2004). All of these species were listed by Arbonnier (2004), which is an indication that they are relatively common and widespread species that have been traditionally used in the dry zones of West Africa, as those were the criteria for Arbonnier to include them in his book. Four individuals of *A. obesum,* which is reported to occur only scattered in the Sahel (Arbonnier, 2004) and was not encountered in several studies of ligneous biodiversity in semi-arid West Africa (Kindt et al., 2008; Lykke et al., 2004; Wezel & Boecker, 1998), were encountered during this survey.

The density of all tree and shrub species that were encountered is indicated in *Table 26*, averaged over all plots. Thirty nine (39) different tree species were identified in SLM sites. The three most abundant species found in SLM sites belong to the genus *Acacia*. Only 20% of all species were present with a density of more than 10 individuals per ha. About 40% had a density of 1-10 and another 40 % had a density of < 1 individual per ha. Standard errors were very high as the distribution of several species was restricted to only one SLM site.

At CLM sites only 22 different tree species were encountered. Apart from the four species of *A. raddiana, Leptadenia pyrotecnica, Acacia nilotica* and *Adansonia digitata,* all species that were present at CLM sites also occurred at SLM sites. The three most abundant species at SLM sites however, were not or rarely present in CLM sites. *B. aegyptiaca* was the only species at CLM sites with an abundance of more than 10 individuals per ha. All other species were present in very low numbers.

The two most common species in both land management systems were Sahelian taxa.

Table 26. All trees with DBH ≥ 2 cm averaged over all plots of sustainable and conventional LM and ranked by mean density in Barkédji, Senegal[1]

	SLM[2]		CLM[2]	
Rank	Species	Mean density (no. ind. ha^{-1})	Species	Mean density (no. ind. ha^{-1})
1	*Acacia seyal*	74.9 [44.3]	*Balanites aegyptiaca*	28.3 [7.5]
2	*Acacia senegal*	58.6 [42.0]	*Combretum glutinosum*	5.7 [3.5]
3	*Acacia macrostachya*	29.5 [13.0]	*Acacia raddiana*	4.0 [2.1]
4	*Combretum glutinosum*	23.1 [7.9]	*Pterocarpus lucens*	3.5 [1.7]
5	*Grewia bicolor*	22.6 [8.9]	*Guiera senegalensis*	3.1 [2.1]
6	*Guiera senegalensis*	17.8 [7.6]	*Commiphora africana*	1.4 [1.1]
7	*Feretia apodanthera*	13.5 [7.4]	*Acacia senegal*	1.1 [0.6]
8	*Pterocarpus erinaceus*	11.7 [9.2]	*Grewia bicolor*	0.7 [0.5]
9	*Combretum micranthum*	7.1 [4.8]	*Sclerocarya birrea*	0.3 [0.3]
10	*Pterocarpus lucens*	7.1 [3.9]	*Adenium obesum*	0.3 [0.3]
11	*Boscia senegalensis*	6.1 [2.4]	*Combretum aculeatum*	0.3 [0.3]
12	*Prosopis juliflora*	6.0 [4.0]	*Leptadenia pyrotecnica*	0.3 [0.3]
13	*Commiphora africana*	5.2 [2.5]	*Acacia seyal*	0.1 [0.1]
14	*Acacia ataxacantha*	4.2 [3.7]	*Ziziphus mauritiana*	0.1 [0.1]
15	*Combretum nigricans*	3.8 [2.1]	*Faidherbia albida*	0.1 [0.1]
16	*Balanites aegyptiaca*	2.6 [1.1]	*Acacia nilotica*	0.1 [0.1]
17	*Euphorbia balsamifera*	2.2 [2.1]	*Prosopis juliflora*	0.04 [0.04]
18	*Sclerocarya birrea*	2.2 [1.0]	*Feretia apodanthera*	0.04 [0.04]
19	*Lannea acida*	1.9 [1.8]	*Combretum micranthum*	0.04 [0.04]
20	*Stereospermum kunthianum*	1.9 [1.8]	*Acacia ataxacantha*	0.04 [0.04]
21	*Citrus limon*	1.6 [1.6]	*Azadirachta indica*	0.04 [0.04]
22	*Adenium obesum*	1.4 [1.0]	*Adansonia digitata*	0.04 [0.04]
23	*Eucalyptus camaldulensis*	1.1 [0.9]		
24	*Dichrostachys cinerea*	0.9 [0.9]		
25	*Azadirachta indica*	0.7 [0.5]		
26	*Bauhinia rufescens*	0.6 [0.5]		
27	*Anogeissus leiocarpus*	0.5 [0.5]		

	SLM[2]		CLM[2]	
Rank	Species	Mean density (no. ind. ha^{-1})	Species	Mean density (no. ind. ha^{-1})
28	*Combretum aculeatum*	0.5 [0.5]		
29	*Lawsonia inermis*	0.5 [0.4]		
30	*Ziziphus mauritiana*	0.5 [0.3]		
31	*Ziziphus mucronata*	0.4 [0.4]		
32	*Piliostigma reticulatum*	0.3 [0.2]		
33	*Faidherbia albida*	0.2 [0.1]		
34	*Moringa oleifera*	0.2 [0.2]		
35	*Sterculia setigera*	0.2 [0.1]		
36	*Tamarindus indica*	0.2 [0.2]		
37	*Calotropis procera*	0.1 [0.1]		
38	*Leucaena leucocephala*	0.1 [0.1]		
39	*Mindioli (nom vernaculaire)*	0.1 [0.1]		

[1] Standard errors are given in parenthesis.
[2] For SLM: sample size n=17. For CLM: sample size n=23

Tree density, species richness and diversity

The Mann-Whitney U test showed that tree density and species richness at sites under SLM were significantly higher than at sites under CLM ($p < 0.05$) (see *Table 27*). The same was shown for the Shannon diversity index ($F_{1,39}$=17.27, $p < 0.05$) by a one-way Analysis of Variance (ANOVA).

Figure 14 illustrates species richness and diversity at sites under SLM and CLM with a rank-abundance curve (for more information on rank-abundance curves see chapter 3.3.5.1., p. 28). The width of the curve shows that species richness was higher at sites under SLM than CLM (39 vs. 22 species, see *Table 27*). The shape of the curves indicates that species were more evenly distributed at SLM than CLM sites. More than 50% of all encountered trees at CLM sites belonged to the species of *B. aegyptiaca.* At SLM sites the two dominant species of *A. seyal* and *A. senegal* each accounted for only about 20% of all individuals. Higher species richness and evenness in SLM resulted in higher diversity than in CLM.

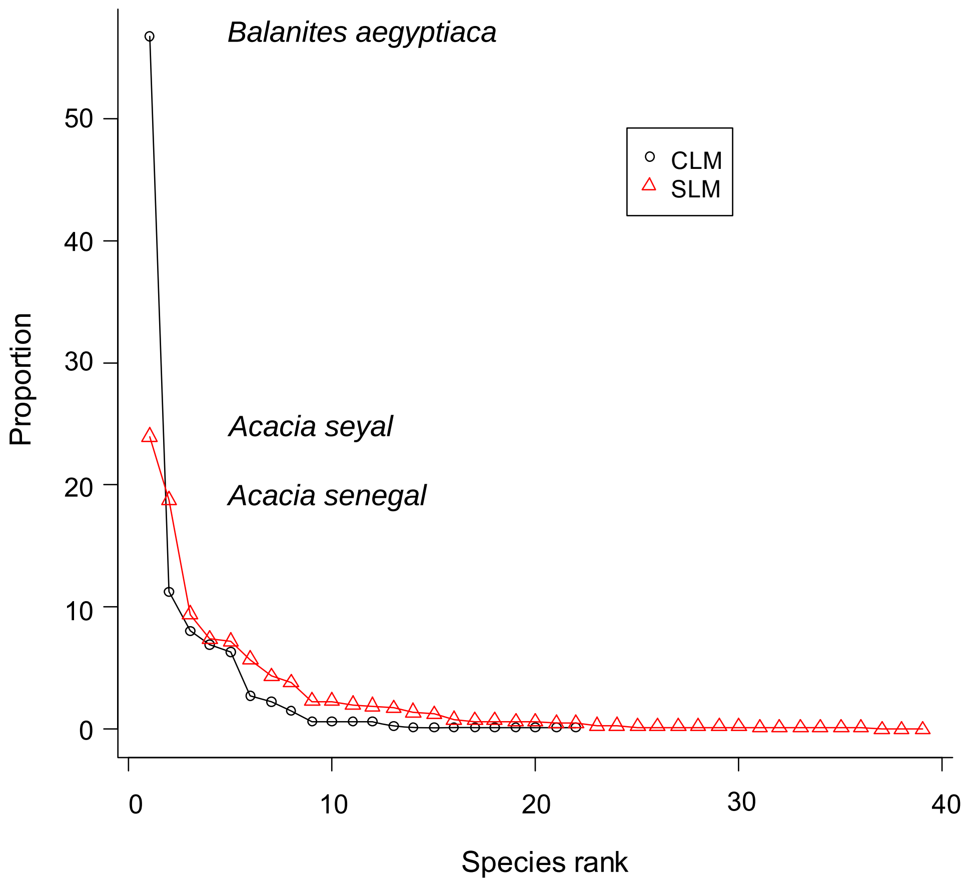


Figure 14. Rank-abundance curves for all species found at sites under SLM and CLM (one dot represents one species). Abundance is proportional abundance (percentage of each species of total abundance). The most abundant species at CLM sites and the two most abundant species at SLM sites are indicated.

Table 27 provides an overview of tree density, species richness and species diversity. Average tree density per plot was more than six times higher at SLM than CLM sites but highly variable between sites. For SLM sites high standard errors can be explained by low tree density in parklands in contrast to dense stands in the natural grove. Regarding CLM sites, out of 20 plots assessed in conventional pasture, 3 had densities of more than 100 trees per ha, whereas in the other plots density was low, which generated high standard errors.

Species richness showed high variability at SLM as well as CLM sites (see *Table 27*). Variability at CLM sites was caused by comparatively high species richness in two plots of "crop production". Given the expectation that more species will be encountered on a larger surface, this was most probably a result of larger plot surface sampled than in the other sites. Variability in species richness for SLM sites however, cannot be explained by differences in sample size, as the sites with the highest species richness (homegardens) had a small surface.

Table 27. Total number of species, mean species number per plot, Shannon diversity index H´ and tree density per ha for trees DBH ≥ 2 cm averaged over all plots of sustainable and conventional LM in Barkédji, Senegal[1]

			Species richness (No. spp. / plot)			**Tree density (No. ind. ha^{-1})**	
	n	total no. spp.	range	mean	mean H´[2]	range	mean
SLM sites	17	39	2-13	7.0 [0.9]	1.42 [0.2]	7-955	312.0 [81.9]
CLM sites	23	22	1-9	2.8 [0.5]	0.57 [0.2]	8-152	49.9 [8.8]
Sign.				**p < 0.05**	**p < 0.05**		**p < 0.05**

[1] Standard errors are given in parenthesis. n=no. of samples.
[2] $H' = -\sum p_i \ln p_i$ where p_i is the proportion of individuals of species i in the community (Magurran, 1988)

Figure 15 shows that species accumulation curves for SLM and CLM almost evened out. This means that sample size was nearly large enough in order to encounter all different species present in the investigated area. The probability of finding a species not encountered up to this point by adding additional plots is very small.

Species accumulation curves allow for comparison of species richness for different sample sizes. Since only 17 plots were sampled for SLM, it would make sense to compare the species richness of those 17 plots with the species richness at a sample size of 17 for CLM (instead of the total number of 23 plots for CLM). From the curve for CLM it can be seen that at a sample size of 17 the species richness would be 18.7 (instead of 22 at the total sample size of 23). Thus, in reality the difference between species richness of SLM and CLM is even larger than it appears when comparing the number of species found in the total number of plots sampled.

However, the comparison of species richness between the two land management types should still be treated with caution, because not only the number of plots but also the size of plots was different, with a larger total area sampled for CLM than SLM.

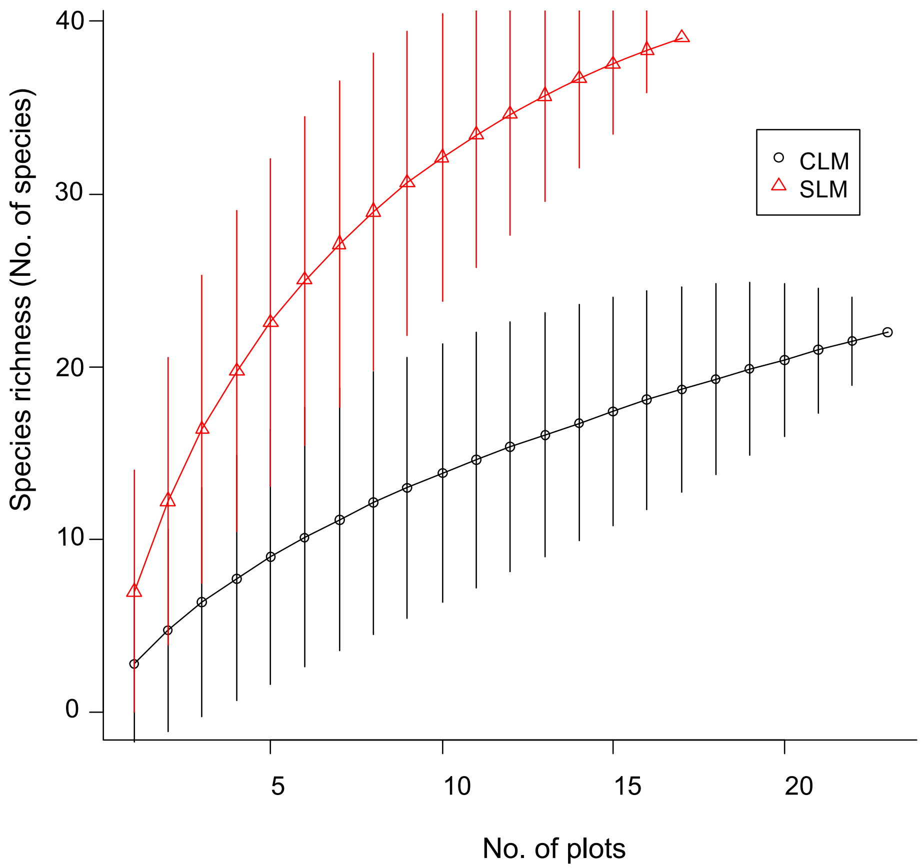


Figure 15. Species accumulation curves for SLM and CLM plotting species richness against accumulated number of plots sampled, Barkédji, Senegal; the bars indicate +2 and -2 standard deviations

Figure 16 shows species richness and tree density of the different SLM technologies and the CLM systems (for more details regarding differences between land use types consult Appendix 2, p. 147). "Homegarden" was the most species rich land use type followed by "pasture reserve". All SLM technologies had significantly higher species richness than the CLM of "pasture" ($p < 0.05$) or showed a strong trend in this direction. The CLM of "crop production" only had comparatively high species richness because the surface of the area that was sampled was much higher than that for all other systems (see *Table 4*, p. 26).

The tree density was significantly higher at the SLM sites of "natural grove" and "pasture reserve" than at any of the two conventional land use types of "crop production" or "pasture" ($p < 0.05$). "Natural grove" had the highest number of trees per ha and "parkland" the lowest. The two CLM types of "pasture" and "crop production" showed similar levels of tree densities, which were in between those of "natural grove" and "parkland". "Agroforestry with *A. senegal"* showed very high variability in tree density. This can be explained by the fact that the system consisted of a fallow part, densely populated by *A. senegal,* whereas in the cultivated part only scattered trees occurred (*Figure 16*).

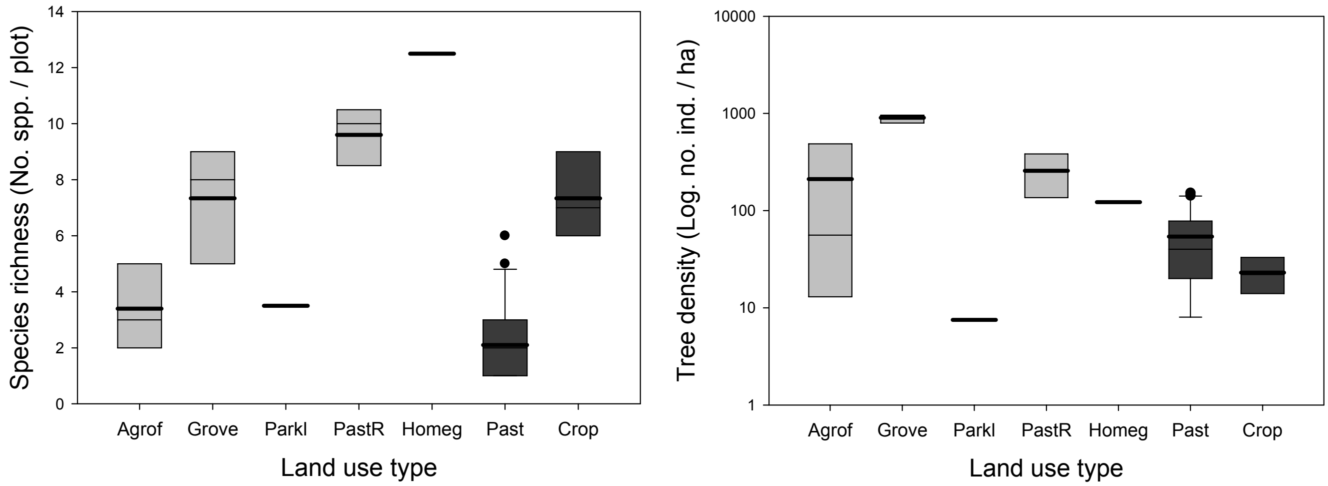
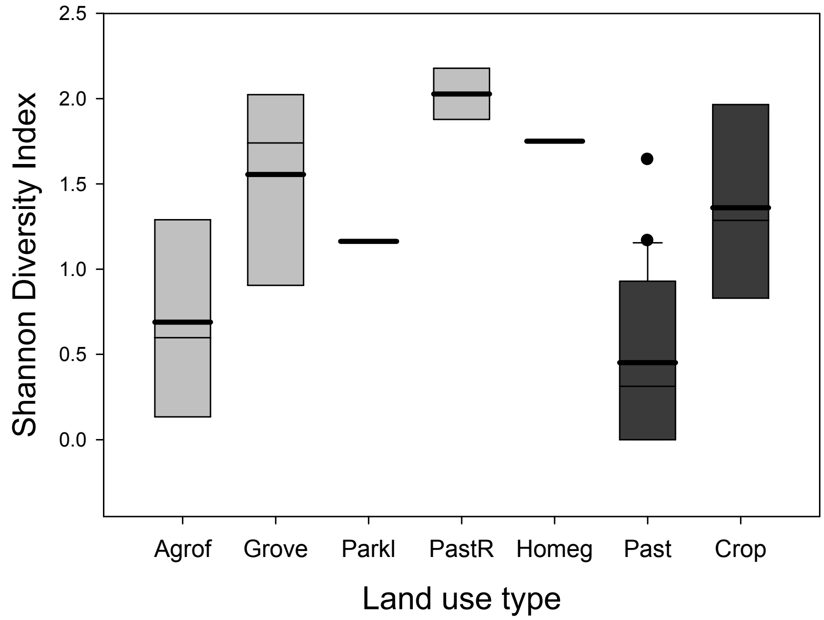


Figure 16. Species richness (left) and log tree density (right) for five SLM (light grey) and two CLM (dark grey) systems, Barkédji, Senegal; the thick line represents the mean and the thin line the median

Figure 17 presents two ways of showing differences in diversity, once with the Shannon diversity index and once with a Rényi diversity profile (for details about the computation of Rényi diversity profiles see chapter 3.3.5.1., p. 28).

The SLM technologies of “pasture reserve”, “homegarden” and “natural grove” each had a Shannon index that was significantly higher than at the CLM site “extensive pasture” ($p < 0.05$). Parkland showed the same trend, but the difference was not significant. The reason why “homegarden” did not have the highest woody species diversity (as it did for richness) lies in the uneven distribution of tree species in this land use type (illustrated by the slope of the curve in the Rényi diversity profile, *Figure 17*). Regarding differences between SLM sites it was found that tree species diversity of “pasture reserve” was significantly higher than of “agroforestry with *A. senegal”* ($p < 0.05$).

Additionally, the Rényi diversity profiles suggest that the SLM of “pasture reserve” was more diverse than the SLM sites of “natural grove” and “parkland”, by having a consistently higher profile. Furthermore, the Rényi diversity profiles show that the CLM of “crop production” had higher species diversity than the SLM technology of “agroforestry with *A. senegal”,* which is likely an artifact of the larger surface sampled for “crop production” compared to “agroforestry with *A. senegal*”.



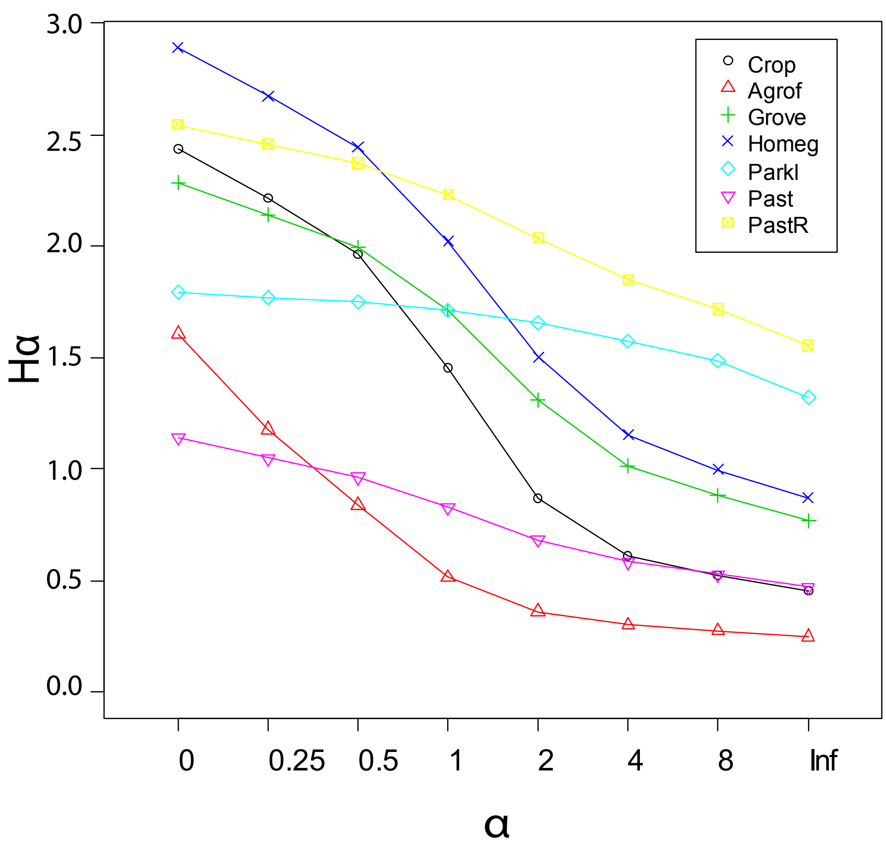


Figure 17. Shannon diversity index (upper figure) and Rényi diversity profiles (lower figure) for five SLM (light grey) and two CLM (dark grey) sites; the thick line represents the mean and the thin line the median

Canopy cover, damages and mortality

The Mann-Whitney U test showed that the canopy cover of woody plants was significantly higher at SLM than at CLM sites ($p < 0.05$). *Table 28* presents percentages of canopy cover, damaged and dead trees in the GAA of Barkédji. The two CLM systems together with the sustainable agroforestry technologies of "parkland" and "agroforestry with *A. senegal*" had the lowest canopy cover of all assessed systems. The SLM site "natural grove" showed significantly higher canopy cover than all other assessed sites ($p < 0.05$). The difference between "pasture reserve" and "crop production" was almost significant ($p < 0.05$) but standard errors were high. There was a clear trend towards higher canopy cover for "homegarden" compared to CLM types.

The percentage of damaged individuals and dead individuals did not differ significantly between CLM and SLM (see *Table 28*). The two outliers showing a high percentage of damaged individuals at SLM sites were one plot in the pasture reserve and one of the "homegarden" plots. One plot in the natural grove had a much higher percentage of dead trees than the other SLM plots.

Table 28. Mean percentage of canopy cover, damages and dead trees for trees DBH ≥ 2 cm at separate sites and averaged over all plots of sustainable and conventional LM, Barkédji, Senegal[1]

		n	Canopy cover (%)	Damages (%)	Dead (%)
SLM	Agroforestry *A. senegal*	5	1 [0.1][b]	2 [2][b]	0
SLM	Homegarden	2	14 [4][b]	42 [24][ab]	0
SLM	Parkland	2	4 [1][b]	0	0
SLM	Natural grove	3	47 [5][a]	12 [6][ab]	9 [5]
SLM	Pasture reserve	5	13 [4][b]	10 [6][ab]	6 [2]
	SLM sites	**17**	**16 [4]**	**10 [4]**	**3 [1]**
CLM	Extensive pasture	20	3 [1][b]	11 [3][ab]	9 [3]
CLM	Crop production	3	2 [1][b]	51 [12][a]	16 [10]
	CLM sites	**23**	**2 [0]**	**16 [4]**	**10 [3]**
	Sign.[3]		**$p < 0.05$**	**ns**	**ns**

[1] Standard errors are given in parenthesis. n=no. of samples.
[3] The last row indicates significance between total values of SLM and CLM. Within columns different superscripts indicate significance between land use types.

Tree height and diameter at breast height (DBH)

The Mann-Whitney U test showed that trees were significantly higher under sustainable than conventional land management ($p < 0.05$). However, this difference was only due to the SLM technology "parkland", which, with a mean of 10 m, had significantly higher trees than all other SLM and CLM sites. If this outlier was removed from the analysis, no difference between tree height under SLM and CLM could be found. No difference was found for tree DBH between SLM and CLM sites. "Parkland" also showed a trend for higher DBH than all other sites, however, this was not significant. *Figure 18* shows tree DBH and height at different land use types.

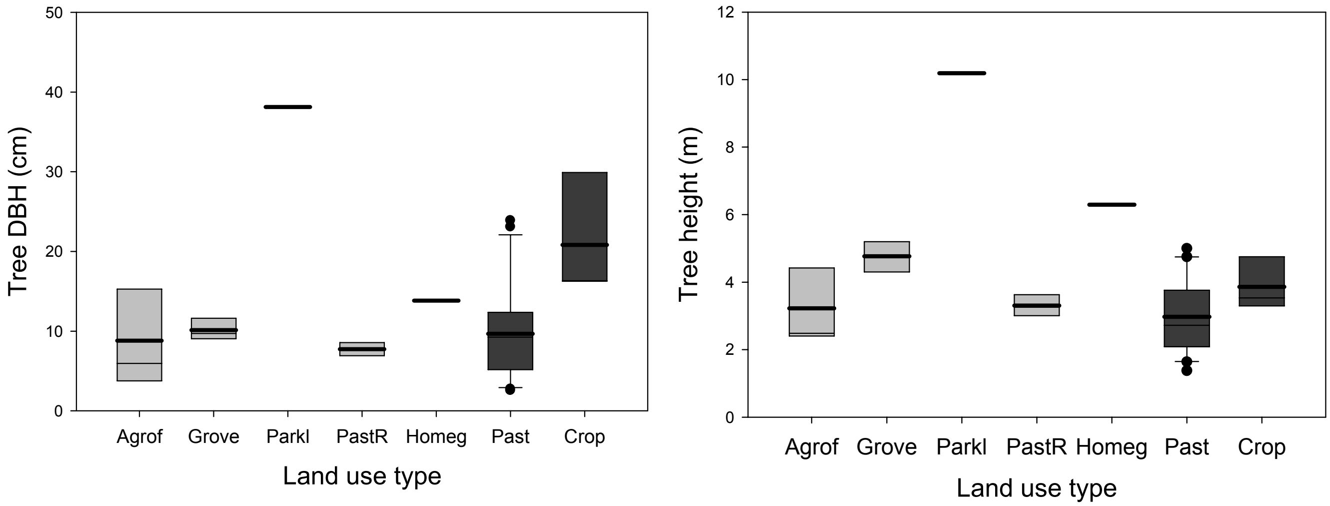


Figure 18. Tree DBH and height at five SLM (light grey) and two CLM (dark grey) sites in Barkédji, Senegal; the thick line represents the mean, the thin line the median

4.1.2.2. Regeneration of woody species

A total of 25 woody species were identified regenerating at 40 plots of sustainable and conventional land management in contrast to 43 species encountered as mature trees. The density of all woody species in a state of regeneration is indicated in *Table 29*. All species found regenerating were also encountered as mature trees in the area.

G. bicolor was the most common species encountered as regenerating at SLM sites. About 20% of regenerating species were present with a density higher than 10 individuals per ha, 55% had a density of 1-10 individuals per ha and the remaining 25% were very rare with a density < 1 individual per ha. The order of species dominating the list of regeneration is different from the order of species found as mature trees (see *Table 26*). The three species of the genus *Acacia* which dominate the list of mature trees at SLM sites were present with relatively low densities as regeneration. At CLM sites, regeneration was generally low with only *B. aegyptiaca* present with a density of more than 10 individuals per ha. The same species also dominated the list of mature individuals at CLM sites. The number of individuals per ha was lower than four for all other species found as regenerating at CLM sites.

Almost no regeneration was found at any of the 40 plots for the two species from the genus *Pterocarpus*, except for one individual of *P. lucens* at the CLM of "extensive pasture". Regeneration of the following indigenous species of *A. ataxacantha*, *S. birrea*, *L. acida*, *Z. mucronata*, *F. albida* and *C. procera* was not encountered at any of the 40 assessed plots. A striking phenomenon is that rarely any exotic species were found to be regenerating. Only *A. raddiana* and *P. juliflora* were present in low numbers.

Table 29. Density of tree regeneration[1], averaged over all plots of sustainable and conventional LM and ranked by mean density in Barkédji, Senegal[2]

	SLM		CLM	
Rank	Species	Mean density (no. ha^{-1})	Species	Mean density (no. ha^{-1})
1	*Grewia bicolor*	91.4 [41.1]	*Balanites aegyptiaca*	14.5 [4.1]
2	*Commiphora africana*	35.2 [21.4]	*Combretum glutinosum*	3.9 [2.7]
3	*Combretum glutinosum*	18.8 [9.6]	*Guiera senegalensis*	3.2 [2.8]
4	*Anogeissus leiocarpus*	11.2 [8.2]	*Grewia bicolor*	2.4 [1.8]
5	*Feretia apodanthera*	9.4 [5.9]	*Acacia senegal*	2.1 [1.4]
6	*Guiera senegalensis*	9.1 [3.5]	*Acacia raddiana*	1.2 [0.8]
7	*Balanites aegyptiaca*	8.5 [3.7]	*Commiphora africana*	0.7 [0.7]
8	*Acacia macrostachya*	7.5 [3.8]	*Acacia seyal*	0.4 [0.4]
9	*Acacia senegal*	6.1 [4.4]	*Pterocarpus lucens*	0.3 [0.3]
10	*Acacia seyal*	5.6 [5.6]	*Combretum aculeatum*	0.3 [0.3]
11	*Combretum micranthum*	4.2 [3.8]	*Adenium obesum*	0.3 [0.3]
12	*Ziziphus mauritiana*	3.5 [2.5]	*Acacia nilotica*	0.1 [0.1]
13	*Boscia senegalensis*	2.8 [1.5]	*Ziziphus mauritiana*	0.1 [0.1]
14	*Combretum nigricans*	1.9 [1.9]		
15	*Stereospermum kunthianum*	1.9 [1.9]		
16	*Piliostigma reticulatum*	1.1 [0.9]		
17	*Dichrostachys cinerea*	0.9 [0.9]		
18	*Bauhinia rufescens*	0.9 [0.9]		
19	*Combretum aculeatum*	0.9 [0.9]		
20	*Acacia raddiana*	0.8 [0.5]		
21	*Sterculia setigera*	0.2 [0.2]		
22	*Prosopis juliflora*	0.1 [0.1]		

[1] DBH < 2 cm
[2] Standard errors are given in parenthesis. For SLM: sample size n=17. For CLM: sample size n=23.

Table 30 presents species richness, tree density and the Shannon diversity index of regenerating trees at SLM and CLM systems.

One-way ANOVA showed that species richness at sites under SLM was significantly higher than at sites under CLM ($F_{1,38}=14.73$, $p < 0.05$). The Mann-Whitney U test showed that the density and the Shannon diversity index of tree regeneration at SLM sites were significantly higher than at sites under CLM ($p < 0.05$).

Table 30. Mean species richness per plot, Shannon diversity index H´ and density per ha for tree regeneration[1] averaged over all plots of sustainable and conventional LM in Barkédji, Senegal[2]

		Species richness (No. spp. / plot)			Plant density (No. ind. ha^{-1})	
	n	range	mean	mean H´[3]	range	mean
SLM sites	17	1-8	4.2 [0.6]	1.00 [0.3]	2-1273	222 [139.9]
CLM sites	23	0-6	1.7 [0.4]	0.33 [0.3]	0-128	29.7 [21.5]
Sign.			**p < 0.05**	**p < 0.05**		**p < 0.05**

[1] DBH < 2 cm
[2] Standard errors are given in parenthesis. n=no. of samples.
[3] $H' = -\sum p_i \ln p_i$ where p_i is the proportion of individuals of species i in the community (Magurran, 1988)

Figure 19 presents species richness and density of tree regeneration at the different SLM and CLM sites.

An LSD post-hoc test indicated that the species richness of regeneration under the SLM technologies of “natural grove“, “pasture reserve“ and “agroforestry with *A. senegal*“ was significantly higher than at the CLM of “extensive pasture” ($p < 0.05$). The SLM technologies of “homegarden” and “parkland” had very low densities of regeneration and therefore species richness was low as well. Surprisingly, species richness of regeneration that was observed for “crop production“ was similar to the one at the SLM sites of “natural grove“, “pasture reserve“ and “agroforestry with *A. senegal*“ and significantly higher than at “homegarden“, “parkland“ or “extensive pasture”. This might be an artifact of the large plot size in “crop production”. The differences between sites regarding the Shannon diversity index were the same as for species richness.

The two SLM technologies of “natural grove” and “pasture reserve” had significantly higher densities of tree regeneration than all other SLM and CLM types ($p < 0.05$). Although “agroforestry with *A. senegal”* had significantly higher species richness of regeneration than “extensive pasture”, this was not the case for regeneration density. However, the same trend was observed. The two plots of “homegarden” had highly variable densities of regeneration, as did “extensive pasture”. Low densities of regeneration were found at the CLM site “crop production”.

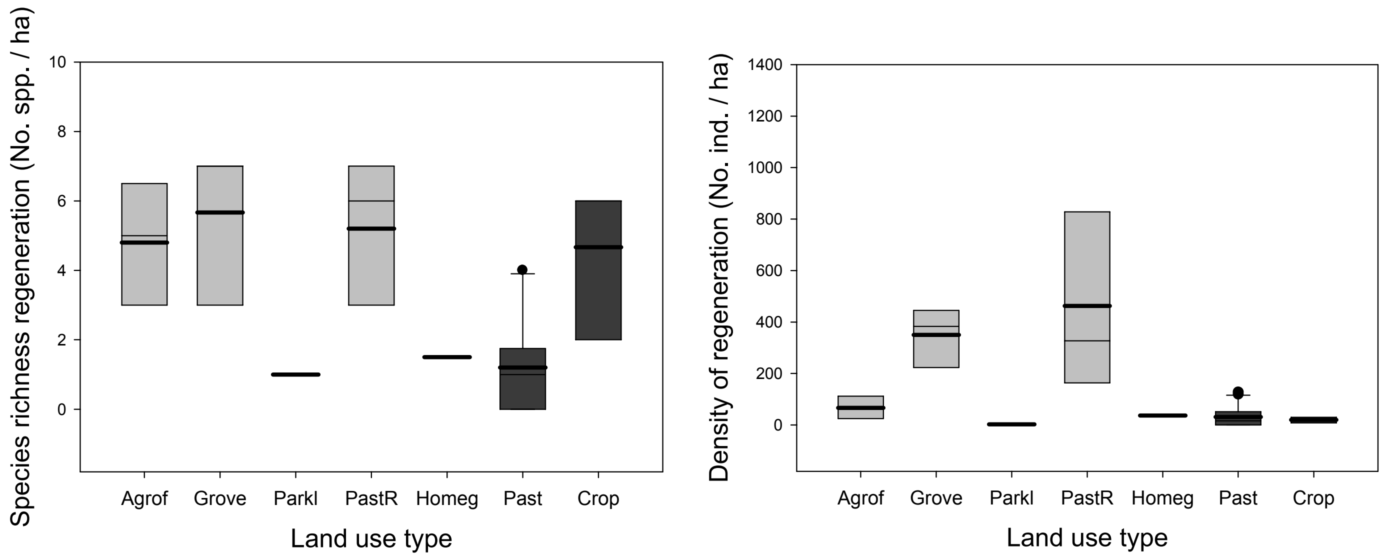


Figure 19. Species richness (left) and density (right) of tree regeneration (DBH < 2 cm) at five SLM (light grey) and two CLM (dark grey) sites in Barkédji, Senegal; the thick line represents the mean, the thin line the median

4.1.2.3. Distribution of species into diameter classes

The distribution of all measured trees into diameter classes is presented in *Table 31*. Details for every land use type can be found in Appendix 6, p. 154.

Table 31. Number of measured individuals per ha in six different diameter classes in Barkédji, Senegal

Species	<2 cm	2-9.9 cm	10-19.9 cm	20-39.9 cm	40-79.9 cm	≥80 cm
Acacia ataxacantha	0	0.04	0	0	0	0
Acacia macrostachya	0.26	0.65	0.04	0.04	0	0
Acacia nilotica	0.04	0	0.04	0	0	0
Acacia raddiana	0.83	0.65	0.39	0.39	0.17	0
Acacia senegal	0.56	6.26	0.22	0.04	0	0
Acacia seyal	0.74	0.3	1.52	0.09	0	0
Adansonia digitata	0	0	0	0	0.09	0.13
Adenium obesum	0.04	0.04	0.09	0.04	0	0
Anogeissus leiocarpus	0.26	0	0	0.04	0	0
Azadirachta indica	0	0.04	0.04	0.26	0.04	0
Balanites aegyptiaca	3.26	2.65	0.61	0.35	0.17	0
Bauhinia rufescens	0.09	0.09	0	0	0	0
Boscia senegalensis	0.22	0.56	0	0	0	0
Calotropis procera	0	0.09	0	0	0	0
Citrus limon	0	0	0.61	0	0	0
Combretum aculeatum	0.13	0.04	0	0	0	0
Combretum glutinosum	0.65	0.04	0	0.09	0.04	0

Species	<2 cm	2-9.9 cm	10-19.9 cm	20-39.9 cm	40-79.9 cm	≥80 cm
Combretum micranthum	0.09	0.87	0	0	0	0
Combretum nigricans	0	0.17	0.04	0	0	0
Commiphora africana	0.04	0	0.09	0	0	0
Dichrostachys cinerea	0.09	0.09	0	0	0	0
Eucalyptus camaldulensis	0	0	0.39	0	0	0
Faidherbia albida	0	0.04	0	0	0.13	0
Feretia apodanthera	0.22	0.35	0	0	0	0
Grewia bicolor	0.74	0.78	1.96	0	0	0
Guiera senegalensis	1.65	6.78	0.09	0	0	0
Lannea acida	0	0	0	0.04	0	0
Leptadenia pyrotecnica	0	0.04	0	0	0	0
Leucaena leucocephala	0	0	0.04	0	0	0
Mindioli (local name)	0	0.04	0	0	0	0
Moringa oleifera	0	0.04	0	0	0	0
Piliostigma reticulatum	0.26	0	0.09	0.04	0.04	0
Prosopis juliflora	0	0	0.09	0	0	0
Pterocarpus erinaceus	0	0.35	0.04	0.04	0	0
Pterocarpus lucens	0.39	0.61	0.13	0	0	0
Sclerocarya birrea	0	0.09	0.04	0	0.09	0
Sterculia setigera	0.13	0	0	0	0.13	0
Stereospermum kunthianum	0	0	0	0.04	0	0
Tamarindus indica	0	0	0.09	0	0	0
Ziziphus mauritiana	2.09	0.13	0.48	0.04	0	0
Ziziphus mucronata	0	0.17	0	0	0	0
Total	**12.78**	**22.03**	**7.13**	**1.56**	**0.91**	**0.13**

The majority of tree species had trees in the second smallest diameter class (2-10 cm) followed by the intermediate diameter class of 10-20 cm and the smallest diameter class (< 2 cm). *A. digitata* was the only species that had individuals in the largest diameter class but none in the small diameter classes. About 50% of all measured trees had a DBH between 2 and 10 cm, about 30% were counted as regeneration with a diameter < 2 cm and 15 % had a diameter between 10 and 20 cm.

4.1.2.4. Tree species used by the local population

In total, 39 out of 43 tree species encountered during the survey could be attributed to one or several of the chosen use categories (for information on attribution of species to categories see chapter 3.3.5.2., p. 30).

Table 32 presents the five different use categories and the species attributed to them.

Table 32. Species used by the local population assigned to one or several of five categories: food, firewood, construction, fodder and medicine, ordered alphabetically, Barkédji, Senegal

	Species	Food[1]	Firewood	Construction	Fodder	Medicine
1	*Acacia nilotica*			x [a),g)]	x [a)]	
2	*Acacia senegal*	x	x [g)]	x [a), g)]	x [a)]	x [g)]
3	*Acacia seyal*			x [a),g)]	x [a)]	
4	*Acacia raddiana*		x [g)]		x [b)]	
5	*Acacia nilotica*		x [g)]			
6	*Adansonia digitata*	x			x [a)]	
7	*Adenium obesum*					x [g)]
8	*Anogeissus leiocarpus*			x [a),g)]	x [a)]	
9	*Azadirachta indica*		x [g)]			x [g)]
10	*Balanites aegyptiaca*	x	x [g)]	x [a), g)]	x [a)]	
11	*Bauhinia rufescens*				x [a)]	
12	*Boscia senegalensis*	x		x [g)]	x [a)]	x [g)]
13	*Calotropis procera*			x [a), g)]		x [g)]
14	*Citrus limon*	x				
15	*Combretum aculeatum*	x			x [a)]	
16	*Combretum glutinosum*		x [g)]	x [a), g)]	x [a)]	x [g)]
17	*Combretum micranthum*	x		x [b), g)]	x [a)]	x [g)]
18	*Combretum nigricans*			x [b), g)]	x [b)]	
19	*Commiphora africana*				x [a)]	
20	*Dichrostachys cinerea*				x [a)]	
21	*Euphorbia balsamifera*					x [g)]
22	*Faidherbia albida*				x [a)]	
23	*Feretia apodanthera*			x [g)]	x [a)]	
24	*Grewia bicolor*	x	x [g)]	x [a), g)]	x [a)]	

	Species	Food[1]	Firewood	Construction	Fodder	Medicine
25	*Guiera senegalensis*		x [g)]	x [b, g)]	x [a), f)]	x [g)]
26	*Lannea acida*					
27	*Leucaena leucocephala*				x [b)]	
28	*Mangifera indica*	x				
29	*Moringa oleifera*	x			x [e)]	
30	*Piliostigma reticulatum*				x [a)]	
31	*Prosopis juliflora*		x [g)]		x [b)]	
32	*Pterocarpus erinaceus*			x [c), d), f)]	x [a), f)]	
33	*Pterocarpus lucens*			x [a)]	x [a)]	
34	*Sclerocarya birrea*	x		x [g)]	x [a)]	x [g)]
35	*Sterculia setigera*	x			x [e)]	
36	*Stereospermum kunthianum*				x [a)]	
37	*Tamarindus indica*	x			x [a)]	
38	*Ziziphus mauritiana*	x	x [g)]	x [a), g)]	x [a)]	x [g)]
39	*Ziziphus mucronata*			x [g)]	x [a)]	

[1]See *Table 34* for sources on food, for the other categories sources are:
a) Lykke et al. (2004)
b) Arbonnier (2004)
c) Gakou et al. (1994)
d) Kristensen & Balslev (2003)
e) Oral personnal communication: Wélé, A. Ingénieur des Eaux et Forêts. In Barkédji, 01.08.2009.
f) Lykke (2000)
g) Von Maydell et al. (1983)

Medicine and firewood were the categories with the fewest attributed species (10 and 11 respectively), which made them the most interesting for an analysis of differences between SLM and CLM.

Two of the few tree species that were preferred for firewood, *G. senegalensis* and *C. glutinosum*, were present at both land management systems. However, they were more abundant at sites under SLM than CLM. *A. raddiana* and *A. nilotica,* also highly regarded firewood species, were only found at sites under CLM and the latter was rare. The other species used were *B. aegyptiaca*, *G. bicolor*, *A. senegal*, *Z. mauritiana, A. indica,* and *P. juliflora* (Von Maydell et al., 1983).

Of the most important medicinal plants, two species of the genus *Combretum (C. glutinosum* and *C. micranthum)* were abundant at SLM sites. Some of the most effective species are at the same time very toxic, such as *A. obesum, E. balsamifera* and *C. procera* (Von Maydell et al., 1983). These species were rare in the assessed area. *A. indica*, an important species for treating Malaria, had its main distribution in the homegarden. *S. birrea*, used against sexually transmitted diseases and skin infections, was one of the selected species in the parkland. Medicinal plants usually have some general uses as well as some specific to ethnicity, village or even family (Von Maydell et al., 1983). An overview of the uses of the most important medicinal plants is provided in the following table.

Table 33. The most important medicinal plants and their uses in Barkédji, Senegal[1]

Species	Use
Acacia senegal	gum arabic in case of stomach issues, closure of wounds
Adenium obesum	wide range of uses, poisonous
Azadirachta indica	tea against malaria, burning of leaves provides protection from insects
Boscia senegalensis	against sexually transmitted diseases and skin problems
Calotropis procera	wide range of uses, poisonous
Combretum glutinosum	tea against cold
Combretum micranthum	tea against cold and as a fortifier
Guiera senegalensis	stomach issues, internal diseases
Sclerocarya birrea	against sexually transmitted diseases and skin problems
Ziziphus mauritiana	bark against stomach issues

[1] A selection from Von Maydell et al. (1983)

About one-third of all species that were encountered could be attributed to the categories of food and construction whereas the majority of trees have some use value as fodder. This has to do with the harsh conditions of this semi-arid silvopastoral zone, where every plant providing nutrients to livestock has to be used. In times of drought, less important fodder species all of a sudden might be highly important for the survival of livestock (Lykke et al., 2004).

Some of these species are more preferred than others and in the food category the most important indigenous species in this region are *B. aegyptiaca*, *B. senegalensis, Z. mauritiana* and *A. digitata* (Becker, 1983). The first one was actually more common at conventional land use systems than at sites under SLM as it constituted the main and often only tree species found in the generally degraded extensive pasture land. *B. senegalensis* was only present at the SLM site "pasture reserve" and at none of the other assessed sites. *Z. mauritiana* was rare in the whole study area and completely absent from the most common land use system in the area, extensive pasture. *A. digitata* was one of the rarest trees species in the whole assessment area as only five individuals were encountered at one agricultural field under CLM. *Table 34* provides detailed information for every species in the "food" category.

The population in the Ferlo is very selective in the choice of wood for construction purposes as it should be termite-resistant and able to endure many years (Lykke et al., 2004). Some of the very abundant species which can be used in construction are not necessarily employed a lot whereas others that are rare and difficult to obtain are highly favored (Von Maydell et al., 1983). Trees belonging to the first category are *B. aegyptiaca*, *C. glutinosum*, *G. bicolor* and *G. senegalensis* whereas *S. birrea*, *C. procera* and *Dalbergia melanoxylon* were rare or absent (*D. melanoxylon*) from the studied area. These seven species are the most important for construction in the area, according to Von Maydell et al. (1983).

Pterocarpus erinaceus is a highly preferred species used for livestock fodder (and construction) (Magurran, 1988) and protected in agricultural fields around Fathala Forest on the west coast of Senegal (Lykke, 2000). In Barkédji*, P. erinaceus* was only found at the SLM sites of "natural grove", where it was relatively abundant and "pasture reserve". *G. senegalensis,* also a preferred fodder species in Fathala Forest, was one of the most common species both at SLM and CLM sites in Barkédji.

Table 34. Information on parts of the plant used for food, product gained and ethnicity making use of the plant of all species encountered around Barkédji, Senegal

Species	Parts used	Product	Used by	Remarks and source
Acacia senegal	gum	"mbep", same use as "lalo" (a powder used for giving millet couscous a smooth consistency) eaten as a sweet	only Wolof	d)
Adansonia digitata	leaves sour pulp	"lalo" eaten raw, mixed with milk or water	all ethnicities	a), d)
Balanites aegyptiaca	fruit	sweet, eaten raw	all ethnicities	a), d)
	seeds	valuable oil production	mainly Wolof	
	leaves	cooked with crushed melon seeds or peanuts and cheese	Peul	
Boscia senegalensis	leaves	staple food	Peul	needs to be cooked twice to remove toxic substances a), d)
Citrus limon	fruit	seasoning		
Combretum aculeatum	seeds	food		only in times of scarcity a)
Combretum micranthum	leaves	"kinkiliba" tea, popular beverage	Wolof	a)
Grewia bicolor	fibers	"lalo"		only in times of famine a), d)
Moringa oleifera	leaves	sauce for couscous		b)
Sclerocarya birrea	fruit	food		c), d)
Sterculia setigera	gum	"mbep"		a), e), f)
Tamarindus indica	fruit	for sauce		a), d), e)
Ziziphus mauritiana	fruit	food	mainly gathered by Moors	a), d)

a) Becker (1984)
b) Oral personnal communication: Wélé, A. Ingénieur des Eaux et Forêts. In Barkédji, 01.08.2009.
c) WOCAT landuser interview
d) Lykke et al. (2004)
e) Kristensen & Balslev (2003)
f) Diédhiou & Diatta (2004)

Mann-Whitney U test showed that sites under SLM had significantly higher densities of trees used for fodder, food or medicine than CLM sites ($p < 0.05$). No difference was found for species providing wood for construction and firewood (see *Table 35*).

Table 35. Density of trees DBH ≥ 2 cm in five different use-categories at sites under sustainable and conventional LM, Barkédji, Senegal[1]

		n	Tree density (No. ind. ha^{-1}) Fodder	Food	Construction	Firewood	Medicine
SLM	Agroforestry *A. senegal*	5	211 [137][ab]	207 [134][ab]	209 [136][ab]	209 [136][ab]	201 [137][ac]
	Homegarden	2	69 [6][ab]	23 [13][ab]	12 [5.5][ab]	6 [2][ab]	32 [5][ad]
	Parkland	2	8 [1][ab]	4 [0.5][ab]	4 [3][ab]	3 [2][ab]	4 [4][ad]
	Natural grove	3	753 [101][a]	85 [28][ab]	658 [129][a]	170 [38][a]	107 [21][a]
	Pasture reserve	5	221 [46][a]	80 [25][a]	169 [45][a]	112 [37][a]	128 [42][a]
	SLM sites	**17**	**269 [72]**	**102 [41]**	**229 [68]**	**125 [43]**	**120 [43]**
CLM	Extensive pasture	20	53 [10][b]	33 [8][b]	47 [10][b]	47 [10][b]	12 [7][bd]
	Crop production	3	22 [6][b]	17 [10][b]	19 [8][b]	19 [7][b]	12 [1][cd]
	CLM sites	**23**	**49 [9]**	**31 [7]**	**43 [9]**	**43 [9]**	**11 [6]**
	Sign.[2]		**$p < 0.05$**	**$p < 0.05$**	**ns**	**ns**	**$p < 0.05$**

[1] Standard errors are given in parenthesis. n=no. of samples.
[2] The last row indicates significance between total values of SLM and CLM. Within columns different superscripts indicate significance between land use types.

High densities of trees providing food, medicine or firewood were found at the SLM systems of “agroforestry”, “natural grove” and “pasture reserve”. For fodder trees and trees used in construction, it was “natural grove” that harboured by far the highest density.

When looking at the number of different species of plants used by the local population instead of density, different patterns were found. For food trees a trend was observed in which homegardens harbored the highest number of species used by the local population. Differences between land use types were small though, as the richness of food trees only ranged between zero and five. Interestingly, the SLM site “natural grove” contained only one food tree on one of the three plots, *G. bicolor*. For the category of construction, the CLM of “crop production” had the highest average species richness and the CLM of “pasture” the lowest, while SLM sites were in between. The highest species richness for trees used as firewood was also found at the CLM site of “crop production. “Pasture reserve” had the highest richness of fodder and medicinal trees.

4.1.3. Discussion of vegetation assessment

4.1.3.1. Influence of land use type on tree density, species richness and diversity

In general it can be said that the total number of 43 tree species found on the assessed surface of 24 ha was surprisingly high. An investigation of woody vegetation in Fété-Olé, located in the Ferlo like Barkédji, only identified 19 different species on 25 ha (Vincke et al., 2010). However, Fété-Olé is located towards the northern edge of the Ferlo whereas Barkédji is at the southern fringe of this silvopastoral region. The lower species richness in Fété-Olé might therefore be attributed to the drier climate which can only be supported by Sahelian tree species. Furthermore, in Fété-Olé no sites with vegetation stands including trees planted by humans, such as homegardens in Barkédji, were included in the assessment and the practice of tree planting or selecting can increase diversity.

Out of six analyzed SLM technologies in the silvopastoral system of the Ferlo, “pasture reserve” and “natural grove” had the highest density and diversity of woody species. These two technologies both preserve natural vegetation and therefore the human impact on tree diversity is lower than in technologies like “homegarden” or “parkland”. A similar observation was made by a study looking at differences in tree species diversity between the land use systems of forest reserves, silvopastoral zones, bush fields and village fields in the four countries of Niger, Mali, Burkina Faso and Senegal. This study found that forest reserves comprised the highest species richness of all land use systems (Kindt et al., 2008).

When looking at species richness instead of diversity, homegardens showed the highest number of species for all assessed land use types in this area, despite the small surface assed. They are not the most diverse land use type though, because some species dominate and others are rare. As a result, evenness is low. The number of woody species per homegarden (11 and 13 respectively) was surprisingly high compared with gardens of similar sizes from the humid tropics, taking into account the higher natural plant diversity under humid than under semi-arid conditions (Kumar & Nair, 2004). Kumar et al. (1994) found woody species richness between 11 and 39 in homegardens in Kerala, India. In Sri Lanka woody species richness in homegardens was between 4 and 18 species per garden (Jacob & Alles, 1987). One has to be careful when comparing different homegarden studies though, as some include all plant species including cultivated vegetables and weeds, others only consider species attributed to certain use categories (with some studies excluding ornamentals). Few studies describe homegardens in semi-arid climate zones: On the island of Soqotra in Yemen average species richness in homegardens was only 7.6, comprising ligneous as well as herbaceous species (Ceccolini, 2002). A study of urban and peri-urban gardens of Niamey (Niger) found on average 14 species per garden considering all plant species (including vegetables) (Bernholt et al., 2009). Two studies of urban homegardens from Sudan only found three species each per garden (Gebauer, 2005; Thompson, 2007). With an average of 12 species per garden, only considering tree species, homegardens in the Ferlo are therefore comparatively species rich. One characteristic that distinguishes homegardens from all other land use types is the high number of exotic species. Some of them were reported to have invasive potential, such as for *A. indica* (Boffa, 1999) or to have a negative influence on soil properties, such as for *E. camaldulensis.*: the latter was found to reduce microorganism activity and to inhibit the germination and growth of understory plants through phytotoxic effects (Souto et al., 2001). The high species richness in homegardens does therefore not invariably improve the sustainability of the system.

The traditional parkland system had a comparatively low species richness, diversity and tree density due to the fact that only a few large trees had been protected and raised in order to minimize the loss of cultivable surface. It comprised one species however, *S. setigera*, that had not been encountered at any other site assessed. It used to be a typical species of the Ferlo region but as early as 1984 it was recognized that the species was disappearing (Becker, 1984). *S. birrea* was another rare species that was almost exclusively present in the parkland. This species is a relict in the Ferlo from a more humid period that became rare due to overexploitation. Especially large individuals were used for the production of wooden bowls (Becker, 1984). Another explanation for the rarity of these species in the investigated study sites is that they do not tolerate cutting for different uses and / or browsing by animals (Vincke et al., 2010). The parkland therefore has an important role in protecting these two characteristic, local species in the area.

“Agroforestry with *A. senegal*” showed very high variability for tree density and species diversity as the part of the system left fallow was dominated by almost monospecific and dense stands of *A. senegal*, whereas at the cultivated part scattered trees of different species were present. Vincke et al. (2010) stated that *A. senegal* tended to disappear in their study region in the northern Ferlo due to its high sensitivity to grazing. The SLM technology "agroforestry with *A. senegal*" therefore plays an important role for the preservation of this multi usable tree species in the Ferlo. With tree density being almost as high as in the "pasture reserve", this SLM technology further contributes to the mitigation of land degradation by protecting soil from erosion.

"Extensive pasture" showed low tree species richness whereas "crop production" only showed comparatively high species richness and diversity due to the higher sample size than for most SLM sites. *B. aegyptiaca* was by far the most common tree species at these two conventional land use systems. The abundance of this drought-tolerant plant is typical of the process of Sahelisation or aridification (Vincke et al., 2010). A reason for the high density of this species could be bushfires. *B. aegyptiaca* is fire resistant and therefore has an advantage over other species in the area (Becker, 1984). Its foliage further benefits from browsing by animals (Vincke et al., 2010). Inhabitants of the village of Oursi in northern Burkina Faso stated that *B. aegyptiaca* had vastly increased in number, from having very low abundance a generation ago to being the dominant species in the region today (Rasmussen et al., 2001). Accordingly, there is no indication that the intensive and uncontrolled exploitation of the fruits combined with low regeneration rates has led to a drastic decline of the species as it was stated by Ndoye et al. (2004). After *B. aegyptiaca*, *C. glutinosum* and *A. raddiana* are the most common tree species at the CLM systems and all of them are indicators for cultivation or intense livestock browsing (Rasmussen et al., 2001).

4.1.3.2. Canopy cover, height, DBH, damages and mortality of mature trees

In general, the woody vegetation cover in this silvopastoral zone was very open, especially in the widely degraded pastureland, where it never exceeded 10%. This is in agreement with the findings of Tappan et al. (2004) that from 1965 onwards, the woody cover in the Ferlo decreased from 10-15% to 1-5%. With an average of 47%, "natural grove" showed by far the highest canopy cover compared to all other SLM technologies. Variability of canopy cover was high in the pasture reserve as some plots contained a high proportion of dead tree stumps and hence lower canopy cover. Homegardens had a comparatively high percentage of canopy cover, but with a sample size of only two, no significant difference between this technology and the conventional land uses or other SLM technologies could be shown. As no other homegardens were encountered along any of the three LADA transects, there was no possibility to improve sample size in order to confirm the observed trend. The agroforestry technologies "agroforestry with *Acacia senegal*" and "parkland" had very low canopy cover. This can probably be explained by the fear of farmers that a closed canopy would impede crop growth due to reduced sunlight. Ahuja et al. (1978) noted that herbaceous production was most depressed under high densities of *A. senegal*. However, a closed canopy can also create favorable microclimate (Martius et al., 2004). As for the variables of species diversity, richness and tree density it can be concluded that of the given SLM technologies, those protecting natural vegetation were increasing the percentage of canopy cover the most. As it is known that herbaceous above-ground production in the Ferlo is up to four times greater under a woody canopy than in the open sunlight (Grouzis & Akpo, 1997) the significance of the documented SLM technologies, especially the pasture reserve, for improving herbaceous fodder availability cannot be overlooked. The two CLM types both had reduced canopy cover and the extensive pastureland can therefore be seen as degraded.

Tree height and DBH were very similar among different SLM and CLM technologies except for "parkland" and "homegarden" which were characterized by large and wide trees, almost being two times as high as in all other land use types. This reflects the impact of human selection on the formation of these land use systems as the trees are so different when compared to the original savanna vegetation (Boffa, 1999). Trees were probably not only protected but also pruned and tended in order to reach large height and crown dimensions. *Faidherbia albida* is naturally bushy but will develop into tall trees when pruned early (Boffa, 1999). The CLM of "crop production" was also characterized by a large tree DBH, mainly because it contained several individuals of *A. digitata*, a species with an exceptionally high DBH.

The fact that no difference was found between damaged and dead trees at SLM and CLM sites was mainly due to the outliers in the natural grove and the two homegardens. The natural grove has not been officially protected but was instead being kept by the local population as a source of wood. It therefore exhibited a high percentage of cuts. The homegardens on the other hand comprised many trees which, according to the land users, had been pruned in order to enhance solar radiation for crops grown underneath. However, according to the local forest engineer of the LADA assessment team, pruning had been carried out in a way that trees were actually damaged. The lack of knowledge related to correct pruning techniques is a general problem observed in all study areas. Training is usually essential to assure that the trees are pruned in a way that makes them appropriate for the required product. Huxley (1999) stated that "pruning procedures, e.g., to maximize the production of fodder or fruits, are probably the least well understood practices that farmers become engaged in". In this case the forestry extensionists should provide knowledge on pruning techniques to the farmers. Especially in this zone dominated by Peul who do not look back on a tradition of farming, support would be needed in order to encourage and improve agroforestry efforts. Some of the plots in the extensive pastureland did not comprise any damaged trees, mainly because tree density was already so low that the probability of one of the trees left showing signs of damage was greatly reduced.

For the percentage of dead trees the picture is similar since part of the tree mortality was due to the observed damages. Land users applying SLM technologies are always dealing with constraints, especially in the Ferlo where most of them uniquely depend on raising livestock, crop production and natural resources. It is therefore not surprising that this is manifested in the form of damage due to exploitation of trees in some of the SLM technology sites. However, only few of the damaged trees were actually dead and regeneration through regrowth of tree stumps is common (Augusseau et al., 2006).

4.1.3.3. Species used by the local population

The protection of natural vegetation as was the case at the SLM systems of "natural grove" and "pasture reserve" helps to maintain high numbers of individual trees used by the local population. Since stands were dense, they constituted a valuable resource for local farmers and herders. Although the density of trees used was lower at the SLM sites under stronger human influence such as the homegardens, they offered a higher number of different tree species useful for the local population. "Parkland" had the lowest density of species used by the local population due to the already low density of trees in the system. However, the few trees that were encountered were valuable species hardly present in any other site, such as *F. albida, S. setigera* and *S. birrea*. The reason that CLM sites contained relatively high densities of plants useful for the local population was that the food tree *B. aegyptiaca* was very abundant at extensively used pastures. It should therefore be kept in mind that not only the density of those species is important, but rather the diversity, as this gives the local population the possibility to cover more of the various needs during a longer time of the year.

Although firewood is rare in the shrub savanna of Barkédji, only few species are used (Von Maydell et al., 1983). *A. senegal* is an excellent firewood species and therefore agroforestry with *A. senegal* has the highest density of firewood trees. This renders this land use system even more productive, as senescent trees can still be exploited as firewood. As the most preferred firewood species also qualify for other uses, the population will always be in a dilemma which species to use.

Wild plants, and in particular woody plants, are still a major source of medicine in the Sahel, where access to western medicine is limited because of high prices (Lykke et al., 2004). It is therefore alarming that some of the most important medicinal species used by the population in the Ferlo are very rare. *C. procera,* one of these species, was hardly encountered during the vegetation assessment. However, this could be an effect of the small sample size, as in the Ferlo an increase of this species, known as a colonizer of degraded soils can be expected. For the valuable medicinal species of *A. obesum* and *S. birrea,* it would probably be necessary to take special measures, in order to maintain them in the Ferlo. As each species serves difference purposes in medicine, high plant diversity is therefore particularly important for the provision of medicinal products (Lykke, 2000).

In the Sahel the majority of the human population experiences a "hungry season" every year and therefore trees providing edible resources such as fruits or leaves are an important supplement to the otherwise monotonous diet (Lykke et al., 2004). Despite its importance as a food tree, *B. aegyptiaca* was only scarcely present at SLM sites. A reason might be the free availability of the tree in the natural environment which discourages people from growing it in gardens or parklands. The same was found in a study on the integration of indigenous fruit trees in the agricultural landscape in Ethiopia (Fentahun & Hager, 2010) and in Western Kenya (Kindt et al., 2006b). Regeneration of *B. aegyptiaca* was however common in one of the two homegardens as well as in the SLM technology "agroforestry with *A. senegal*" and if the preservation of natural regeneration will be maintained, the density of this fruit tree could increase. It is an alarming fact that the other three preferred food trees were so rare in the assessed area. This might be a consequence of overexploitation due to the high appreciation of the species. The SLM technologies of "homegarden" and "agroforestry with *A. senegal*" are helping to maintain another important food tree, *Z. mauritiana,* in the area, whereas for *B. senegalensis* "pasture reserve" has the same role. Von Maydell et al. (1983) recommended that *Z. mauritiana* seedlings should be provided to local households by forestry extension agents. The concept of homegardens received great interest among the villagers of Diagaly as they could observe the diversity of products in the already existing homegarden (see SLM technology 2: Agroforestry homegarden, p. 51). It could therefore be an optimal moment for the forestry extension service to provide seedlings of *Z. mauritiana* and other food trees, once adoption of this SLM technology takes place.

In this study the SLM technologies "natural grove" and "pasture reserve" were mainly found to preserve trees valuable for construction purposes. *A. seyal* for example was very abundant at the natural grove and absent (except for very few individuals at "crop production") in all other sites. However, exploitation permits are usually required for the local population in order to get access to wood for construction purposes[10]. As early as 25 years ago, Von Maydell et al. (1983) stated that the preferred trees species for construction were only sparsely available or had disappeared in the Ferlo. This has severe implications for households as construction wood mainly has to be bought from traders (Von Maydell et al., 1983).

P. erinaceus, a highly preferred fodder species in the woody savanna of "Delta du Saloum"-Nationalpark in south-western Senegal (Lykke, 2000), could only be found at the SLM sites of "natural grove" and "pasture reserve". In interviews with elderly villagers in the mentioned study it was stated that *P. erinaceus* was in decline (Lykke, 2000) whereas in one other forest close to the studied one the species had completely disappeared (Sambou et al., 1994). The decline can probably be attributed to overexploitation as the species has been legally and illegally logged (Lykke, 2000). *P. erinaceus* is known to grow on wet soils mainly in valleys and it is therefore likely that its actual density has been overlooked by this study as remnants of natural forest on valley bottoms could not be sampled due to the already high water level at the time of the assessment. Those forest relicts, however, are under high human pressure in this degraded silvopastoral landscape and a decline of the species is most likely. More details could only revealed by gaining information from village elders as was done in the "Delta du Saloum"-Nationalpark (Lykke, 2000).

4.1.3.4. Regeneration of tree species

Differences in density, species richness and diversity of regeneration between different SLM technologies were very high. The technologies in which humans had the strongest influence on selection and establishment of ligneous species, "parkland" and "homegarden", had the lowest observed densities of regeneration. The soil in these systems was under cultivation and therefore seedlings were probably damaged during field preparation or deliberately removed by land users to reduce competition with crops for light and nutrients. At the SLM site "agroforestry with *A. senegal*" the higher density of regeneration at the fallow part masked the low density at the parts under cultivation, but in general, the same phenomenon was observed. For the CLM of "crop production" low densities of regeneration were encountered, whereas for the CLM of "extensive pasture" regeneration density was highly variable.

Interestingly, *G. bicolor* was the most common species regenerating at SLM sites. Von Maydell et al. (1983) mentioned that despite the species being rather drought resistant due to its presence in depressions, regeneration in the Ferlo was very weak or not observed at all. *C. glutinosum* and *G. senegalensis* were common as seedlings at CLM sites. Although these species play a crucial role in the regeneration of vegetation and thus of soil fertility during fallowing (Kessler & Breman, 1995), large densities are considered an indication of degradation (LeHouérou, 1989).

In general, species richness, density and diversity were lower for regenerating than for mature trees found in the area. Analysis of size class distributions confirmed that the number of tree species having individuals in the smallest diameter class (< 2 cm, therefore counted as regeneration in this study) was low compared to the number of tree species with individuals in the second smallest (2-9.9 cm) and intermediate (10-19.9 cm) diameter classes. As species will only regenerate into the largest diameter class if they have a so-called reverse-J population structure (a size distribution curve that drops exponentially with increasing

[10] Written personnal communication of Wélé, A. Ingénieur des Eaux et Forêts. 29.01.2010.

DBH) (Lykke, 1998), most species except for *B. aegyptiaca* and *C. glutinosum* might be facing decline. On the other hand most tree species had no individuals in the large diameter classes. This pattern could be an indication of another emerging problem with regeneration, namely that not enough mature trees remain to produce the next generation (Kindt et al., 2008). In the Sahel zones, particularly in the drier part, trees and shrubs establish in years with sufficient rainfall only (Breman & Kessler, 1995) and such suitable conditions are relatively rare events (Westoby et al., 1989). At least 400 mm rainfall during one year is considered sufficient for the establishment of woody plants on sandy soils in semi-arid systems (Breman & Kessler, 1995). Long-term annual rainfall means in Dahra (about 80 km west of Barkédji) fell from 523 mm before 1970 to 328 mm (37% decrease) after 1970 (Vincke et al., 2010). For the western Sahel there are still discrepancies between the models predicting future precipitation changes, some projecting a significant drying and others simulating a progressive wetting (Boko et al., 2007). It is therefore difficult to predict if the observed rareness of regenerating tree species in Barkédji is only a temporary phenomenon or if it indicates an irrevocable impoverishment of vegetation cover and species diversity.

Exotic species were not found regenerating in the investigated sites in Barkédji. This might be beneficial for the maintenance of indigenous vegetation cover in this silvopastoral region for several reasons. World wide, there are many records of the invasion of pasturelands by exotic woody legumes, mainly in Australia, South Africa and Zimbabwe. They often reduce the availability of fodder for grazing and create dense stands impenetrable for livestock (Haysom & Murphy, 2003). In Benin it was found that exotic tree species induced an impoverishment of the original vegetation related to ecological factors (litter amount, soil acidity, competition, allelopathy, etc.) (Djego & Sinsin, 2006). Seedlings of indigenous species can be outcompeted by exotic ones such as neem (*A. indica*). Neem first appeared in Sahelian countries around 1920, being introduced from the British colonies along the West African coast. Since then it has been planted for a variety of uses such as shade provision, construction and medicine. It has very competitive properties such as tolerance of limited rainfall as low as 150 mm and it's growth is often better on rocky, lateritic and shallow soils than that of indigenous species (Von Maydell, 1981). It competes aggressively with local parkland species for light and nutrients. Due to bird dissemination, high densities of neem seedlings usually occur around parkland species like *V. paradoxa, F. albida*, *A. digitata* and others. This phenomenon is generalized through the Sahel and has been found to be detrimental to *F. albida*. In parklands of Bulkiemdé province of Burkina Faso it is already the second most common species after *V. paradoxa* (Boffa, 1999). Another negative effect resulting from the invasiveness of exotic tree species is hybridization which can occur between the introduced tree species and a native tree species (Haysom & Murphy, 2003). An investigation of farmers' preferences for tree species in Senegal, Mali, Burkina Faso and Niger (ICRAF, 1995) showed that out of 28 preferred species only two were exotic (*A. indica* and *T. indica*), suggesting that farmers heavily rely on and appreciate local species. For tree planting activities, however, many land users prefer exotic species due to social customs and the long time required for indigenous species to reach maturity and yield expected benefits (Boffa, 1999). Most exotic species introduced for agroforestry have been selected for a number of beneficial traits e.g. their suitability for firewood and fodder. In some cases aggressive spreading of trees has lead to the reforestation of formerly deforested land and provided the local populations with a continuos supply of forest products. A well known example is *P. juliflora* (Haysom & Murphy, 2003). For the homegarden sites where the aim is to improve food security, the maintenance of a certain percentage of exotic fruit trees such as mango can be favorable.

4.1.4. Verification of hypotheses

H1: Sites managed by the documented SLM technologies show higher tree density, species richness and species diversity than sites under CLM

H2: Sites managed by the documented SLM technologies show a higher percentage of woody canopy cover than sites under CLM and therefore protect the soil from degradation

Sustainable management did have a positive impact on all of those variables compared to the CLM practices of crop production and extensive pasture. Differences between different SLM technologies regarding the increase of tree density, species richness and species diversity were pronounced. Canopy cover at sites under the given SLM technologies was higher than at sites under CLM. Thus, hypotheses H1 and H2 can be accepted.

H3: The number of woody individuals showing damage caused by humans was higher at sites under CLM than under SLM.

No significant difference was found regarding damages between SLM and CLM. Therefore hypothesis H3 is rejected.

H4: Density and richness of species useful for the local population are higher at sites under the documented SLM technologies compared to sites under CLM

SLM sites harbored more different species and more individuals of these species providing food, construction wood, fodder, firewood and medicine to the local communities than sites under CLM. Hypothesis H4 is accepted.

H5: Density, species richness and species diversity of tree regeneration (DBH < 2 cm) is higher at sites under SLM than at sites under CLM

Analysis of richness, density and diversity of regeneration showed that hypothesis H5 can be accepted, as each of these parameters was higher at sites under one of the given SLM technologies than under CLM.

4.2. Case Study Lompoul

4.2.1. Analysis of SLM technologies and the conventional land management (CLM)

Analog to the previous chapter (4.1. Case study Barkédji), in this chapter the CLM system of "extensive pasture" and all SLM technologies documented for the WOCAT database are described and analyzed. A short description of the respective study area (see p. 17) is given before the description of the SLM technologies. Information on biophysical characteristics of the SLM of "small grove" that was not documented for the WOCAT database can be found in Appendix 3 (see p. 150). The results of the statistical analysis of the vegetation assessment at SLM and CLM systems are presented in chapter 4.2.2., p. 109.

4.2.1.1. Conventional land use systems in the geographical assessment area (GAA) of Lompoul

CLM 1: Extensive pasture

<u>Key characteristics</u>

Animal husbandry in the Niayes is intensive or semi-intensive due to space constraints (Touré Fall, 2005). This means that livestock receives supplementary fodder e.g. in the form of blood flour or bone flour. An extensive system of pastoralism is applied for small ruminants and at night the animals are kept enclosed (Touré Fall & Salam Fall, 2001). Integrated systems dominate with about 97% of the farmers being agropastoral. One household owns 5 sheep, 32 cattle, 25 goats, 2 horses, 1 donkey and 48 poultry on average (Touré Fall, 2005). Pastures are dominated by *A. raddiana,* a widespread species in the Sahel, but indigenous to eastern Africa (ICRAF, 2009) (see *Figure 20).*

Figure 20. Extensive pasture with *A. raddiana* in Lompoul-sur-Mer, (northern littoral of Senegal)

<u>Biophysical characteristics</u>

The soil at the CLM site of “extensive pasture” was of sandy texture and contained 0.06 g organic carbon / kg soil on average (CSE, 2009b) which is considered a poor value for sandy soils (Moody et al., 2008).

The canopy cover was much higher compared to extensively used pastureland in the Ferlo (see *Table 7*, p. 34.). The same can be said of herbaceous cover. The trees were of shrubby architecture with low height and small DBH. No signs of lopping or other damage were observed and all individuals were alive (see *Table 36*).

Table 36. Characteristics of vegetation at the CLM site “pasture” in Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	25 [9.9]
Herbaceous cover (%)	76 [21.1]
Tree height (m)	4 [0.6]
Tree DBH (cm)	15 [0.5]
Percent trees damaged	0
Percent dead trees	0
Number of trees ha^{-1}	64 [21.1]
Number of regenerating trees ha^{-1}	0
Shannon diversity index	0.41 [0.2]

[1] Standard errors are given in parenthesis. Sample size was n=3.

Table 37 shows the density of mature and regenerating tree species per ha. The woody vegetation in this pasture almost exclusively consisted of *A. raddiana* with a few individuals of *F. albida*, *M. senegalensis* and *C. africana*. The tree density was only little higher than in pastures around Barkédji in the Ferlo (see *Table 8*, p. 35). No regeneration of tree species was found.

Table 37. Density of mature and regenerating woody species per ha and their origin (ind: indigenous, ex: exotic) at the CLM site “extensive pasture”, Lompoul, (northern littoral of Senegal)[1]

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Acacia raddiana	ex	53.1 [17.4]	0
Faidherbia albida	ind	5.3 [5.3]	0
Maytenus senegalensis	ind	2.7 [2.7]	0
Commiphora africana	ind	2.7 [2.7]	0
Total		**63.8 [21.1]**	**0**

[1] Standard errors are given in parenthesis. Sample size was n=3.

Table 38 shows the percentage of cover of eight different herb species that were found in pastureland of which five were more or less equally distributed. All species together covered about 76% of the soil. From visual observation it was realized that the herbaceous cover was much denser under tree canopies than in the open (illustrated by *Figure 20*).

Table 38. Percentage of soil cover of herbaceous species at the CLM site "extensive pasture", Lompoul (northern littoral of Senegal)[1]

Species	**Soil cover (%)**
Aristida mutabilis	20 [12]
Chloris prieurii	17 [7]
Pennisetum pedicellatum	13 [8]
Abutilon macropodum	12 [3]
Fimbristylis sp.	10 [10]
Cenchrus biflorus	4 [2]
Digitaria horizontalis	< 1
Ipomoea vagans	< 1

[1] Standard errors are given in parenthesis. Sample size was n=12.

Analysis

All of the present tree species are mentioned by Arbonnier (2004) as having some fodder value. According to the local specialist for the LADA assessment the present herbaceous composition does not have a high fodder value, probably due to the impact of droughts. An alarming finding is that not a single tree species was found regenerating. Pasture enrichment with fodder species such as *Acacia holocera* and *A. raddiana* was recommended by the LADA assessment team to improve pasture quality (CSE, 2009b). Because the focus of agricultural activities in the Niayes lies on horticulture, there is a need to develop pastoral activities especially the integration of livestock and horticulture. Pastoral practices are still archaic and the production system is traditional (Touré Fall & Salam Fall, 2001).

4.2.1.2. SLM technologies in Lompoul-sur-mer

Characteristics of Lompoul-sur-Mer / Thioucougne

For a general description of the zone des Niayes see chapter 3.3.2.3., p. 21. The village of Lompoul-sur-Mer with the small hamlet of Thioucougne was chosen as one of the two study areas in the GAA of Lompoul.

The village of Lompoul-sur-Mer was founded by transhumant Peul herders in the search for the richest pastures. With their installation they diversified activities and started practicing crop production. They also engaged in fishery activities because of repeated contacts with fishermen coming from the St.Louis region. Later, Wolof people arrived in the area, looking for cultivable grounds and today the two ethnicities live together (CSE, 2009b).

SLM technology 1: Dune fixation with *Casuarina equisetifolia* ("Bande de Filao")

Key characteristics

Plantations of *Casuarina equisetifolia* (Filao)[11], an exotic species of Malaysian (Maheut & Dommergues, 1959) or Australian origin (Whistler & Elevitch, 2006), were established along the "Grande Côte" from Dakar to St.Louis, covering an area of about 9,700 ha in a 200 m wide belt (Mailly et al., 1994) to halt wind erosion and therefore movement of sand dunes. This technology is known in Senegal as the "Bande de Filao". The reafforestation of sand dunes took place from the 1970ies until the late 1990ies. Filao reaches senescence with about 40 years (Mailly et al., 1994), a point that has already been attained by some of the trees and will be reached by the rest soon. Therefore, a management plan was developed to assure the continuity of this important protective system. *Figure 21* shows a part of the Filao plantation in Lompoul-sur-Mer.

Figure 21. Filao (*C. equisetifolia*) plantation in Lompoul-sur-Mer, (northern littoral of Senegal)

Technology origin and history

If not especially mentioned, the information following in this subchapter, based on Maheut & Dommergues (1959), concerns the area in which the first plantations of Filao were established (Cap Vert Peninsula) but is most probably valid for the establishment of the rest of the "Bande de Filao".

Long before Senegal's independence in 1958 it became clear for the colonial government that measures had to be undertaken to reduce the wind speed and therefore the movement of sand all along the Senegalese coast in order to allow for agricultural exploitation of this area, which is characterized by a favorable climate different from the rest of the country (CSE, 2009b). According to local inhabitants the problematic consequences of removing the natural vegetation on sand dunes first occurred around 1919. Until then, sand dunes had been relatively well fixed by the natural shrub and herb cover. But due to livestock herds, assembling in the vicinity of the beach during nights in the rainy season, this vegetation cover progressively disappeared. The reason for livestock to assemble in this area was that parasites were less common close to the beach than in the interior of the land and that their owners wanted them to be far

[11] In the following mostly the local name will be applied

from the cultivated zones. In zones where grazing was inhibited, the littoral dunes hardly showed any signs of degradation. With the influence of marine trade winds blowing from the North during the dry season, sand advanced between 10 and 12 meters a year, covered agricultural as well as pastoral land and filled up the littoral lakes (see *Figure 22*). In view of this alarming development of the zone, an intervention of the forestry service was decided in 1948. An earlier intervention by the agricultural service in 1925 was a failure with even the Filao being threatened by the advancement of the sand (Mailly et al., 1994). The aim was to first reforest a stretch of 200 m width which would then allow to progressively fixing the rest of the interdunal zone. In order to choose the most appropriate and adaptable species for this undertaking, an experiment was conducted with 27 different species (see Appendix 4, p. 152) of indigenous and exotic origin (Maheut & Dommergues, 1959). The plant would need to be able to grow in close proximity to the sea on poor sandy soils, to support the effects of violent winds and to withstand aggradation. Filao showed all of these characteristics. It is able to colonize poor soils because of its symbiosis with nitrogen fixing bacteria of the genus *Frankia* and with endo- and ectomycorrhizae. However, it presented the inconvenient of early senescence (with 30-40 years) (Mailly et al., 1994), of not regenerating naturally in the climate around Dakar and of not regenerating from stumps. In the experiment site, however, only a few *Cocos*, some lines of *E. balsamifera* and one bunch of *Pithecellobium dulce* protected by a Filao plantation survived. The destructive role of crabs, especially for the germination of *Anacardium occidentale*, was one of the reasons for the weak establishment of the tested plants. Filao therefore seemed to be the only option but it was emphasized that in the hinterland of the plantations, reforestation with different species, notably *Cocos* should be tried.

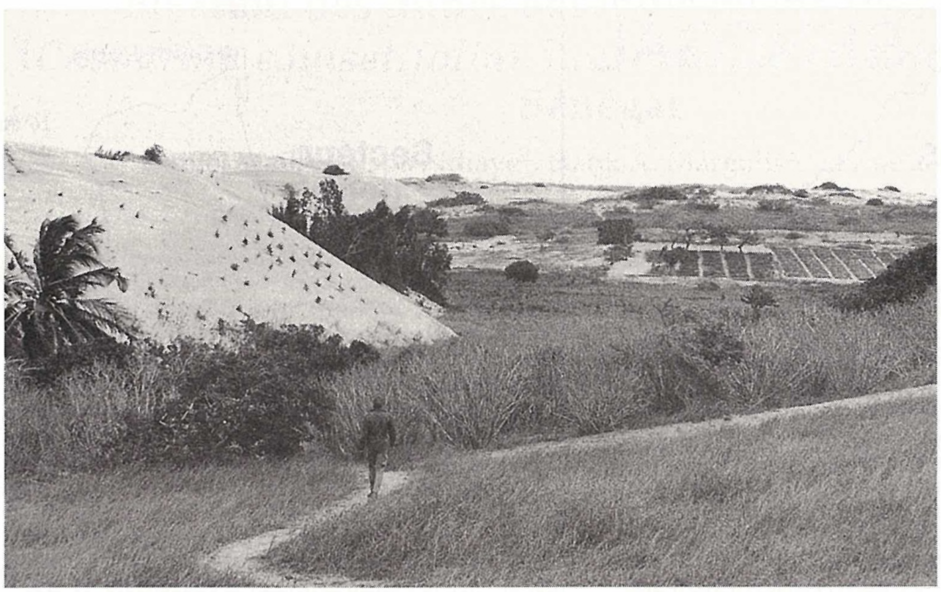


Figure 22. Vegetable plot threatened by non-stabilized wandering dunes;
source: Mailly et al. (1994)

After this first initiative which managed to reforest an area of 513 ha with Filao, it took a rather long time for the next initiatives to be implemented. In 1972, the Senegalese government asked for financial assistance from the United Nations Development Program (UNDP) to continue the plantation efforts. The “Projet de Fixation des Dunes de Kébémer” in the centre of the Niayes (where data for the present case study was collected), co-financed by the UNDP and the Senegalese government, was created in 1975. Objectives were the reinforcement of natural vegetation cover and therefore the fixation of wandering dunes, the creation of a windbreak to protect the vegetable plots located in the depressions and the introduction of tree species improving soil conditions and providing fodder. This project was followed by the “Projet Autonome de Fixation des Dunes du Gandiolais” which was co-financed by the “Agence Canadienne pour le Développement International (ACDI)” and covered the northern sector of the Niayes. Two years later the “Projet de Fixation des Dunes de Kayar”, co-financed by the United States Agency for International Development (USAID) was implemented south of Kébémer. The government’s objective to establish a continuous green wall, 200 m wide, and reaching from Dakar to St. Louis was attained in 1982. In 1988, the ACDI took over the USAID project in the south to merge it with the “Projet Autonome de Fixation des

Dunes du Gandiolais" in the north to form the combined "Project de Conservation des Terroirs du Littoral" (Mailly et al., 1994). After the goal of fixing the white maritime dunes was attained, the work concentrated on the fixation of the interior red dunes and on the protection of vegetable plots with windbreaks of *Eucalyptus* (Gueye, 2000).

The different phases of establishment

In this section, except if noted otherwise, information is based on Mailly, et al. (1994) who used Maheut & Dommergues (1959) as the main reference.

Initial protection

The most important step in establishing a Filao plantation is to prevent the sand from moving during a time span long enough for young trees to establish. This can be achieved by installing artificial wind breaks in two stages: About one year before establishment of the plantation a palisade of about 1 m height has to be set up, usually in a distance of 70 m from the water to serve as a mechanical barrage for the sand. In 1959 it consisted of a meshwork of 75 cm height with branches of *Oxytenanthera abyssinica* or leaves of *Phoenix.* In those first plantations the resulting artificial dune was more than 10 m long and up to 2 m high (Maheut & Dommergues, 1959). The palisade only had a transient role, as during the first two years the young Filao seedlings are threatened by the sand but after are already high enough to withstand the effects of aggradation. In order to protect the plantations from roaming animals, an enclosure consisting of a triple range of barbed wire on wooden poles (*Borassus*, *Cassia* or Filao) was constructed. As the littoral palisade was not sufficient to hinder the movements of sand on the whole length of the area to reforest, it was necessary to install fascines of 50 cm height rectangular to the wind. This was done before plantation, usually between November and June. Distance between fascines was 20 meters on slopes with an angle of 0-5% and 10-15 m on slopes with an angle exceeding 5%. They consisted of meshwork using bamboo (of 40 cm height) or *Phoenix* leaves (50 cm length) in 1959 (Maheut & Dommergues, 1959) and of *G. senegalensis* or poles of *E. balsamifera* in plantations established later (Mailly et al., 1994). In order to protect one ha of plantation 500 m of meshwork was required (Maheut & Dommergues, 1959).

Excavation of wells (Maheut & Dommergues, 1959):

The necessity to irrigate Filao seedlings during the first dry season made it inevitable to excavate about one well per ha in the whole plantation area. The wells were lined with metal sheets and they were equipped with membrane pumps working even if the water was loaded with salt and demanding only little maintenance. Of course the wells also had to be protected against aggradation. For this purpose some of the meshwork was used.

Plantation techniques:

The work in tree nurseries was started once all protection measures were completed, usually in January or February. The objective was to produce enough Filao seedlings to cover the demand of one planting season. Two types of tree nurseries were established: a permanent one (producing about 150,000 plants / year) and a mobile one (producing about 200,000 plants / year) which could be moved around according to the demand from the areas under plantation.

The seeds were gained from mature trees in December. They were then brought up in polyethylene bags of 80 micrometers thickness, filled with a mixture of sand, humus or turf. The transplantation took place after four to six weeks of growth or when the seedlings reached a height of ten cm. Daily watering was done manually using the wells established for this purpose. The seedlings were inoculated with *Frankia* (for detailed information consult Sougoufara, Diem, & Dommergues (1989)). After four to five months the seedlings reached fifty cm height.

The first plantations were created when the year's rainfall accumulated to about 50 mm. The spacing between the seedlings was set at 2.5x2.5 m resulting in about 1,600 plants per ha. Maheut & Dommergues (1959) as well as the forestry extension agent based in Khonkh Yoye emphasized the need for irrigation during the first year (until the end of the second rainy season), and believed that irrigation was one of the most determinant factor for the success of the plantations as well as for the costs. However, Mailly et al., (1994) stated that once seedlings were planted at their final destination they did not need any further irrigation but they would depend on soil humidity for their survival. As the territory was not difficult to work on, the plantation activities were fast (up to 20 ha a day). The survival rate oscillated between 80 and 90%. *Figure 23* shows plantation activities in the Niayes.

Figure 23. Preparations to plant Filao seedlings (front left); in the background a Filao plantation aged seven years; source: Mailly et al. (1994)

A new plantation technique was used in Filao plantations in Vietnam and consists of adding one to two layers of litter from Filao to the planting hole in order to hold off the scarce amount of water that falls in the dry season. Like this, the Filao seedlings can profit from this water reserve to survive the long dry season. Young trees should only be transferred from the tree nursery to the plantation side once they have attained 1-1.20 m height and be deeply sunk into the dune (0.5-0.6 m). This brings the roots in a good position to take up soil humidity from the litter layer and protects the lower part of the stem from wind and sun (Cong Dinh, 1998).

Objectives of the technology

This SLM technology was employed in order to reduce wind speed and to stabilize the sand dunes along the Senegalese coast which would as a consequence protect the vegetable production in the interdunal depressions. A second objective was to build up wood resources that could at some point be exploited for firewood or timber.

Benefits, disadvantages and constraints

Reduced wind speed and its consequences (reduced wind erosion and no further movement of dunes) is one of the most important benefits of this dune fixation. It should always be kept in mind that without the fixation of the dunes it would still not be possible for people to live and cultivate the soil within 15 km from the beach and Senegal’s most important region for vegetable production would not exist.

Probably as important, but more surprising is the impact of the “Bande de Filao” on inshore fishery. Before the establishment of the wind break, fishery along the coast of Lompoul-sur-Mer was only possible during the short rainy season. During the nine month dry season, maritime trade winds from the Azores anticyclone made it impossible or at least very dangerous for the fishermen to work. Once Filao trees were mature, reduced wind speed was not only observed on the landside of the plantation but also on the sea side. From then on fishery was possible during the whole year. An important benefit of the technology is therefore the creation of an additional income source and product diversification. *Figure 24* shows the presence of fishery activities at the beach of Lompoul-sur-Mer.

Figure 24. “Quai de pêche” or fish drying facilities (left) and fishing boats (right) at the beach of Lompoul-sur-Mer, (northern littoral of Senegal)

A benefit from the land users’ point of view is the production of firewood, as the collection of dead wood in the Filao plantations is permitted. Due to its compact and heavy wood, Filao is one of the best species to be used as firewood (Mailly et al., 1994). The creation of an income source regarding the logging permits for senescent trees and their sale is rather a consequence of the management plan for the renewal of the plantations and not of the initial plantations (CSE, 2009b). Mailly et al. (1994), suggested that the production of timber for construction from Filao could be an interesting option as the tree has red-brown wood with black veins which gives it an esthetic aspect.

Furthermore, the Filao plantations have developed into an attraction for (mainly Senegalese) tourists enjoying the shade provided so close to the beach for picnics and family excursions. However, this involves negative consequences for the environment, since plastic waste that remains after every public holiday or weekend within the Filao plantations is covering the soil.

One constraint or disadvantage of the technology is the high establishment costs. In general this technology of dune fixation is expensive because the chosen species does not regenerate naturally in its stand and therefore the whole process of planting trees has to be repeated about every 30 years in order to guarantee for the sustainability of the system. The most determinate factors affecting the costs in the case of Lompoul-sur-Mer are the need for transportation of the Filao seedlings from the tree nursery to the plantation and for fencing material to protect the young trees from roaming animals (or vandalism).

Table 39 presents all benefits and disadvantages of this SLM technology.

Table 39. Benefits and disadvantages of the SLM technology “dune fixation” according to the WOCAT criterias, Lompoul, (northern littoral of Senegal)

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased wood production	high	Increased demand for irrigation water High establishment costs	high high
Socio-cultural	Increased recreational opportunities Community institution strenghtening	medium medium		
Ecological	Reduced wind velocity Increased biomass	high high	Increased amount of plastic waste (due to attraction of tourists)	medium

	Benefits		Disadvantages	
	Type	Degree	Type	Degree
	Reduced soil loss	high		
	Increased soil organic matter	medium		
	Reduced hazard towards adverse events (storms)	medium		
	Increased soil cover (with Filao litter)	medium		
	Improved carbon storage	medium		
Offsite	Reduced wind transported sediments	high		
	Reduced damage on public / private infrastructure	high		
	Reduced damage on neighbors fields	high		
	Enabling all year round fishery	high		

Biophysical characteristics

All information in this section was collected in the frame of the LADA project and only applies for three sites in the Filao plantations around the village of Lompoul-sur-Mer (CSE, 2009b).

The soil in the Niayes consists of sand of marine origin and the presence of shell debris led to a pH oscillating around 8. The groundwater sources are exclusively fed by rainwater (Maheut & Dommergues, 1959). The amount of soil organic carbon in the labile fraction ranged between 0.03 and 0.26 g C / kg soil in different sites within the plantation but was higher in sites where litter cover was thick. For soil pH findings were similar with higher pH (up to 8.5) in sites containing more litter (CSE, 2009b).

C. equisetifolia was the only tree species encountered at this SLM technology site. According to a local forest engineer who had a lot of experience with Filao plantations[12] the canopy cover of this plantation (see *Table 40*) was lower than expected. Herbaceous cover and regeneration were practically absent due to the thick cover of dead litter on the soil. The only herbaceous species encountered were *Leptadenia hastata*, *Momordica balsamina, Abutilon macropodum* and *Cassia occidentalis* with some single individuals present. Only few trees showed signs of cutting by humans or were dead. The average density was surprisingly low with 353 individuals per ha as 1,600 seedlings were planted initially and seedling survival was described as oscillating between 80 and 90% (Mailly et al., 1994). This low number is due to three assessment plots in a recent area of the plantation in the hinterland of the initial “Bande de Filao” which had an average density of only 132 individuals per ha. Initial densities are not known for this part of the plantation and might be lower than for the main “Bande”. If we only consider the average of the five plots located in the initial “Bande”, density was 462 trees per ha.

[12] Oral personal communication of Wélé, A., Ingénieur des Eaux et Forêts. In Lompoul, 10.10.2009.

Table 40. Characteristics of vegetation at the SLM technology site "dune fixation" in Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	23 [11]
Herbaceous cover (%)	< 1
Tree height (m)	11 [3]
Tree DBH (cm)	18 [3]
Percent trees damaged	5 [0.1]
Percent dead trees	4 [0.9]
Number of trees ha^{-1}	353 [120]
Number of regenerating trees ha^{-1}	0
Shannon diversity index	0

[1] Standard errors are given in parenthesis. Sample size was n=8.

Evaluation and Outlook

First of all, it has to be emphasized that the reforestation of the northern littoral was a great success and that its positive impacts were numerous and widespread. The growth of Filao along the northern littoral was described as satisfactory taking into consideration the severity of the environment (Mailly et al., 1994). Without this initiative, life in the Niayes would be impossible as villages would constantly be threatened by the dunes let alone agricultural production. The technology therefore had a huge impact on the livelihoods of people in this region. Many farmer families that had left the area before, returned and resettled due to the positive effects of the dune stabilization (Mailly et al., 1994). The Niayes are Senegal's most important region for vegetable cultivation accounting for two-thirds of the production. In addition, mango and lemon are produced for exportation, primarily to countries of the European Union (EU) (Gueye, 2000).

Another important impact is the one mentioned on local fishery. No research has been conducted yet on this phenomenon that would certainly deserve a detailed analysis. It has a yet unknown impact on the social structures and the future of vegetable farming as most young people are now working as fishermen (notably the men) and elder farmers are complaining about not having enough field workers at their disposal anymore. Lompoul-sur-Mer disposes of a high-tech fish processing installation ("quai de peche", see *Figure 24*), financed by the Japanese cooperation agency (JICA) (apparently in return for offshore fishing rights for the Japanese government) (CSE, 2009b).

However, the future of this technology is uncertain, as trees have reached senescence and need to be replaced with seedlings. A management plan for this challenge has been developed and envisages the attribution of 50 ha blocks of Filao plantation to local user groups (the "groupements d'interêt économique"), which will be responsible for the exploitation and more important, reforestation, of 2 ha within the 50 ha block per year. Within 25 years from the start of this cycle the whole "Bande de Filao" should then be renewed and at the time the first trees start to age the reforestation starts again. The feasibility of this undertaking has already been contested since a visual observation during the LADA assessment of one of these blocks in Lompoul-sur-Mer has revealed an extremely poor presence of Filao seedlings, probably due to insufficient irrigation. Any kind of future mismanagement could have serious impacts on the livelihoods of about 120,000 people in the Niayes and Senegal's economy in general. Under no circumstances should the continuity of this technology be jeopardized.

SLM technology 2: Fruit orchard

Key characteristics

This fruit orchard, mainly containing Mango (*Mangifera indica*) and Citrus (*Citrus limon*) trees, is located in the hamlet of Thioucougne which is part of the village of Lompoul-sur-Mer. The surface accounts for about 0.46 ha. Long before the establishment of the orchard, land cover consisted of denuded or sparsely covered white wandering sand dunes threatening agricultural production and villages alike (CSE, 2009b). For some years vegetable production took place on this plot of land and later the orchard was established. Fruits are aimed at sale on the local market but production is insufficient for commercial purposes due to a pest (see subchapter of “constraints”) and senescence of fruit trees. Citrus fruits are used by the cultivator and his family for pharmaceutical purposes. Inorganic fertilizers and organic manure are both used in order to improve soil fertility. Irrigation with water from one of the 8-9 m deep wells is practiced for a few *Cocos nucifera* plants but not for the other species. The labor is done by employees with whom the assigned care taker of the orchard shares the little revenues from selling fruits on the market. The orchard is protected by a hedge constructed of dead *B. aegyptiaca* and *A. raddiana* branches and contains a small number of individuals of other species. *Figure 25* shows the less densely populated part of the fruit orchard with *Cocos* palms and the Filao plantations in the background.

Figure 25. Fruit orchard in foreground with Filao plantations in the background, Thioucougne, (northern littoral of Senegal)

Technology origin and objectives

According to the care taker of the orchard, the owner is a high-positioned Senegalese government official he is sharing a friendship with. As the owner did not find time or motivation to cultivate this piece of land any longer, he confined the orchard to his friend about nine years ago (around the year 2000). This current care taker is an elderly man from the hamlet of Thioucougne.

The initial objective of establishing a fruit orchard was to produce fruits for sale on the local market and for subsistence. However, the care taker stated that his motivation was mainly personal, namely the friendship that connects him to the land owner.

Benefits, disadvantages and constraints

The benefits and disadvantages of this SLM technology are listed in *Table 41*. The degree of the different benefits was mostly estimated as “little” due to the following reasons: The objective of commercial fruit production cannot be attained any longer as 80% of the mangoes are infected with eggs and larvae of the “mango fruit fly” (*Ceratitits cosyra*) causing festering of the fruit (IRIN, 2006). Only the non-affected fruits can be used for consumption. The *Citrus* trees are all pruned but are not producing a high number of fruits anymore which is probably related to their age.

Soil properties are not appropriate for this kind of land use according to the land user’s statement and he has to apply 400 kg of inorganic fertilizers (10-10-20 formula) to the soil per dry season which costs him about 40,000 FCFA (=83 USD). In addition he spends 25,000 FCFA (=51.80 USD) a year for organic manure being transported from Touba to the orchard (131 km distance from Lompoul-sur-Mer). Furthermore, he complained about the soil lacking humidity.

A problem for this elderly land user is the fact that his children are not willing to do farm work in the orchard anymore since they either left to Mauritania to work as fishermen or got engaged with fishery activities in Lompoul-sur-Mer (see “Evaluation and Outlook” in chapter “Dune fixation with *C. equisetifolia*” p. 89 for information on fishery in Lompoul-sur-Mer).

Lacking the means for investment were further mentioned as a constraint for the well-functioning of the orchard, since the care taker thinks that with appropriate maintenance and investment the orchard could generate a high profit every year.

Table 41. Benefits and disadvantages of the SLM technology “fruit orchard” according to the WOCAT criterias, Lompoul, (northern littoral of Senegal)

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Diversification of income sources	little	Increased demand for irrigation water	little
	Increased farm income	little		
	Increased product diversification	little		
Socio-cultural	Improved food security / self-sufficiency	little		
Ecological	Reduced soil loss	medium	Increased niche for pests (mango fly)	high
	Increased biomass	little		
	Increased plant diversity	little		
	Improved carbon storage	little		
	Increased soil organic matter (from application of manure)	little		
Offsite	Reduced wind transported sediments	little		

Biophysical characteristics

According to the LADA rapid assessment the soil conditions in the fruit orchard were the poorest among all sites assessed in the study area of Lompoul-sur-Mer (CSE, 2009b). The amount of soil organic carbon in the labile fraction was 0.1 g C / kg soil, which is considered a moderate proportion for sandy soils (Moody et al., 2008).

The canopy cover was low since all the *Citrus* trees were pruned and therefore had small canopies. This also explains the high percentage of damaged trees as the pruning was not done in an appropriate way (see *Table 42*).

Natural regeneration of *B. aegyptiaca,* which is an elsewhere preferred fruit tree, was very abundant but will be removed, because the land user is convinced that thorny trees (like *Balanites*) are unable to coexist with fruit trees.

About 20% of the orchard's surface was covered with herbs of the following species: *Hibiscus sabdariffa, Cassia occidentalis, Cenchrus biflorus, Ipomoea vagans, Eragrostis tremula, Digitaria horizontalis*. However, according to the land user all herbs will be removed at the end of the rainy season*.*

Table 42. Characteristics of vegetation at the SLM technology "fruit orchard" in Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	8 [3]
Herbaceous cover (%)	20 [0]
Percent trees damaged	38 [10]
Percent dead trees	1 [1]
Number of trees ha^{-1}	376 [146]
Number of regenerating trees ha^{-1}	> 500 (*Balanites aegyptiaca*)
Shannon diversity index	1.07 [0.1]

[1] Standard errors are given in parenthesis. Sample size was n=3.

Ten (10) different tree species were found at this SLM technology site. Apart from the two fruit tree species, mango and lemon, all species were relatively rare. Some of the species, *C. nucifera, Z. mauritiana, T. indica* and *A. digitata* are fruit trees but they were not mentioned by the land user to be used in any way. The *Cocos* palms are only four years old and should bear fruits from the fifth year on. *P. juliflora, A. raddiana, A. indica* and *C. equisetifolia* were only present in the hedge. *A. digitata* and *Z. mauritiana* were the only indigenous out of 10 tree species found in the orchard. *Table 43* presents the density of all tree species present in the fruit orchard.

Table 43. Origin (ind: indigenous, ex: exotic) and density per ha of mature trees at the SLM technology site "fruit orchard", Lompoul, (northern littoral of Senegal)[1]

Species	Origin	No. of trees ha^{-1}
Mangifera indica	ex	224.7 [132.0]
Citrus limon	ex	118.9 [19.5]
Prosopis juliflora	ex	10.7 [9.7]
Cocos nucifera	ex	6.3 [6.3]
Ziziphus mauritiana	ind	5.0 [2.9]
Acacia raddiana	ex	3.7 [3.2]
Tamarindus indica	ex	3.3 [3.3]
Adansonia digitata	ind	2.1 [2.1]
Azadirachta indica	ex	0.7 [0.7]
Casuarina equisetifolia	ex	1.0 [1.0]
Total		**376.4 [145.5]**

[1] Standard errors are given in parenthesis. Sample size was n=3.

Evaluation and Outlook

This SLM technology helped to improve vegetation cover, tree abundance and tree diversity at an else bare spot of land. However, the sustainability of the technology might be threatened as the main stands of trees (mango and lemon) are already overage and the land user does not dispose of the necessary means to replace them. The objective of the land owner (which is not identical to the land user or care taker) is to cultivate this land in order to legally keep the property rights. Since the appointed care taker is already very old and because his offspring does not take any interest in farming activities, the future of the orchard is very uncertain. Since trees are senescent and mango production is suffering from a pest, the plot might be turned into a vegetable or crop field. Depending on the type of management (e.g. under agroforestry or not) there would be the possibility of lower or higher sustainability than under the present management.

SLM technology 3: Plantation with *Eucalyptus camaldulensis*

Key characteristics

Plantations with *E. camaldulensis* are located in the hinterland of the "Bande de Filao", where they were established in order to stabilize the soil and to mitigate the impact from the remaining force of the wind that could not be fully absorbed by the wind break with *Casuarina*. In the Niayes they cover an area of about 170 ha as plantations and 482 km as windbreaks, protecting the vegetable plots (Gueye, 2000). *E. camaldulensis* seedlings were planted with 2x3 m spacing. Therefore, the seedling density was about 1,660 individuals per ha. *Figure 26* shows a site within the *Eucalyptus* plantations near Lompoul-sur-Mer.

Figure 26. Plantation with *E. camaldulensis* and litter cover near Lompoul-sur-Mer, (northern littoral of Senegal)

<u>Technology origin and objectives</u>

Parallel to the project of dune fixation with Filao, several projects undertook the reforestation of about 2,380 ha of dunes in the interior, mainly using *E. camaldulensis*, several Australian *Acacias* and *A. occidentale* (Mailly et al., 1994). Objectives of the plantations with *E. camaldulensis* were to stabilize the soil and to serve as a windbreak for the vegetable fields while at the same time constituting a major source of construction- and firewood.

<u>Benefits, disadvantages and constraints</u>

Stabilization of the soil and therefore the fixation of the dunes are the main advantages of this technology. In addition the plantations constitute an important source of construction- and firewood that can be exploited by the local population once the stands need to be replaced with regeneration.

A major disadvantage is the high costs related to the tree nursery, transport, fencing and survey of the *Eucalyptus* plantations. Establishment of one ha of plantation costs about 850,000 to 1,000,000 FCFA (=1,762 to 2,073 USD) according to the local forestry extension agent[13]. Gonzalez (2001) stated, that because of a lack of water, *Eucalyptus* plantations in the region showed a survival rate of only 18%. Furthermore, local farmers complained that on several occasions *E. camaldulensis* was invading their fields and competing with other trees or crops for water.

Although no exploitation (except for the collection of dead wood) of the *Eucalyptus* plantations is allowed yet, people are illegally cutting branches and sometimes whole trees for construction- and firewood. The forestry extension service which is supposed to protect the plantations from illegal activities does not dispose of the means to implement any protective measures.

Table 44 presents the benefits and disadvantages of this SLM technology.

[13] Oral personnal communication, Waly, P. Ingénieur des Eaux et Forêts. In Lompoul, 11.10.2009.

Table 44. Benefits and disadvantages of the SLM technology "*Eucalyptus* plantation" according to the WOCAT criterias, Lompoul, (northern littoral of Senegal)

	Benefits		Disadvantages	
	Type	Degree	Type	Degree
Production and socio-economy	Increased wood production	high	Increased demand for irrigation water	high
			High establishment costs	high
Socio-cultural	Community institution strenghtening	medium		
Ecological	Reduced wind velocity	high	Lowering of groundwater table	medium
	Increased biomass	high	Decreased soil moisture	medium
	Reduced soil loss	high		
	Increased soil organic matter	medium		
	Reduced hazard towards adverse events (storms)	medium		
	Increased soil cover (with *Eucalyptus* litter)	medium		
	Improved carbon storage	medium		
Offsite	Reduced wind transported sediments	high	Increased competition on neighbors fields (through *Eucalyptus* seedlings invading fields)	high
	Reduced damage on public / private infrastructure (through protection from aggradation)	high		
	Reduced damage on neighbors fields (through protection from aggradation)	high		

Biophysical characteristics

The biophysical data presented in this subchapter only concerns two sites in an *E. camaldulensis* plantation in the hinterland of Lompoul-sur-Mer, which was established in 1990 and is 11 km wide and 15 km long (CSE, 2009b).

The amount of soil organic carbon in the labile fraction was very low, ranging between 0.04 and 0.09 g C / kg soil (CSE, 2009b). Values below 0.1 g C / kg soil are considered poor for sandy soils (Moody et al., 2008).

The canopy cover was medium on average but varied between 14 and 58% at the different plots. The tree height was only half of the normal mature height of *E. camaldulensis* (Arbonnier, 2004), which should be from 12 to 20 m (see *Table 45*). This can probably be explained by environmental factors such as wind, because trees on top of the dune were smaller than trees in the depression. The trees showed damage by humans at all plots except of one. In most cases only single branches were cut. The soil was covered with litter from *E. camaldulensis* up to 90%. Where this was not the case and litter was only found directly under the tree canopies, the rest of the soil was bare. Only single individuals of herbs of the genus *Aristida* and *Leptadenia* were observed.

Table 45. Characteristics of vegetation at the SLM technology site "*Eucalyptus* plantation" in Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	27 [12]
Herbaceous cover (%)	0
Tree height (m)	6 [3]
Tree DBH (cm)	10 [4]
Percent trees damaged	11 [5]
Percent dead trees	0
Number of trees ha^{-1}	554 [69.4]
Number of regenerating trees ha^{-1}	0
Shannon diversity index	0.05 [0.05]

[1] Standard errors are given in parenthesis. Sample size was n=5.

The density of *E. camaldulensis* trees per ha was highly variable in the plantations. The two assessment sites were located in an interdunal depression and on top of a dune. The stands in plots on top of the dune showed lower density than in the plots in the depression. One single individual of *Acacia raddiana* was found in one of the plots (see *Table 46*).

Table 46. Origin (ind: indigenous, ex: exotic) and density per ha of mature trees (DBH ≥ 2 cm) at the SLM site "*Eucalyptus* plantation", Lompoul, (northern littoral of Senegal)[1]

Species	**Origin**	**No. ind.** ha^{-1}
Eucalyptus camaldulensis	ex	547.5 [71.5]
Acacia raddiana	ex	6.4 [6.4]
Total		**553.9 [69.4]**

[1] Standard errors are given in parenthesis. Sample size was n=5.

Evaluation and Outlook

Regarding the impact of this SLM technology on soil fixation and wind erosion it can be considered a success. However, *E. camaldulensis* is known to have a negative influence on soil properties. It was found to reduce microorganism activity and to inhibit germination and growth of understory plants through phytotoxic effects (Souto et al., 2001). This could undoubtedly be recognized in the field as herb cover was not present and even where the soil was not covered by litter, no plants (including regeneration of *E. camaldulensis*) were found. The fact that *E. camaldulensis* is known to be invasive is highly problematic and the impacts are perceptible for the local farmers who find *E. camaldulensis* growing within their vegetable fields. As for the Filao plantation, the renewal of *Eucalyptus* plantations will be necessary at some point. The harvesting method of the senescent *E. camaldulensis* trees will play an important part in the conservation of nutrients in the system. Harmand et al. (2004) showed, that when stems of *E. camaldulensis* were debarked before harvest, the loss of nutrients could be considerably reduced, especially for Ca and Mg.

Although people in the area generally seem to esteem the importance of the mitigating effect of *E. camaldulensis* on wind erosion, the illegal exploitation of the plantations is common. The undulating terrain consisting of sand dunes makes it especially hard to control. The local forestry extension agent who has the mandate to protect the plantations does not even dispose of a vehicle and the specificities and size of the area make it even less probable that a single person could fulfill this task. The employees of the forestry extension service, which is part of the governmental "Ministère de l'Environnement, de la Protection de la nature, des Bassins de rétention et des Lacs artificiels", are underpaid and their impact on promoting sustainable resource use or protecting resources from illegal exploitation is therefore restricted. In Mali the technical services have been described as unmotivated and as not having a good relation with the rural communities (Cuny, 2001). If this is also the case in Senegal would need to be investigated.

4.2.1.3. SLM technologies in Mabouye Niayes and Khonkh Yoye

Characteristics of Mabouye Niayes and Khonkh Yoye

While the foundation of the village of Khonkh Yoye has a history similar to that of Lompoul-sur-Mer (see p. 88), the village of Mabouye was only created in 1959 by Wolof people. In this zone horticulture is only practiced in depressions, whereas the rest of the land is reserved for pastoralism (CSE, 2009b).

SLM technology 1: Agroforestry (mainly with *Neocarya macrophylla* and *Faidherbia albida*)

Key characteristics

Many of the vegetable farming plots around the villages of Mabouye Niayes and Khonkh Yoye fall into the category of agroforestry. Trees are being maintained in the fields and the natural regeneration is protected because of a widespread knowledge that cutting trees is harmful to the environment. The most common tree species to the system is *N. macrophylla* followed by *F. albida* (see *Figure 27*). The rest of the species mainly belong to the Sudano-Guinean or Guinean ecozone but due to the special climatic conditions naturally occur as relict species in the Niayes. Fields under agroforestry, cultivated by different land users, show differences in species composition.

Figure 27. Two fields under agroforestry, with *F. albida* (left) and with *N. macrophylla* (right) in Lompoul, (northern littoral of Senegal)

Some of the trees are exploited for their edible fruits or for medical purposes. After two years of continuous cultivation the fields are left fallow for one year before they are cultivated again. Vegetables are grown in the dry season and are mainly aimed at commercialization. The most important vegetables are cabbage (*Brassica oleracea),* green bean (*Phaseolus vulgaris*), tomato (*Solanum lycopersicum*) and onion (*Allium cepa*). Additionally, jaxatu or African eggplant (*Solanum aethiopicum*), eggplant (*Solanum melongena*), chili (*Capsicum sp.*) and watermelon (*Citrullus lanatus*) are cultivated. Carrot (*Daucus carota)* is exclusively cultivated in the "ndiouki", depressions between wandering or yellow dunes. Two types of inorganic fertilizer together with organic poultry manure are used in the beginning of the dry season to improve soil fertility. A characteristic of these small exploitations is that the land owners often rent small lots to national or foreign migrants (mainly from the Republic of Guinea). They have a contract of sharing all benefits that arise from selling the grown vegetables or other products after the charges have been deduced (Touré Fall & Salam Fall, 2001).

Technology origin and objectives

Only one of the land users cultivating one of the five fields investigated during the LADA assessement could be personally interviewed. Information in this and the next subchapter therefore relates to this example of the technology only (for detailed information on this plot see Appendix 5, p. 153).

This field of 0.86 ha has been cultivated by the interviewed land user for the last eight years. He and his siblings were taught by their father not to cut any tree when preparing the land for cultivation. As the land user does not want to object his father's opinion, the real objective of the technology therefore is to follow the family tradition. The advantages that come with preserving the trees in the fields were a consequence.

Benefits, disadvantages and constraints

The land user seemed to be generally pleased with this agroforestry system as he listed a number of advantages but rarely any disadvantages. The advantages he mentioned included the provision of shade in the fields which is a very convenient feature during breaks from work and the production of fruits for the market, for self-consumption (*N. macrophylla*) or for animal fodder (*P. africana*). The land user further stated that the trees have a slightly positive effect on the growth of vegetables.

The only disadvantage that came to the land user's mind was that the trees reduce the size of the cultivable area but as the density is rather low, this does not have a large impact on the vegetable production. See *Table 47* for the presentation of the benefits and disadvantages of this SLM technology.

A constraint for vegetable farming in this field, however, is the decline of the groundwater level due to the overexploitation of this water source. Water is needed for the irrigation of vegetables which are grown during the dry season and it is usually of good quality. Phytosanitary problems with crickets and caterpillars which are feeding on vegetables as well as with parasites of *N. macrophylla* are another concern of the land user.

Table 47. Benefits and disadvantages of the SLM technology "agroforestry" according to the WOCAT criteria, Lompoul, (northern littoral of Senegal)

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased product diversification	medium	Increased demand for irrigation water	medium
	Increased farm income	medium	Decreased production area	little
	Diversification of income sources	little	Hindered farm operations	little
	Increased crop yield	little		
Socio-cultural	Improved food security / self-sufficiency	little		
Ecological	Increased plant diversity	medium	Increased competition for water, sunlight and nutrients (between trees and crops)	medium
	Increased biomass	little		
	Improved carbon storage	little		
	Increased soil organic matter (from the application of manure)	little		
	Increased soil moisture	little		

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
	Reduced evaporation	little		
	Reduced soil loss	little		
	Increased soil cover	little		
Others	Provision of shade in the fields	medium		

Biophysical characteristics

Well drained, sandy, tropical ferruginous soils dominate this agroforestry system. In Senegal these soils are called "dior" and constitute almost 70% of the Niayes region. Although they are generally poor in humus and organic matter they have been under exploitation by rainfed agriculture for a long time (Touré Fall & Salam Fall, 2001). The amount of "active" soil organic carbon ranged from 0.06 to 0.65 g C / kg soil at different measurement sites (CSE, 2009b).

The canopy cover in these agroforestry systems was very low (see *Table 48*). Only few trees were dead or showed any damage caused by humans. The trees were not very high and mostly had shrubby growth forms typical for a semi-arid savanna area. The regeneration of trees was not very common and absent for most of the species present as mature trees.

Table 48. Characteristics of vegetation at the SLM site "agroforestry" in Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	3 [1.1]
Tree height (m)	6 [0.8]
Tree DBH (cm)	27 [4.7]
Percent trees damaged	4 [3.2]
Percent dead trees	3 [2.4]
Herb cover (%)	0
Number of trees ha^{-1}	25 [9.2]
Number of regenerating trees ha^{-1}	7 [4.4]
Shannon diversity index	1.31 [0.1]

[1] Standard errors are given in parenthesis. Sample size was n=5.

Seventeen (17) different tree species (including regeneration) were found in the five agroforestry plots (see *Table 49*). The main species were *N. macrophylla* and *F. albida* followed by *C. procera* and *C. nucifera*. All other species were mostly present with only few individuals in one out of the five plots. *J. chevalieri* and *M. senegalensis* were present as regenerating only. Some of the species belong to the Sudanian or Guinean ecozone as this has been a special feature of natural vegetation in the interdunal depressions of the Niayes. Examples are *C. nucifera*, *E. guineensis* (Sudano-Guinean to Guinean forests and savannas), *A. occidentale* (Sudanese to Guinean savannas), *F. gnaphalocarpa* (Sahelo-Sudanese to Sudano-Guinean savannas), *Z. zanthoxyloides* (Guinean and Sudanese savannas), *D. guineense* (Guinean to Sudano-Guinean fringing forest) and *M. senegalensis* (Guinean and Sudanese savannas) (Arbonnier, 2004).

Table 49. Origin (ind: indigenous, ex: exotic) and density per ha of mature trees and regeneration at the SLM site "agroforestry", Lompoul, (northern littoral of Senegal)[1]

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Neocarya macrophylla	ind	7.6 [4.7]	0
Faidherbia albida	ind	5.0 [4.0]	0
Calotropis procera	ind	2.9 [1.2]	4.3 [3.9]
Cocos nucifera	ex	2.5 [1.8]	0
Elaeis guineensis	ind	1.5 [1.1]	0
Acacia raddiana	ex	1.2 [1.2]	0.1 [0.1]
Anacardium occidentale	ex	0.9 [0.9]	0
Mangifera indica	ex	0.8 [0.8]	0
Azadirachta indica	ex	0.7 [0.5]	0
Ficus gnaphalocarpa	ind	0.6 [0.5]	0
Zanthoxylum zanthoxyloides	ind	0.5 [0.5]	0
Sclerocarya birrea	ind	0.3 [0.3]	0
Dialium guineense	ind	0.3 [0.3]	0
Prosopis africana	ind	0.3 [0.3]	0
Adansonia digitata	ind	0.3 [0.3]	0
Jatropha chevalieri	ex	0	0.3 [0.3]
Maytenus senegalensis	ind	0	2.7 [2.7]
Total		**25.3 [9.2]**	**7.4 [4.4]**

[1] Standard errors are given in parenthesis. Sample size was n=5.

Evaluation and Outlook

Although the tree density in the five agroforestry systems that were investigated was highly variable and on average rather low (ranging from minimum 6 to maximum 54 trees per ha), the technology helps to maintain a number of different species, especially of the Sudano-Guinean and Guinean ecozone in the Niayes. However, those species mostly occur as single individuals and regeneration is absent. In order to preserve those species which once formed the natural vegetation in the Niayes, a region that is located in the Sahelian sector but in which climatic peculiarities led to a unique ecosystem that could else only be found 500 km further south, concerted actions should be undertaken with the help of the local forestry extension agents. Selected tree species could be raised in tree nurseries and then introduced into farmers fields. It is not clear, if farmers would be willing to undertake such actions, especially if the tree species cannot be exploited for at least some products as their willingness to protect trees concentrates on trees that are already present or grow naturally in their fields. In general, the habit to protect trees in the fields is widespread but not all land users give the same importance to this family tradition. *F. albida* is the second most common tree in agroforestry in Lompoul. Positive effects of crop growth could further be improved if more individuals of this species would be planted. About 20 adult trees of *F. albida* per ha cause high yield for millet and more than 1,500 kg of pods for feeding cattle and small ruminants (Advisory Committee on the Sahel Board on Science and Technology, 1984). Farmers in this region are generally sensitized to the importance of trees for the environment as they are all well aware that they owe their existence in the Niayes to the Filao (*C. equisetifolia*) that was used to fix the wandering dunes (see "Dune fixation with *C. equisetifolia*" p. 89). But many people are also aware that *C. equisetifolia* is not an indigenous tree species. They could therefore be the right people to develop and improve agroforesty in the region.

SLM technology 2: Composting with litter of *Casuarina equisetifolia*

Key characteristics

For this composting technology a hole is dug in the soil and filled with layers of Filao litter, cattle dung and inorganic fertilizer. The following amounts of ingredients are needed: 4.5 times the load of a donkey kart for litter and dung each and 50 kg of fertilizer. According to the land user fertilizer is added to reduce the risk of nematodes slowing down the decomposition process. During one month, the mixture has to be stirred and watered every day.

Origin of technology

The land user who was interviewed about this technology during the LADA local assessment in Khonkh Yoye, explained that he learnt about composting from friends who practice horticulture around Dakar about 10 years ago. Later he tried to divulge his knowledge among land users in Khonkh Yoye and some people took up the technology.

Advantages and disadvantages

The main advantage of this technology is the increase of organic matter in horticulture fields. Filao litter is abundant in the area and can be obtained for free. However, the transport of litter from the plantations to the agricultural fields is time consuming in the case of Khonkh Yoye as the village is at some kilometers distance from the plantations. In addition, cattle feces have to be bought and transported as well. Costs are relatively high: the required amount of cattle dung costs about 90,000 FCFA (=186.50 USD) and the fertilizer 12,500 FCFA (=25.90 USD).

Table 50 shows the benefits and disadvantages connected to this SLM technology.

Table 50. Benefits and disadvantages of the SLM technology “composting with litter of *C. equisetifolia*” according to the WOCAT criterias, Lompoul, (northern littoral of Senegal)

	Benefits		**Disadvantages**	
	Type	Degree	Type	Degree
Production and socio-economy	Increased crop yield	medium	Increased labour constraints (litter collection, composting)	medium
	Reduced expenses on agricultural inputs (compared to the use of only inorganic fertilizers)	little	Increased input constraints (manure, inorganic fertilizers)	medium
			Increased demand for irrigation water (the compost needs to be watered every day)	medium
Ecological	Increased soil organic matter	medium		
	Increase in soil fertility	medium		

Evaluation

At the moment this composting technique is not being applied by the population of Khonkh Yoye because the effort is perceived as too big. The interviewed land user, however, emphasized that the compost was improving soil conditions and that for him it was only due to his high age that he was not taking the effort anymore. In order to render the technology more attractive, the need for large amounts of expensive cattle dung would need to be reduced. Ramial chippe wood from *C. equisetifolia* would be another possibility to increase soil fertility in this area (Seck & Lo, 1998), as according to the new management plan for the Filao plantations, senescent trees can be exploited by the population (Seck & Lo, 1998).

4.2.2. Results from vegetation assessment in the GAA of Lompoul

4.2.2.1. Mature woody species

Species composition

In 26 plots covering a total area of about 6.3 ha in the GAA of Lompoul (see *Table 5*), 24 woody species were encountered. The total number of trees encountered was 771. Nine (9) of the 24 species were not belonging to the Sahelo-Sudanian or Guinean ecozone and therefore nominated exotic, whereas the rest were indigenous species. Except of *C. equisetifolia*, all of the found species were listed by Arbonnier (2004). As is typical for the coastal region of the Niayes, some species belonged to the Sudanian or even Guinean ecozone. Typical species of the Guinean zone for example are *E. guineensis, D. guineense* or *N. macrophylla.*

Table 51 presents plant densities for all woody species found in Lompoul. Twenty two (22) species were present at SLM sites. The two most abundant species at SLM sites were the exotic species used in plantations: *C. equisetifolia* and *E. camaldulensis.* About 10% of tree species at SLM sites had densities of more than 100 individuals per ha. Fifeteen (15)% of tree species had more than 10 individuals per ha and the remaining 75% had low densities of less than five individuals per ha.

CLM sites harbored only four species of which two, *M. senegalensis* and *C. africana*, were not present at SLM sites. The most abundant species at CLM sites, *A. raddiana,* had a density of about 50 individuals per ha whereas the other 3 species were rare.

Table 51. All woody species with a DBH ≥ 2 cm found at sustainable and conventional land management sites and ranked by mean density in Lompoul, (northern littoral of Senegal)[1]

	SLM[2]		**CLM**[3]	
Rank	Species	Mean density (no. ind. ha^{-1})	Species	Mean density (no. ind. ha^{-1})
1	*Casuarina equisetifolia*	122.3 [42.3]	*Acacia raddiana*	53.1 [17.4]
2	*Eucalyptus camaldulensis*	119.0 [50.2]	*Faidherbia albida*	5.3 [5.3]
3	*Mangifera indica*	29.5 [21.6]	*Maytenus senegalensis*	2.7 [2.7]
4	*Acacia raddiana*	16.2 [9.7]	*Commiphora africana*	2.7 [2.7]
5	*Citrus limon*	15.5 [8.8]		
6	*Neocarya macrophylla*	3.0 [1.4]		
7	*Prosopis juliflora*	1.8 [1.4]		
8	*Cocos nucifera*	1.4 [0.9]		
9	*Faidherbia albida*	1.1 [0.9]		
10	*Azadirachta indica*	0.7 [0.5]		
11	*Balanites aegyptiaca*	0.7 [0.7]		
12	*Ziziphus mauritiana*	0.6 [0.5]		
13	*Calotropis procera*	0.6 [0.3]		
14	*Tamarindus indica*	0.4 [0.4]		
15	*Elaeis guineensis*	0.3 [0.2]		
16	*Adansonia digitata*	0.3 [0.3]		
17	*Anacardium occidentale*	0.2 [0.2]		
18	*Ficus gnaphalocarpa*	0.1 [0.1]		
19	*Zanthoxylum zanthoxyloides*	0.1 [0.1]		
20	*Sclerocarya birrea*	0.1 [0.1]		
21	*Dialium guineense*	0.1 [0.1]		
22	*Prosopis africana*	0.1 [0.1]		

[1] Standard errors are given in parenthesis.
[2] Sample size n=23
[3] Sample size n=3

Tree density, species richness and diversity

The Mann-Whitney U test did not show a significant difference between species richness, diversity and tree density at SLM and CLM sites. For species richness and diversity this was due to the plantation technologies, "dune fixation" and "*Eucalyptus* plantation" which were almost monospecific. When these technologies were excluded from the analysis, the Mann-Whitney U test showed significance between SLM and CLM for species richness and diversity ($p < 0.05$). Although the average tree density per plot was about five times higher at SLM than CLM sites, this difference was not significant as it ranged between 6 and 700 individuals per plot (see *Table 52*). Rényi diversity profiles, however, suggested, that sites under SLM had higher tree diversity than sites under CLM, as the curve for SLM did not intersect with the curve for CLM (see *Figure 28*; for details about the computation of Rényi diversity profiles see chapter 3.3.5.1., p. 28).

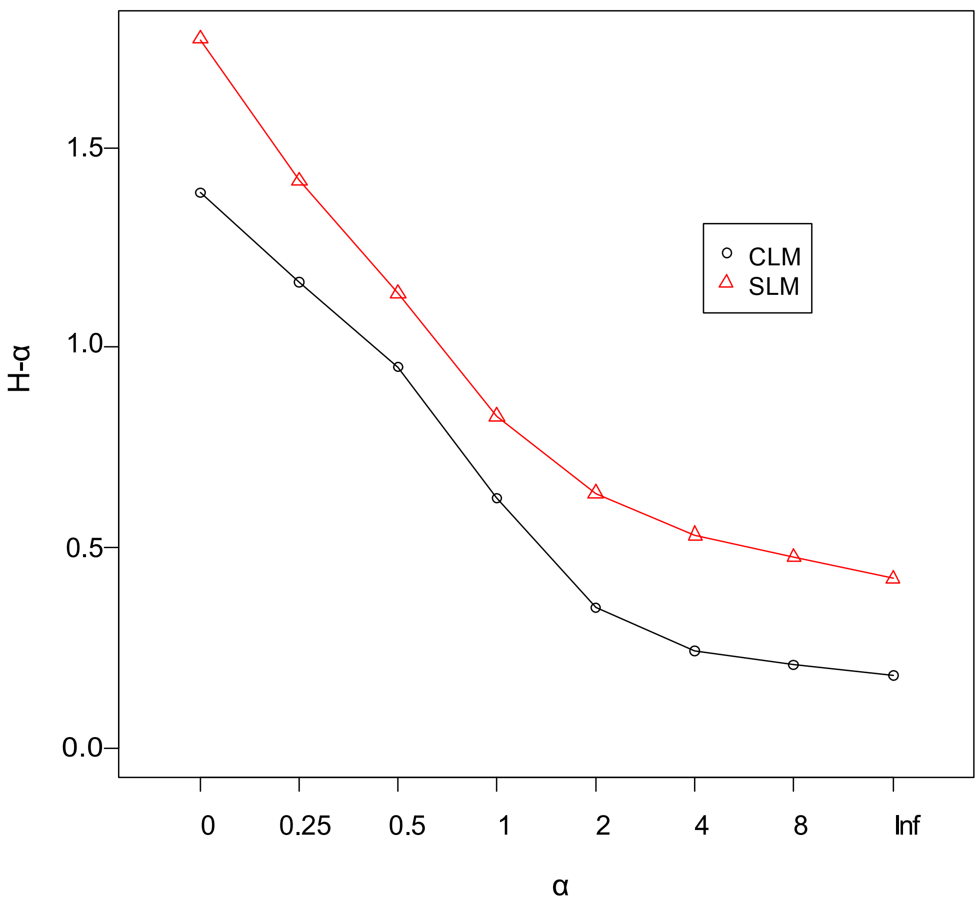


Figure 28. Rényi diversity profiles for SLM and CLM in Lompoul, (northern littoral of Senegal)

Figure 29 presents species accumulation curves for the sampling of tree species in plots under SLM and CLM. The sample size for CLM was very small with only three plots and the curve shows that more samples would have been required in order to get an overview of the tree species present at this land management system. However, the angle of the curve for CLM is less steep than the one for SLM which indicates that even with a larger sample size for CLM the trend for lower species richness than at sites under SLM would probably have remained.

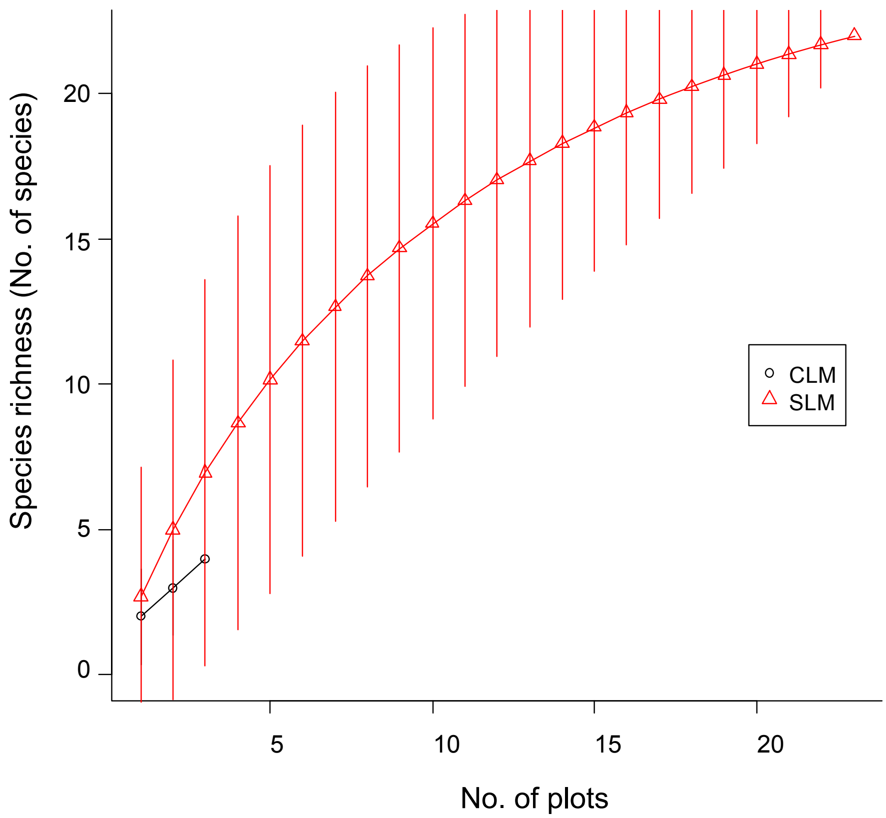


Figure 29. Species accumulation curves for SLM and CLM plotting species richness against accumulated number of plots sampled, Lompoul, Senegal; the bars indicate +2 and -2 standard deviations

Table 52 presents species richness, diversity and tree density at sites of SLM and CLM. Total number of species means the number of different tree species found under SLM or CLM, taking all plots together, whereas the mean species richness is the average of species richness in each plot under the respective land management.

Table 52. Total number of species, mean species number per plot, Shannon diversity index H´ and tree density per ha for trees and shrubs DBH ≥ 2 cm at sites under sustainable and conventional LM in Lompoul, (northern littoral of Senegal)[3]

	n	total no. spp.	**Species richness (No. spp. / plot)** range	mean	H´[2]	**Tree density (No. ind. ha^{-1})** range	mean
SLM sites	23	22	1-8	2.7 [0.5]	0.48 [0.1]	6-700	314.2 [50.5]
CLM sites	3	4	1-3	2 [0.6]	0.41 [0.2]	32-104	63.7 [21.1]
Sign.				**ns**	**ns**		**ns**

[1] Standard errors are given in parenthesis. n=no. of samples.
[2] H´= -∑ p_i ln p_i where p_i is the proportion of individuals of species i in the community (Magurran, 1988)

The analysis of the different SLM technologies led to a more detailed picture (see *Figure 30*). Species richness, diversity and tree density varied a lot between different SLM sites as the plantation technologies “dune fixation” and “*Eucalyptus* plantation” had high tree densities but low species richness whereas for “agroforestry”, the opposite was the case.

“Fruit orchard” and “agroforestry” were the most species rich land management types while “dune fixation” and “*Eucalyptus* plantation” had the lowest number of species. The Mann-Whitney U test showed that species richness and diversity were significantly higher at the SLM technology sites of “agroforestry” and “fruit orchard” than at the CLM site of “pasture” ($p < 0.05$). A comparison of the different SLM technologies to each other showed that furthermore, “agroforestry” and “fruit orchard” had significantly higher species richness than “dune fixation” and “*Eucalyptus* plantation”.

For differences between land use types regarding the Shannon diversity index, the same pattern as for species richness (see *Figure 30*) was found.

Regarding tree density, the results looked different (see *Figure 30*). Tree density was highest at the land use type of “*Eucalyptus* plantation”, followed by “fruit orchard” and “dune fixation”, while “agroforestry” was the land use type with the lowest number of trees. “*Eucalyptus* plantation”, “fruit orchard” and “dune fixation” had significantly higher tree density than the CLM of “pasture” and the SLM of “agroforestry” ($p < 0.05$).

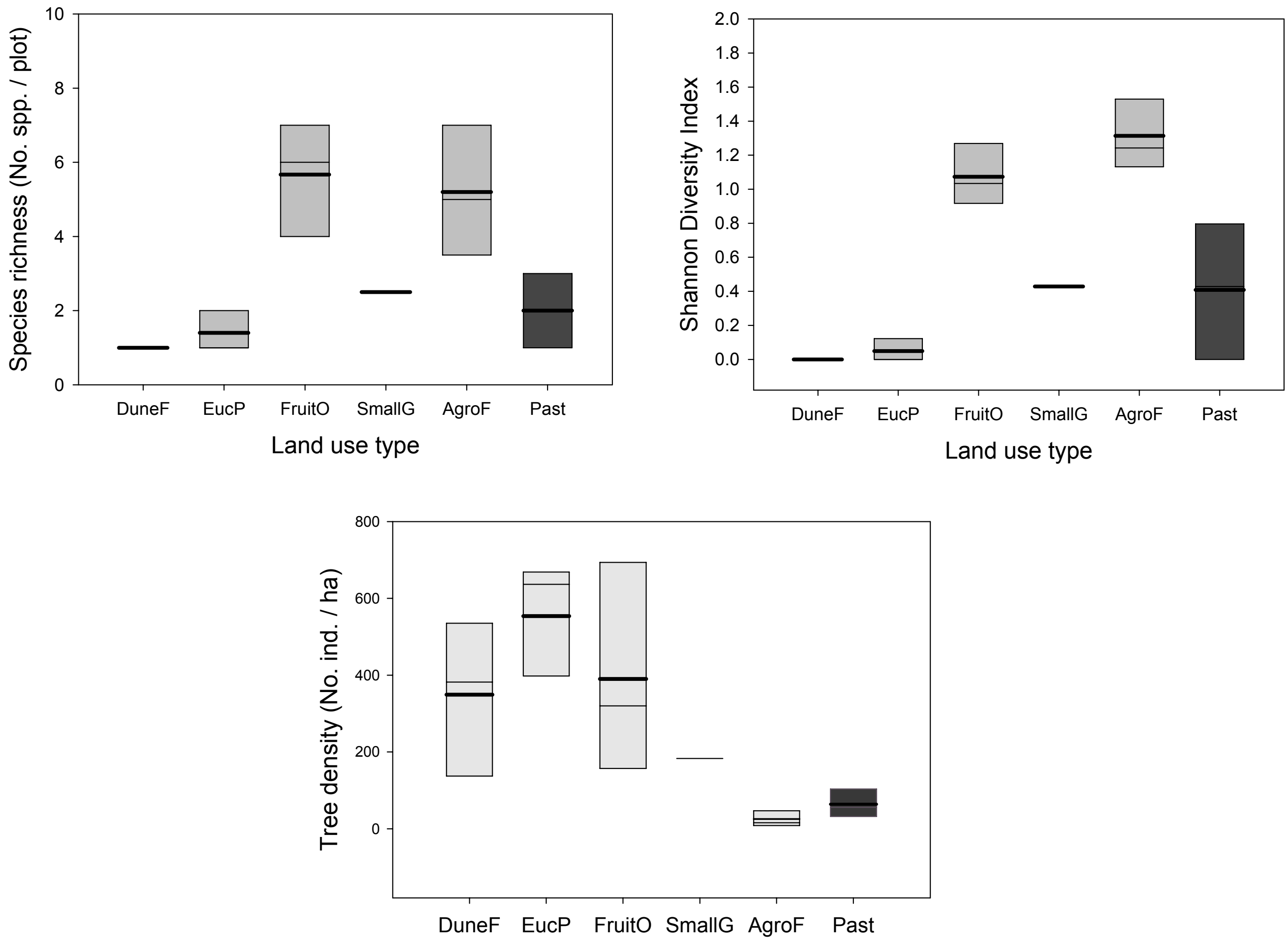


Figure 30. Species richness, Shannon diversity index and density of woody species at five sustainable (light gray) and one conventional (dark grey) land use type(s); the thick line represents the mean, the thin line the median

Canopy cover, herbaceous cover, tree damages and mortality

No significant difference was found between SLM and CLM regarding canopy cover, human induced damage and tree mortality. Herbaceous cover was significantly higher at the CLM site of “pasture” than at SLM sites ($p < 0.05$). For canopy cover, the only statement that can be made, is that the two SLM technologies of planted forests “dune fixation” and “*Eucalyptus* plantation” had significantly higher canopy cover than the SLM technology of “agroforestry” ($p < 0.05$). Furthermore, a trend to higher woody cover at the CLM of “pasture” and “small grove” than at “agroforestry” or “fruit orchard” could be observed. *Figure 31* shows the woody canopy cover (left) and the herbaceous cover (right) at different SLM and CLM sites.

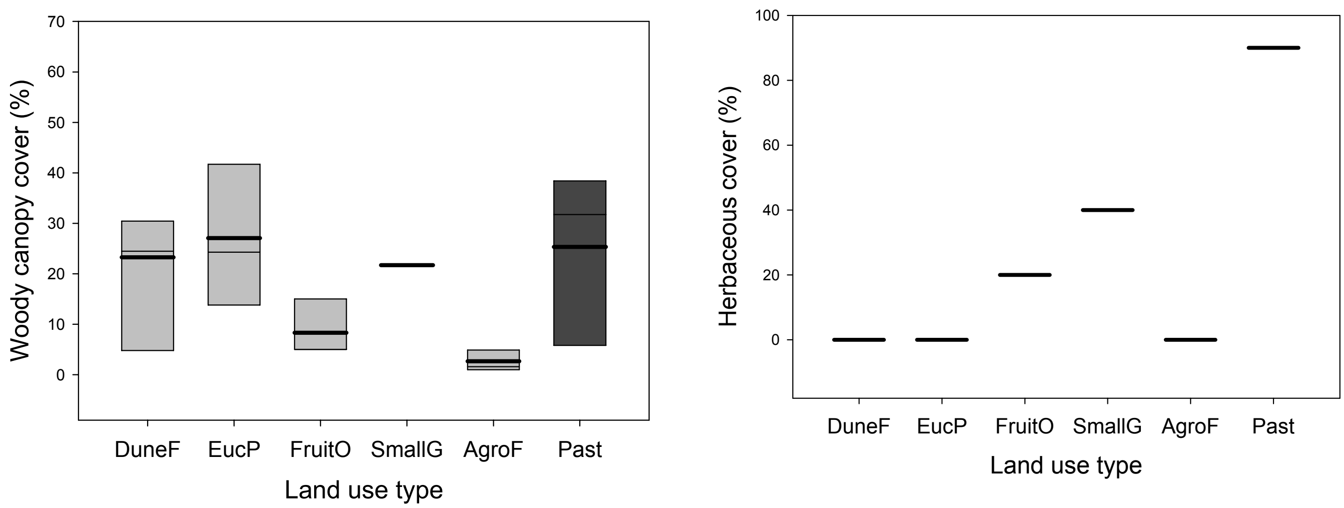


Figure 31. Woody canopy cover at sites under five sustainable (light grey) and one conventional (dark grey) land management type(s), Lompoul, (northern littoral of Senegal); the thick line represents the mean, the thin line the median

The percentage of damage on trees was significantly higher at the fruit orchard than at all other sites ($p < 0.05$), except for “dune fixation”. Dead trees only occurred at the sites of “agroforestry”, “dune fixation” and “fruit orchard”.

Table 53 presents the percentages of damaged and dead trees at the different land use types in Lompoul.

Table 53. Percentage of damaged and dead trees of all trees encountered at different sites under sustainable and conventional land use in Lompoul (northern littoral of Senegal)[1]

		n	Damages (%)	Dead (%)
SLM	Dune fixation	8	5 [0.1][ac]	4 [1]
	Fruit orchard	3	38 [10][a]	1 [1]
	Eucalyptus plantation	5	11 [5][bc]	0
	Agroforestry	5	4 [3][bc]	3 [2]
	Small grove	2	0[bc]	0
	SLM total	**23**	**10 [3]**	**2 [1]**
CLM	Pasture	3	0[bc]	0
	CLM total	**3**	**0**	**0**
	Sign.[2]		**ns**	**ns**

[1] Standard errors are given in parenthesis. n=no. of samples.
[2] The last row indicates significance between total values of SLM and CLM. Within columns different superscripts indicate significance between land use types.

Tree height and diameter at breast height (DBH)

Figure 32 presents DBH and tree height at different sites of SLM and CLM. The tree height was significantly higher at SLM than at CLM sites ($p < 0.05$). This difference was mainly due to “dune fixation” which had significantly higher trees than “pasture” ($p < 0.05$). No significant difference was found for DBH between SLM and CLM. The SLM technology of “agroforestry” however had significantly higher DBH than all other SLM and CLM systems ($p < 0.05$).

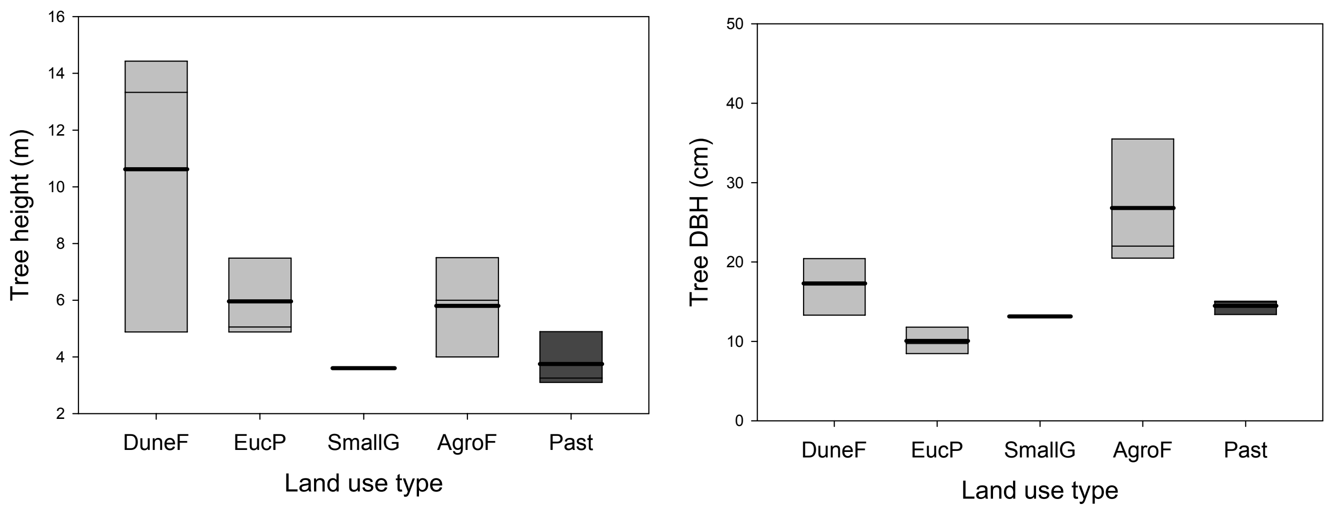


Figure 32. Tree height and DBH at sites under five sustainable and one conventional land management type(s), Lompoul, (northern littoral of Senegal); the thick line represents the mean, the thin line the median

4.2.2.2. Regeneration of woody species

In total 6 tree species were found as regenerating in 23 plots of SLM in contrast to 22 species for mature trees. The two SLM technologies of planted forest, "dune fixation" and "*Eucalyptus* plantation", did not harbor any regeneration. No regeneration was found at sites under conventional land management. The density of all woody species found as regenerating at sites under SLM is shown in *Table 54*. The standard errors were high, as most species were only found in a single plot.

J. chevalieri and *A. senegalensis* were not found as mature trees in the assessed area. *B. aegyptiaca* was the most abundant species found as regenerating. However, it was only present at the fruit orchard. According to the local land user, it will be removed at the beginning of the dry season. *B. aegyptiaca* was the only species with abundant regeneration as all other species were present with only one or fewer individuals per ha.

The species dominating the list of mature trees at sites under SLM, *C. equisetifolia* and *E. camaldulensis*, were not found as regenerating and regeneration of *A. raddiana*, the most abundant species at sites under CLM, was very rare.

Table 54. All woody species found as regenerating[1], averaged over all plots, at sites under sustainable land management in Lompoul, (northern littoral of Senegal)[2]

Species	**Mean density (no. ha^{-1})**
Balanites aegyptiaca	122 [69.5]
Jatropha chevalieri	1.4 [1.4]
Calotropis procera	0.9 [0.9]
Maytenus senegalensis	0.6 [0.6]
Annona senegalensis	0.3 [0.3]
Acacia raddiana	0.04 [0.04]

[1] DBH < 2 cm
[2] Standard errors are given in parenthesis.

No significant difference was found between density, species richness and diversity of regenerating trees at SLM and CLM sites.

Figure 33 shows the density of regeneration at the different land use types. The highest density was found at the fruit orchard with its abundance of *B. aegyptiaca*. The species richness at the three sites that harbored regeneration was between one and two.

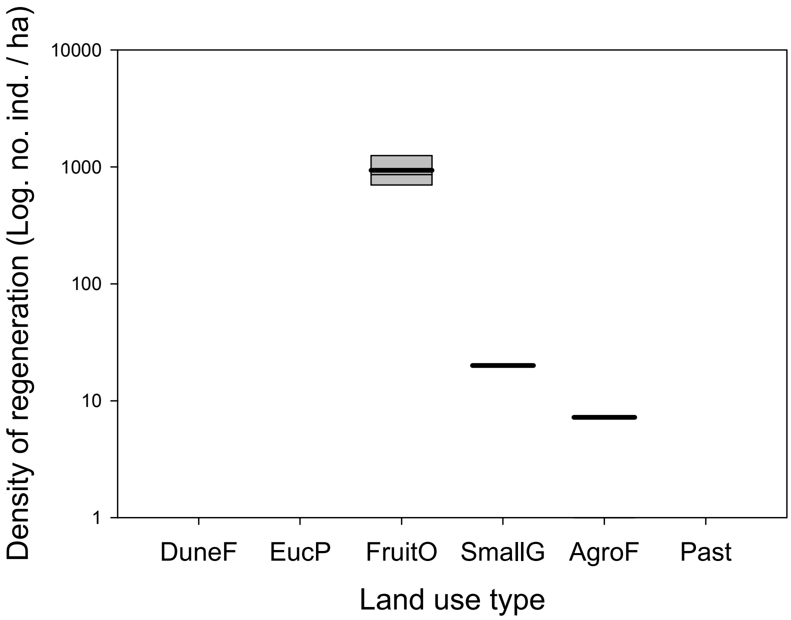


Figure 33. Density of tree regeneration (DBH < 2 cm) at five sustainable and one conventional land use type(s) in Lompoul, (northern littoral of Senegal); the thick line represents the mean, the thin line the median

4.2.2.3. Distribution of species into diameter classes

An analysis of diameter classes was made for the sites of “agroforestry”, “small grove” and “pasture”. The plantation sites “dune fixation” and “*Eucalyptus* plantation” were not considered, as all trees at these sites were planted at the same time and no natural regeneration was present. The DBH was not measured at the fruit orchard because of the large stand size and difficulties with the accessibility of species in the hedge.

Table 55 presents all trees encountered at the mentioned sites and their distribution into different diameter classes. For detailed information on the distribution of trees into diameter classes at each of the analyzed land use systems, see Appendix 6, p. 154.

Table 55. Tree species found at the SLM sites “agroforestry” and “small grove” and the CLM site “extensive pasture” and number of individuals per ha in six different diameter classes, Lompoul, (northern littoral of Senegal)

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Acacia raddiana	0.2	3.1	6.6	0.6	0	0
Adansonia digitata	0	0	0	0	0	0.2
Anacardium occidentale	0	0	0	0.2	0.2	0
Annona senegalensis	0.2	0	0	0	0	0
Azadirachta indica	0	0	0	0.2	0	0

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Balanites aegyptiaca	0	0	0.2	0.2	0	0
Calotropis procera	5.0	1.6	0.8	0	0	0
Cocos nucifera	0	0	0	1.3	0	0
Commiphora africana	0	0.2	0	0	0	0
Dialium guineense	0	0	0	0.2	0	0
Elaeis guineensis	0	0	0	0.5	1.0	0
Faidherbia albida	0	0	0.8	1.1	0.3	0
Ficus gnaphalocarpa	0	0	0	0.3	0	0
Jatropha chevalieri	0.8	0	0	0	0	0
Mangifera indica	0	0	0	0.5	0	0
Maytenus senegalensis	1.5	0.2	0	0	0	0
Neocarya macrophylla	0	0	0.6	3.7	0	0
Prosopis africana	0	0	0	0.2	0	0
Sclerocarya birrea	0	0	0.2	0	0	0
Zanthoxylum zanthoxyloides	0	0.2	0	0	0	0
Total	**7.7**	**5.3**	**9.2**	**9.0**	**1.5**	**0.2**

The majority of species (14 species) had trees in the intermediate diameter classes (10-19.9, 20-43.9 cm), whereas only six species had individuals in the small diameter classes (<2, 2-9.9 cm). Only *A. digitata* had a tree in the largest diameter class (> 80 cm). About 57% of all encountered trees had a DBH between 10 and 40 cm and about 38% had a diameter lower than 10 cm. The individuals in the smallest diameter class almost exclusively belonged to *C. procera*.

4.2.2.4. Tree species used by the local population

All encountered tree species could be attributed to one or several use categories. *Table 56* shows the tree species and their different uses.

Table 56. List of all plants used by the local population, distributed into the categories of food, firewood, construction and fodder in Lompoul, (northern littoral of Senegal)

	Species	Food	Firewood	Construction	Fodder
1	*Acacia raddiana*	x[a)]	x[e), a)]	x[a)]	x[a)]
2	*Adansonia digitata*	x[e), a)]			x[a)]
3	*Anacardium occidentale*	x[b), a)]	x[a)]		x[a)]
4	*Azadirachta indica*		x[e)]		

	Species	Food	Firewood	Construction	Fodder
5	*Balanites aegyptiaca*	x[a]	x[e, a]	x[e, a]	x[a]
6	*Calotropis procera*		x[a]	x[e]	x[a]
7	*Casuarina equisetifolia*		x[c]	x[c]	
8	*Citrus limon*	x[b]			
9	*Cocos nucifera*	x[a]			
10	*Commiphora africana*	x[a]			x[a]
11	*Dialium guineense*	x[a]	x[a]	x[a]	x[a]
12	*Elaeis guineensis*	x[a]		x[f, a]	
13	*Eucalyptus camaldulensis*		x[a]	x[a]	
14	*Faidherbia albida*				x[f]
15	*Ficus gnaphalocarpa*	x[a]	x[a]	x[a]	x[f], x[a]
16	*Mangifera indica*	x[b]		x[a]	x[a]
17	*Maytenus senegalensis*	x[b], x[a]	x[a]		x[a]
18	*Neocarya macrophylla*	x[a, d]	x[a]	x[a]	x[d]
19	*Prosopis africana*		x[a]	x[f], x[b]	x[a, d]
20	*Prosopis juliflora*		x[e, a]	x[a]	x[a]
21	*Sclerocarya birrea*	x[a]	x[a]	x[e, a]	x[a]
22	*Tamarindus indica*	x[b, a]	x[a]	x[a]	x[a]
23	*Zanthoxylum zanthoxyloides*		x[a]	x[a]	
24	*Ziziphus mauritiana*	x[b]	x[e]	x[b, a]	x[a]

[a] Arbonnier (2004)
[b] Gakou et al.(1994)
[c] ICRAF (2009)
[d] CSE (2009b)
[e] Von Maydell et al.(1983)
[f] Lykke (2000)

Seventeen (17) different tree species were attributed to each of the categories of firewood and fodder and 16 species to food and construction. The species having the widest potential for use are *A. raddiana*, *B. aegyptiaca, D. guineense*, *F. gnaphalocarpa*, *N. macrophylla*, *T. indica, S. birrea* and *Z. mauritiana*.

All of the encountered species are in one way or the other used for domestic purposes such as for chewsticks, cooking utensils, tanning, soap, glue, mortars, music instruments, coagulants, ropes, perfumes, sculptures or jewellery. Therefore this use category was not included in an analysis of differences between SLM and CLM. The same applies to the category of medicine.

Table 57 gives an overview of the found species and their domestic uses.

Table 57. Woody species encountered in Lompoul and their domestic uses, Lompoul, (northern littoral of Senegal)[1]

	Species	**Use**
1	*Acacia raddiana*	ropes
2	*Adansonia digitata*	mats, ropes, sewing threads, instrument strings
3	*Anacardium occidentale*	mortars
4	*Azadirachta indica*	cosmetics, soap (from fat)
5	*Balanites aegyptiaca*	chewsticks, soap (from fat)
6	*Calotropis procera*	ropes, sewing thread, tanning
7	*Casuarina equisetifolia*	tanning
8	*Citrus limon*	chewsticks
9	*Commiphora africana*	seeds used as beads, cooking utensils, cosmetics, incense, perfume
10	*Dialium guineense*	chewsticks, cooking utensils, glue
11	*Elaeis guineense*	cosmetics
12	*Eucalyptus camaldulensis*	perfume, incense
13	*Faidherbia albida*	cooking utensils, drums, mortars, tanning
14	*Ficus gnaphalocarpa*	glue, sculptures
15	*Maytenus senegalensis*	seeds used as beads
16	*Neocarya macrophylla*	soap from fat
17	*Prosopis africana*	chewsticks, drums, mortars, sculptures, tanning
18	*Prosopis juliflora*	chewsticks, tanning
19	*Sclerocarya birrea*	chewsticks, cooking utensils, pestles, ropes, tanning
20	*Tamarindus indica*	mortars, coagulant
21	*Zanthoxylum zanthoxyloides*	seeds used as beads, chewsticks
22	*Ziziphus mauritiana*	cooking utensils, tanning

[1] source: Arbonnier (2004)

The density and richness of tree species used by the local communities did not differ between sites under SLM and CLM. However, differences were found between different SLM technologies. *Table 58* presents densities of trees used for fodder, food, construction and firewood at the different land use types.

Table 58. Density of trees DBH ≥ 2 cm in five different use-categories at sites of sustainable and conventional LM, Lompoul, (northern littoral of Senegal)[1]

		n	Tree density (No. ind. / ha) Fodder	Food	Construction	Firewood
SLM	Dune fixation	8	0[b]	0[b]	349 [70][ac]	349 [70][a]
SLM	Fruit orchard	3	240 [132][a]	370 [14][a]	12 [7][b]	38 [17][b]
SLM	*Eucalyptus* plantation	5	6 [6][b]	6 [6][b]	554 [69][a]	554 [69][a]
SLM	Agroforestry	5	20 [8][b]	17 [7][b]	5 [2][b]	15 [7][b]
SLM	Small grove	2	183 [40][ab]	183 [40][ab]	167 [40][bc]	183 [40][ab]
	SLM sites	**23**	**53 [28]**	**69 [37]**	**259 [61]**	**272 [57]**
CLM	Pasture	3	64 [21][ab]	58 [16][ab]	53 [17][b]	56 [17][b]
	CLM sites	**3**	**64 [21]**	**58 [16]**	**53 [17]**	**56 [17]**
	Sign.[2]		**ns**	**ns**	**ns**	**ns**

[1] Standard errors are given in parenthesis. n=no. of samples.
[2] The last row indicates significance between total values of SLM and CLM at a significance level of $p < 0.05$. Within columns different superscripts indicate significance between land use types.

The SLM technology “fruit orchard” harbored the highest densities of food and fodder trees. *M. indica*, the most abundant species provides fruits as food for humans and at the same time leaves browsed by small ruminants. Other food trees present were *C. limon*, *C. nucifera* and *Z. mauritiana*. However, the density of food and fodder trees at the SLM site “fruit orchard” was not significantly higher than under the CLM of “pasture”.

The SLM technologies “*Eucalyptus* plantation” and “dune fixation” harbored the highest densities of trees used as firewood. *A. raddiana*, another preferred firewood species, had its main distribution at the CLM system of “pasture” and at the SLM site of “small grove”. As trees used as firewood and for construction are often belonging to the same species because of their wood properties (Lykke et al., 2004), the highest number of individuals suitable for construction was found at the SLM sites “*Eucalyptus* plantation” and “dune fixation” as well. The density of trees used as firewood and for construction was significantly higher at these two SLM sites than at the CLM site of pasture ($p < 0.05$).

“Agroforestry” harbored low density of trees in general and therefore low densities of trees in different use categories. The SLM site “small grove” had similar densities of trees in all categories, as the dominant species, *A. raddiana*, was assigned to every category. The same can be said of the CLM “pasture”.

Looking at species richness of trees used by the local population, it was seen that “fruit orchard” also contained the highest species richness of food trees (see *Figure 34*). The species richness of food trees was significantly higher in this SLM technology than at the CLM site of “pasture”. A trend was observed for the SLM of “agroforestry” to have higher tree species richness in the categories of food, fodder and firewood than the CLM of “pasture”.

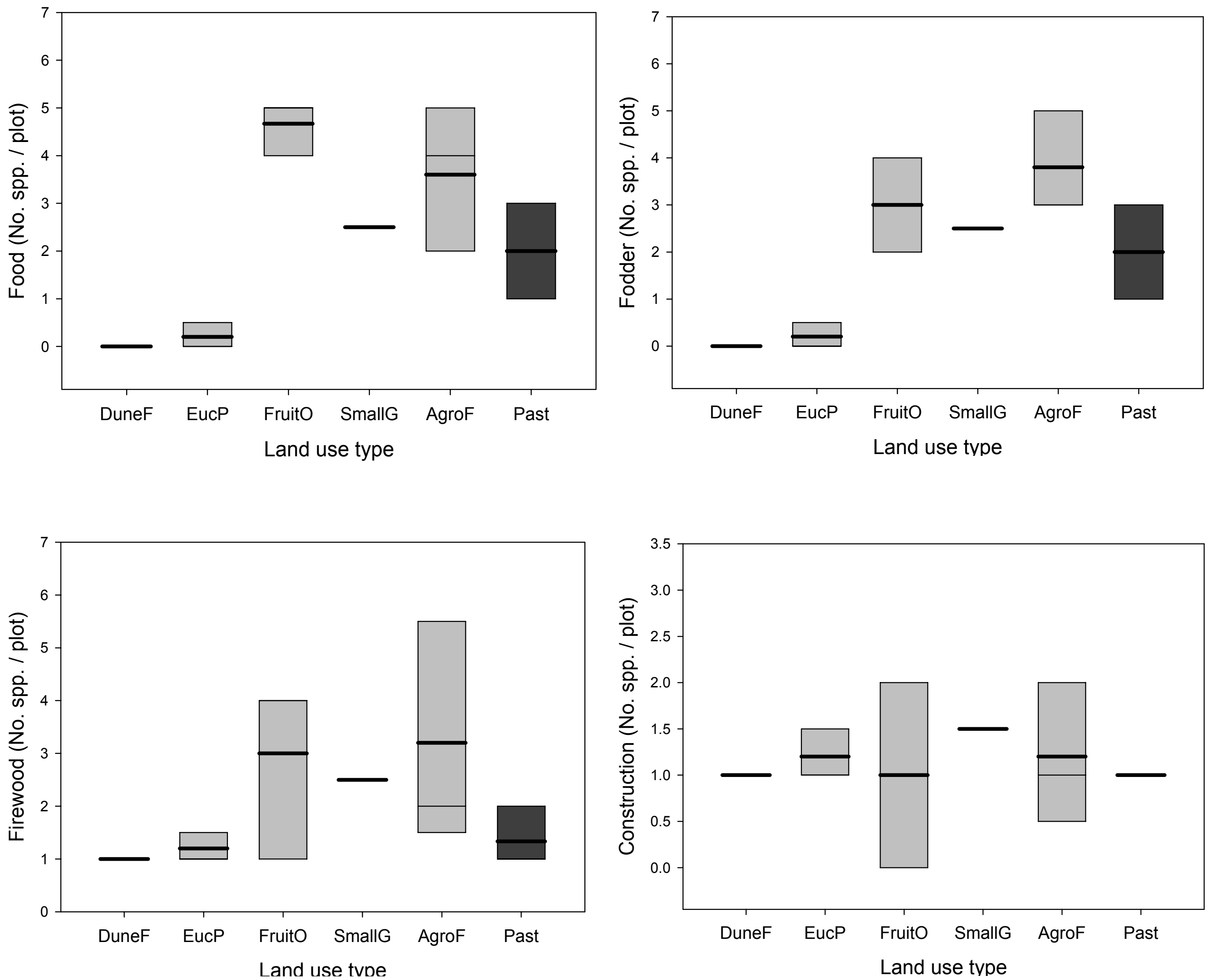


Figure 34. Species richness of trees used for food, fodder, firewood and construction at five sustainable (light grey) and one conventional (dark grey) land use type(s), Lompoul, (northern littoral of Senegal)

4.2.3. Discussion of vegetation assessment

4.2.3.1. Influence of land use type on tree density, species richness and diversity

No difference was found between SLM and CLM regarding tree species richness, diversity and density in the geographical assessment area of Lompoul. This has to do with the choice of SLM technologies for the analysis as well as with the choice of “pasture” as the CLM system. Being aware of the fact that around 1920 the sand dunes were completely denuded due to deforestation and imagining the consequences of this land degradation, any restoration of vegetation can be regarded as an improvement. However, in several cases exotic species were chosen for reforestation and planted in monospecific arrangements. The choice of the CLM system for a comparison was difficult because even horticulture without the integration of trees is seen as more sustainable than the previously bare interdunal depressions. Pastureland is a conventional land management type as no rules or regulations ensure its sustainable use. However, it might be more sustainable than the plantation technologies in the long term, as it protects the soil from wind erosion through a continuous herbaceous cover which is completely absent within sites of the mentioned plantation technologies.

In general, none of the assessed SLM technologies was very species rich, as the maximum averaged richness per plot was 5.7 (see *Table 52*, p. 112). This is less than half of the maximum species richness that was found in the case study of Barkédji (see *Table 27*, p. 65). The maximum average species richness was found in the fruit orchard. More than half of the species, including the two most common, *C. limon* and *M. indica*, were of exotic origin. The presence of tree species typical of the area is not improved through this technology, apart from *Z. mauritiana*, a preferred fruit tree of the Sahel. Since tree density in the fruit orchard was high, this SLM technology is increasing biomass and vegetation cover.

“Agroforestry” had almost equal species richness with the fruit orchard but it was slightly more diverse because of a more even distribution of tree species. Although the tree density was rather low, agroforestry is the most important land use type for the preservation of natural vegetation in Lompoul as it includes a high number of tree species of Sudano-Guinean origin, a characteristic of the Niayes region. For example *E. guineensis*, *F. gnaphalocarpa*, *Z. zanthoxyloides* and *D. guineense* were only found at the SLM site of agroforestry during this vegetation assessment. These species are only found in the humid interdunal depressions which are also the preferred places for vegetable cultivation and therefore agroforestry is probably the only way of preserving those trees in the landscape.

The small grove had low species richness and diversity as it only included the three species of *A.raddiana*, *B. aegyptiaca* and *N. macrophylla*. The latter is a relic species of the Sudano-Guinean ecozone and highly estimated in the Niayes for its fruits. Apart from the forest plantations with exotic species, this grove is one of the few dense fragments remaining of natural forest and may provide a valuable habitat for birds and insects.

The two SLM technologies of “dune fixation” and “*Eucalyptus* plantation” share many features as they both consist of monospecific plantations of an exotic tree species. These SLM technologies therefore did not have any positive impact on tree species richness or diversity but improved the vegetation cover and biomass in a large area.

The CLM system of “pasture” mainly included *A. raddiana* but also harbored some individuals of *F. albida* and other species. Although this land use type harbored only few tree species, the presence of *F. albida*, an important species for the improvement of soil properties, gives this land use type a special importance.

4.2.3.2. Canopy and herbaceous cover, height, DBH, damages and mortality of mature trees

The mean canopy cover was higher at the CLM system of “pasture” than at the SLM systems. This can be explained by low canopy cover at the SLM site of “agroforestry”, where farmers are constrained to increase canopy cover because of the crops demand for light. A well closed canopy, however, effectively protects the soil macrofauna from high temperature variation and drought stress and therefore agroforestry systems should be optimized for canopy closure (Martius et al., 2004). In the fruit orchard canopy was low because a part of the fruit trees had been pruned to stimulate growth. For the herbaceous cover the same result was found, with the highest cover at the CLM system of “pasture”. Visual estimation showed that herbaceous density was highest under the direct canopy of trees. This corresponds with the findings of Grouzis & Akpo (1997) that the herbaceous phytomass was much higher under the canopy of *A. raddiana* than in the open. Probably because of the thick litter layer, the plantations with *Casuarina* did not allow for the growth of a herbaceous cover, as was the case in an experiment with *Casuarina* in Australia (Barritt & Facelli, 2001). *Eucalyptus* trees are known to suppress the growth of ground vegetation by root competition, especially under dry conditions (Poore & Fries, 1985). At the SLM site "agroforestry" herbaceous cover was not present because it had been removed for continuous cultivation of fields.

Casuarina trees at the sites of "dune fixation" were the highest at any of the assessed land use systems in Lompoul. As the extent of the protective impacts of a windbreak is proportional to its height (FAO, 1985), this is a desired outcome of this SLM technology. Trees at the other land use systems were of lower height. DBH however was largest at the SLM system of "agroforestry". Several studies have shown that the nutrient enrichment of the soil by trees increases with tree size (Campbell et al., 1990; Isichei & Muoghalu, 1992; Rhoades, 1995). A positive relationship between tree diameter and carbon and nitrogen content in soil under *A. senegal* and *B. aegyptiaca* in northern Senegal was shown by Bernhard-Reversat (1982). Trees encountered at "agroforestry" are therefore well suited for improving soil fertility.

Damages on trees were not very common, except for the fruit orchard, in which many trees were pruned in an non-professional way and the *Eucalyptus* plantation which suffered from illegal exploitation for firewood. The woody vegetation at all assessed sites under SLM as well as CLM was in a good condition with only few dead trees.

4.2.3.3. Species used by the local population

The plantation technologies with *C. equisetifolia* ("dune fixation") and *E. camaldulensis* provide high densities of firewood and timber for construction. Favored firewood species are usually large and hard-wooded and therefore also qualify for construction purposes (Lykke et al., 2004). The wood of *C. equisetifolia* ignites easily and its ashes keep heat for long. It has therefore even been called "the best firewood in the world" (ICRAF, 2009). However, the exploitation of those trees is only allowed once the stands are senescing in order not to jeopardize the service of these plantations as dune stabilizers. As a consequence, the threat to these SLM technologies by illegal exploitation is high.

As vegetables are abundant in the Niayes region, edible fruits and leaves of trees might be less important for the diet of the local population than in the Ferlo. This might explain why major Sahelian food trees such as *Z. mauritiana* and *B. aegyptiaca* were rare in the Niayes. No specific information on wild plant use in the Niayes could be found. Therefore it is not sure if all trees assigned to the category of "food" are actually being used. However, farmers that were interviewed for the documentation of SLM technologies with WOCAT exploit food trees maintained in their fields for diverse products. More than half of all tree species encountered at the land use type of "agroforestry" provide edible fruits or leaves. The fruit orchard was similar to "agroforestry" in this respect. The land use systems of "small grove" and "pasture" provided relatively high densities of food trees, mainly of the species *A. raddiana*.

Mango trees can be browsed by small ruminants (Arbonnier, 2004), therefore the fruit orchard provides the highest density of fodder trees. *A. raddiana* is more important as a fodder tree though (ICRAF, 2009) and therefore the CLM system of "pasture" and the SLM site "small grove" play a bigger role in the provision of fodder. The low tree species diversity at these land use systems should be improved through enrichment plantings as the usefulness of fodder plants depends on the season and a broad resource base is important in the highly dynamic Sahelian ecosystems (Lykke et al., 2004).

Although the SLM of "agroforestry" only contained small densities of used trees it included the highest number of different species for the categories of firewood and food. As provision services of certain species can all of a sudden become unavailable e.g. due to pests, shifting distribution ranges because of climate change etc., a high species richness guarantees a certain security. Some of the species that were rarely or not at all present at any other site and have high use values are *D. guineense*, *F. gnaphalocarpa*, *T. indica, E. guineensis, S. birrea* and *N. macrophylla.* The promotion of these species could therefore improve the availability of a wide range of products in the region. The population of Fathala Forest on the southern coast of Senegal wished for an improved woody vegetation density with many large trees, fruit trees and Sudano-Guinean to Guinean species (Lykke, 2000), as are many of the abovementioned species. Lykke

(2000) further stated that protection of trees in fields may be important for maintaining populations of highly preferred and otherwise (due to overexploitation) declining species.

4.2.3.4. Regeneration of tree species

The regeneration of tree species in the geographical assessment area of Lompoul was very weak. As *C. equisetifolia* is known not to regenerate naturally within its own stand (Mailly et al., 1994), measures in the shape of a management plan have already been taken to assure the maintenance of the system. The same applies to the *Eucalyptus* plantations in which no regenerating trees were found either. For other systems, such as agroforestry, no management strategy has yet been developed.

At the SLM system of “agroforestry” the highest number of trees was assigned to the diameter class of 20-39.9 cm which also comprised the highest number of species. The number of trees found in the smallest diameter class was only little lower, however, consisted mainly of individuals of *C. procera* and *M. senegalensis*. Trees with a diameter between 2 and 19.9 cm were very rare. For the SLM of “small grove” most trees had a diameter between 10 and 19.9 cm and few trees were assigned to the smallest diameter class. The CLM of “pasture” showed similar distribution of trees into diameter classes with no individuals assigned to the smallest category at all. This indicates that there is a problem with rejuvenation of trees at SLM as well as CLM systems and that some measures to improve the regeneration of trees should be taken. Enrichment planting with selected high-value tree species or the protection of trees in the soil seed bank (Kindt et al., 2008) should be considered as options to assure the maintenance of vegetation cover in this region. The question of the importance of the observed infrequence of regeneration for the future presence of trees was already discussed in chapter 4.1.3.4., p. 83.

N. macrophylla was one of those species with almost 90% of the individuals having a large diameter. If this species should be conserved in Lompoul it will need special attention. The same is true for other species of the Sudano-Guinean ecozone like *D. guineense*, *A. occidentale* or *F. gnaphalocarpa*. One of the few species with a high number of regeneration was *C. procera*, a typical pioneer species in early succession stages (Becker, 1984) that is assumed to be an indicator of over-cultivation and quickly establishes as a weed along degraded roadsides or in overgrazed native pastures (ICRAF, 2009).

4.2.4. Verification of hypotheses

H1: Sites managed by the documented SLM technologies show higher woody tree density, species richness and species diversity than sites under CLM

No significant difference was found between tree density, species richness and diversity at sites under SLM and CLM. Hypothesis H1 is therefore rejected. Only sites under the SLM technologies of “agroforestry” and “fruit orchard” had significantly higher tree species richness and diversity than the CLM site of “pasture”. Tree density was significantly higher at the SLM sites of “dune fixation”, “*Eucalyptus* plantation” and “fruit orchard” than at the CLM site of “pasture”.

H2: Sites managed by the documented SLM technologies show a higher percentage of woody canopy cover than sites under CLM and therefore protect the soil from degradation

The percentage of canopy cover was not significantly higher at sites under SLM than CLM. Hypothesis H2 is therefore rejected.

H3: The number of woody individuals showing damages caused by human beings is higher at sites under CLM than under SLM

No significant difference was found regarding damages between sites under SLM and CLM. Therefore hypothesis H3 is rejected.

H4: The density and richness of species useful for the local population are higher at sites under SLM compared to sites under CLM

No significant difference was found between SLM and CLM sites regarding richness and density of species providing food, construction wood, fodder, and firewood to the local communities. Hypothesis H4 is therefore rejected.

H5: The density, species richness and species diversity of regeneration (DBH < 2 cm) are higher at sites under the documented SLM systems than at sites under CLM

No significant difference was found between the two land management systems of SLM and CLM for density, species richness and diversity of regeneration. Hypothesis H5 is therefore rejected.

5. Discussion of methodology

5.1. Documentation of SLM technologies for the WOCAT database

The choice of the SLM technologies to document in each of the geographical assessment areas (GAAs) depended on the location of transects laid through the landscape for the LADA assessment. Possible land management technologies that were located elsewhere within the GAA were not considered. Therefore the documented technologies should be regarded as a sample and not necessarily as the most sustainable technologies in the GAA.

The information about the technologies that was gained from land users was not always reliable and often biased. Despite detailed information of the concerned populations in the GAAs on the aim of the LADA assessment and the clear statement that no financial or other benefits would arise from the participation in the interviews or group excercises of the LADA project, the land users tended to make themselves look needier than they already were. This influenced the information on SLM technologies inasmuch as they tended not to provide true information on the benefits of a technology especially where financial benefits were concerned. For example, for the technology of “agroforestry with *A. senegal*” in the GAA of Barkédji, the levels of income from the commercialization of gum arabic were stated much lower than what can be expected according to the local LADA specialists. On the other hand, where employees of the forestry or agricultural extension service were interviewed, information on negative impacts or disadvantages of the technology could hardly be obtained as they wanted their efforts to appear as successful as possible.

5.2. Methods of the biophysical assessment

Analyzing the methodology used in this study it has to be kept in mind that it had to follow the methodological approach of the LADA assessment. The LADA manual describes a rapid but robust assessment methodology and this has guided the choice of methods and indicators. The aim is to provide base-line data on land degradation and sustainable land management (McDonagh & Bunning, 2009a).

The sample size for the two land management systems, sustainable and conventional, was unbalanced. As the GAA of Barkédji was chosen by the LADA assessment as a “hot spot” or example of land degradation, more plots were established at sites of CLM than SLM. For the GAA of Lompoul, a “bright spot” or example of sustainable land management practices in the LADA assessment, the opposite was the case.

The biggest constraint for data collection was time. Therefore the sample size for most of the investigated land use types was low. Plot shape and size were decided on by the forestry engineer in charge of the vegetation part of the LADA assessment and depended on the characteristics of the investigated land use type. However, species richness and diversity are variables that are influenced by the size of the sample plot and cannot be converted to a common sample plot size. Thus, the comparison of species richness and diversity in this study is only applicable by being aware of the differences in sample sizes.

The participating researchers all held specific tasks in the vegetation assessment team which were not changed during the whole period of fieldwork, if possible. The person having the longest experience with vegetation assessments in Senegal was responsible for the measurements and estimations of tree properties. In this way, the influence of potential measurement or estimation errors on the results was minimized. Only at the plantation technologies in the GAA of Lompoul the order of dividing the different tasks was changed, as the leading forestry engineer trained the participating employees from the forestry extension service in tree sampling techniques and let them execute the measurements. According to him, estimations of crown diameter were systematically too low and therefore the percentage of canopy cover at the SLM sites of “dune fixation” and “*Eucalyptus* plantation” was probably underestimated.

The timing of the fieldwork for the case study of Barkédji was unsuitable as it coincided with the beginning of the wet season. The herbaceous cover in pastures was not yet sufficiently developed to allow for species determination. As for the LADA assessment the determination of herbaceous cover was not a primary objective this was not considered at the time of planning. Due to logistical and financial constraints it was not possible to return to the field at a later time to complete the assessment of herbaceous cover.

The soil data collected for the LADA assessment may be sufficient for a rapid assessment of degradation but was of limited use for the evaluation of the impact of SLM on soil properties as no replicates of measurements were made within each technology site. The high variability in fertility among tropical soils, even within a field (Boffa, 1999), requires repeated measurements in order to get an appropriate estimation. In addition, measurements were often taken as far away from trees as possible in order to reduce the difficulties with sampling because of tree roots. This made it impossible to find differences in soil fertility due to the presence of trees.

6. Conclusion

Land degradation is a big threat in semi-arid zones and sustainable land management technologies play an important role in the prevention and mitigation of this threat as well as in the rehabilitation of already degraded land. The documented technologies in the silvopastoral zone of Barkédji and the agropastoral zone of Lompoul have in common that they are (with the exception of the plantation technologies in Lompoul) local, traditional technologies, that were developed by land users and not introduced by projects. None of them is a definite solution to the predominant processes of degradation such as wind and water erosion, decline of soil fertility or reduction of vegetation cover but they all have a positive impact on tree density, species richness and diversity or on all of these variables together compared to the state of vegetation under conventional land management. The much lower tree species richness of conventional land use systems than of land under sustainable management illustrates a consequence of land degradation. Because people in northern Senegal depend on tree species to cover a variety of needs, especially in times of famine (Gonzalez, 2001), further degradation of vegetation cover would seriously diminish the human carrying capacity of this semi-arid land. Tree species also help to mitigate desertification and climate change and the disappearance of mature trees could have negative consequences on soil quality by increasing factors such as wind erosion and decreasing soil organic matter (Gonzalez, 2001). Furthermore, in silvopastoral systems the role of trees in the diets of browsing ungulates is of great importance, especially during the dry season (Petit, 2003) and in addition, tree cover influences herbaceous vegetation in several ways, including greater species richness (Grouzis & Akpo, 1997). Irreversible modifications of soil and herbaceous vegetation could be the result of a loss of tree cover (Vincke et al., 2010). It should therefore be of great interest for the local as well as the global population to increase the present extent of sustainable land management in the region.

The results of the present study show that it is important to maintain different land use types in order to preserve the highest possible number of indigenous tree species. In general it can be said that SLM technologies often either had high tree densities with low species richness and diversity (such as in plantations in Lompoul or in the fallow part of agroforestry with *Acacia senegal* in Barkédji) or high species richness and diversity at the same time with low tree densities (as was the case for agroforestry including parkland and homegardens). The SLM technologies achieving both, high tree density as well as high species richness and diversity were those preserving natural vegetation stands. It can therefore be concluded that preserving the natural vegetation is the best way to maintain woody plant biodiversity, density and species richness in the semi-arid ecosystems of northern Senegal. Agroforestry practices on the other hand harbored single individuals of species that were once common in the natural landscape but have widely disappeared due to land degradation. Poverty is omnipresent in northern Senegal, forcing people to assure their livelihoods by cultivating the land. Agroforestry systems are therefore a compromise to preserve part of the natural vegetation while at the same time allowing for crop production and might reduce the pressure on the few remaining stands of natural vegetation.

The low density of regenerating trees compared to the density of mature trees at the majority of the investigated land use systems, sustainable as well as conventional ones, is a striking finding. It agrees with results of several studies that highlighted the decline of woody species in the Sahel (Gonzalez, 2001; Kindt et al., 2008; Lykke, 1998; Sambou et al., 2008; Wezel, 2005). The reason for the infrequence of regeneration at sustainable land management systems that have existed for a long time, such as parklands in Barkédji, is not well understood. Shifts of tree species in response to reduced rainfall and droughts, pressure from heavy livestock browsing and anthropogenic overuse of certain species probably all play a role. A study using satellite imagery, however, suggested a strong recent trend of increasing vegetation cover in the Sahel which was partially linked to an increase in rainfall (Olsson et al., 2005). As the present study only allowed for a snap-shot of seedling density at the investigated land management systems on a local scale it cannot be excluded that a general increase in vegetation cover has occurred since the last drought period. The present state of tree regeneration that was observed in Barkédji and Lompoul does not suggest an increase in tree density in the near future though. While sufficient rainfall will be necessary to facilitate tree regeneration, it strongly depends on the willingness and ability of farmers to protect trees on their fields if a degradation of the vegetation cover in these areas can be avoided. According to Reij et al. (2005), vegetation cover can be greatly improved through the application of soil and water conservation (SWC) measures by farmers: tree density on cultivated fields on the Central Plateau of Burkina Faso treated with SWC measures was much higher than before the introduction of SWC measures. Measures such as the creation of stone bunds along the contour and the protection of natural regeneration might help to maintain tree density as well as diversity in Barkédji and Lompoul. Interviewed land users of agroforestry systems in the present study emphasized the inherited knowledge on the importance of trees but also the need for training on the choice of tree species and planting techniques in order to enhance the positive impact of sustainable land management. Better assistance from the extension services to get access to appropriate planting material, tree management techniques and intercropping regimes will be indispensable for the maintenance or improvement of vegetation cover in the sylvopastoral region of the Ferlo and the agropastoral system of the Niayes.

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Where no source is indicated, pictures are by Julie Zähringer (2009)

Appendices

Appendix 1: Species lists

Appendix 2: Additional information on tree diversity parameters in Barkédji and Lompoul

Appendix 3: Biophysical information for SLM technologies not documented with WOCAT

Appendix 4: List of species tested for stabilization of sand dunes

Appendix 5: Biophysical characteristics of the agroforestry plot, Mabouye Niayes

Appendix 6: Distribution of trees into diameter classes in Barkédji and Lompoul

Appendix 7: Electronical Appendix

Appendix 1: Species lists

Species list with family names, origins (ind: indigenous; ex: exotic) and natural distribution for Barkédji, Senegal; (Arbonnier, 2004)

Species	Family	Origin	Natural distribution
Acacia ataxacantha DC.	*Mimosoideae*	ind	s-s
Acacia macrostachya Reichenb. ex DC.	*Mimosoideae*	ind	sa, su
Acacia nilotica (L. Willd. ex Del.	*Mimosoideae*	ind	s-s
Acacia senegal (L.) Willd.	*Mimosoideae*	ind	sa, s-s
Acacia seyal Del.	*Mimosoideae*	ind	sa, s-s
Acacia raddiana (Savi) Brenan	*Mimosoideae*	ex	
Adansonia digitata L.	*Bombacaceae*	ind	s-s
Adenium obesum (Forssk.) Roem. & Schult.	*Apocynaceae*	ind	s-s
Anogeissus leiocarpus (DC.) Guilll. & Perr.	*Combretaceae*	ind	s-s, su-gu
Azadirachta indica A. Juss.	*Meliaceae*	ex	-
Balanites aegyptiaca (L.) Del.	*Balanitaceae*	ind	sa, s-s
Bauhinia rufescens Lam.	*Caesalpinioideae*	ind	sa, s-s
Boscia senegalensis (Pers.) Lam. ex Poir.	*Capparaceae*	ind	s-s
Calotropis procera (Ait.) Ait. f.	*Asclepiadaceae*	ind	sa
Citrus limon (L.) Burm. f.	*Rutaceae*	ex	-
Combretum aculeatum Vent.	*Combretaceae*	ind	su, s-s
Combretum glutinosum Perr. ex DC.	*Combretaceae*	ind	sa, s-s
Combretum micranthum G. Don	*Combretaceae*	ind	s-s, su
Combretum nigricans Lepr. ex Guill & Perr	*Combretaceae*	ind	su, gu
Commiphora africana (A. Rich.) Engl.	*Burseraceae*	ind	sa, s-s
Dichrostachys cinerea (L.) Wight and Am.	*Mimosoideae*	ind	s-s, gu
Eucalyptus camaldulensis Dehnh.	*Myrtaceae*	ex	-
Euphorbia balsamifera Ait.	*Euphorbiaceae*	ex	-
Faidherbia albida (Del.) A. Chev.	*Mimosoideae*	ind	s-s, su
Feretia apodanthera Del.	*Rubiaceae*	ind	s-s, su-gu
Grewia bicolor Juss.	*Tiliaceae*	ind	s-s, su
Guiera senegalensis J.F. Gmel.	*Combretaceae*	ind	s-s

Species	Family	Origin	Natural distribution
Lannea acida A. Rich	*Anacardiaceae*	ind	gu, su
Lawsonia inermis L.	*Lythraceae*	ex	-
Leptadenia pyrotecnica (Forssk.) Decne.	*Asclepiadaceae*	ind	sa
Leucaena leucocephala (Lam.) de Wit	*Mimosoideae*	ex	-
Mindioli (local name)			
Moringa oleifera L.	*Moringaceae*	ex	-
Piliostigma reticulatum (DC.) Hochst.	*Caesalpiniaceae*	ind	su, s-s
Prosopis juliflora (Sw.) DC.	*Mimosoideae*	ex	-
Pterocarpus erinaceus Poir.	*Fabaceae*	ind	su-gu, gu
Pterocarpus lucens Guill. & Perr.	*Fabaceae*	ind	su, s-s
Sclerocarya birrea (A. Rich.) Hochst.	*Anacardiaceae*	ind	s-s, su
Sterculia setigera Del.	*Sterculiaceae*	ind	s-s, gu
Stereospermum kunthianum Cham.	*Bignoniaceae*	ind	gu, s-s
Tamarindus indica L.	*Caesalpiniaceae*	ex	-
Ziziphus mauritiana Lam.	*Rhamnaceae*	ind	su, s-s
Ziziphus mucronata Willd.	*Rhamnaceae*	ind	gu, su

[1] (Arbonnier, 2004)
[2] s-s: Sahelo-sudanian, sa: Sahelian, su: Sudanian

Species list with family names, origins (ind: indigenous; ex: exotic) and natural distribution for Lompoul, (northern littoral of Senegal)[1]

Species	Family	Origin	Natural distribution[2]
Acacia raddiana (Savi) Brenan	*Mimosoideae*	*ex*	
Adansonia digitata L.	*Bombacaceae*	*ind*	s-s
Anacardium occidentale L.	*Anacardiaceae*	*ex*	-
Annona senegalensis Pers.	*Annonaceae*	*ind*	sa-gu
Azadirachta indica A. Juss.	*Meliaceae*	*ex*	-
Balanites aegyptiaca (L.) Del.	*Balanitaceae*	*ind*	sa, s-s
Calotropis procera (Ait.) Ait. f.	*Asclepiadaceae*	*ind*	sa
Casuarina equisetifolia L.	*Casuarinaceae*	*ex*	-
Citrus limon (L.) Burm. f.	*Rutaceae*	*ex*	-
Cocos nucifera L.	*Arecaceae*	*ex*	-
Commiphora africana (A. Rich.) Engl.	*Burseraceae*	*ind*	sa, s-s
Dialium guineense Willd.	*Caesalpinioideae*	*ind*	gu, su-gu
Elaeis guineensis Jacq.	*Arecaceae*	*ind*	su-gu, gu
Eucalyptus camaldulensis Dehnh.	*Myrtaceae*	*ex*	-
Faidherbia albida (Del.) A. Chev.	*Mimosoideae*	*ind*	s-s, su
Ficus gnaphalocarpa (Miq.) C. C. Berg	*Moraceae*	*ind*	sa-su, su-gu
Jatropha chevalieri Beille.	*Euphorbiaceae*	*ex*	-
Mangifera indica L.	*Anacardiaceae*	*ex*	-
Maytenus senegalensis (Lam.) Exell	*Celastraceae*	*ind*	su, gu
Neocarya macrophylla (Sabine) Prance	*Chrysobalanaceae*	*ind*	su-gu
Prosopis africana (Guill. & Perr.) Taub.	*Mimosoideae*	*ind*	su, gu
Prosopis juliflora (Sw.) DC.	*Mimosoideae*	*ex*	-
Sclerocarya birrea (A. Rich.) Hochst.	*Anacardiaceae*	*ind*	s-s, su
Tamarindus indica L.	*Caesalpiniaceae*	*ex*	-
Zanthoxylum zanthoxyloides (Lam.) Watermann	*Rutaceae*	*ind*	su-gu, gu
Ziziphus mauritiana Lam.	*Rhamnaceae*	*ind*	su, s-s

[1] (Arbonnier, 2004)
[2] s-s: Sahelo-sudanian, sa: Sahelian, su: Sudanian

Appendix 2: Additional information on tree diversity parameters in Barkédji and Lompoul

Barkédji

Total number of species, mean species number per plot[1], Shannon diversity index H´ and tree density per ha for trees DBH ≥ 2 cm at separate sites and averaged over all plots of sustainable and conventional LM in Barkédji, Senegal[2]

				Species richness (No. spp. / plot)			**Tree density (No. ind. ha^{-1})**	
		n	total no. spp.	range	mean	mean H´[3]	range	mean
SLM	Agroforestry *A. senegal*	5	9	3-5	3.4 [0.6][ce]	0.69 [0.3][c]	8-732	210.6 [122.4][ab]
	Homegarden	2	19	11-13	12.0 [1.0][ae]	1.75 [0.1][ac]	88-119	103.5 [15.5][ab]
	Parkland	2	6	3-4	3.5 [0.5][ace]	1.16 [0.2][abc]	7-8	7.5 [0.5][ab]
	Natural grove	3	12	5-9	7.3 [1.2][de]	1.56 [0.4][ac]	796-955	902.0 [53.0][a]
	Pasture reserve	5	21	8-11	9.6 [0.5][ad]	2.03 [0.1][a]	112-383	257.2 [55.8][a]
	SLM sites	**17**	**39**	**2-13**	**7.0 [0.9]**	**1.42 [0.2]**	**7-955**	**312.0 [81.9]**
CLM	Extensive pasture	20	8	1-6	2.1 [0.3][bc]	0.45 [0.1][b]	8-152	53.9 [9.8][b]
	Crop production	3	15	6-9	7.3 [0.9][ace]	1.36 [0.4][ac]	14-33	23.0 [5.5][b]
	CLM sites	**23**	**22**	**1-9**	**2.8 [0.5]**	**0.57 [0.2]**	**8-152**	**49.9 [8.8]**
	Sign.[4]				**$p < 0.05$**	**$p < 0.05$**		**$p < 0.05$**

[1] For plot size see *Table 4*, p. 26
[2] Standard errors are given in parenthesis. n=no. of samples.
[3] $H' = -\sum p_i \ln p_i$ where p_i is the proportion of individuals of species i in the community (Magurran, 1988)
[4] The last row indicates significance between total values of SLM and CLM. Within columns different superscripts indicate significance between land use types.

Mean species richness per plot[1], Shannon diversity index H´ and density per ha for tree regeneration[2] at separate sites and averaged over all plots of sustainable and conventional land management in Barkédji, Senegal[3]

			Species richness (No. spp. / plot)			Plant density (No. ind. / ha)	
		n	range	mean	mean H´[4]	range	mean
SLM	Agroforestry *A. senegal*	5	3-7	4.8 [0.8][ad]	1.27 [0.2][a]	9-152	66.8 [23.9][b]
SLM	Homegarden	2	1-2	1.5 [0.5][de]	0.34 [0.3][ab]	2-73	37.3 [35.0][b]
SLM	Parkland	2	1	1 [0][de]	0[ab]	2-3	2.5 [0.5][b]
SLM	Natural grove	3	3-7	5.7 [1.3][ad]	1.53 [0.3][a]	222-445	350.3 [66.1][a]
SLM	Pasture reserve	5	2-8	5.2 [1.0][ad]	1.06 [0.1][a]	16-1273	462.0 [212.6][a]
	SLM sites	**17**	**1-8**	**4.2 [0.6]**	**1.00 [0.3]**	**2-1273**	**222 [139.9]**
CLM	Extensive pasture	20	0-4	1.2 [0.3][be]	0.24 [0.1][b]	0-128	31.2 [8.9][b]
CLM	Crop production	3	2-6	4.7 [1.3][ac]	0.89 [0.3][a]	4-30	19.7 [6.4][b]
	CLM sites	**23**	**0-6**	**1.7 [0.4]**	**0.33 [0.3]**	**0-128**	**29.7 [21.5]**
	Sign.[5]			**$p < 0.05$**	**$p < 0.05$**		**$p < 0.05$**

[1] For plot size see *Table 4*, p. 26
[2] DBH < 2 cm
[3] Standard errors are given in parenthesis. n=no. of samples.
[4] $H' = -\sum p_i \ln p_i$ where p_i is the proportion of individuals of species i in the community (Magurran, 1988)
[5] The last row indicates significance between total values of SLM and CLM. Within columns different superscripts indicate significance between land use types.

Lompoul

Total number of species, mean species number per plot[1], Shannon diversity index H´ and tree density per ha for trees and shrubs DBH ≥ 2 cm at separate sites and averaged over all plots of sustainable and conventional LM in Lompoul, (northern littoral of Senegal)[2]

		n	total no. spp.	Species richness (No. spp. / plot) range	Species richness (No. spp. / plot) mean	H´[3]	Tree density (No. ind. ha^{-1}) range	Tree density (No. ind. ha^{-1}) mean
SLM	Dune fixation	8	1	1-1	1 [0][b]	0[b]	133-544	352.8 [119.6][a]
	Eucalyptus plantation	5	2	1-2	1.2 [0.2][b]	0.05 [0][b]	318-700	553.9 [69.4][a]
	Agroforestry	5	15	3-8	5.2 [0.9][a]	1.31 [0.1][a]	8-54	25.3 [9.2][b]
	Fruit orchard	3	10	4-7	5.7 [0.9][a]	1.07 [0.1][a]	133-649	367.4 [151][a]
	Small grove	2	3	2-3	2.5 [0.5][ab]	0.43 [0.1][ab]	143-223	183.0 [40]
	SLM sites	**23**	**22**	**1-8**	**2.7 [0.5]**	**0.48 [0.1]**	**6-700**	**314.2 [50.5]**
CLM	Pasture	3	4	1-3	2 [0.6][b]	0.41 [0.2][b]	32-104	63.7 [21.1][b]
	CLM sites	**3**	**4**	**1-3**	**2 [0.6]**	**0.41 [0.2]**	**32-104**	**63.7 [21.1]**
	Sign.[4]				**ns**	**ns**		**ns**

[1] For plot size see *Table 5*, p. 27
[2] Standard errors are given in parenthesis. n=no. of samples.
[3] $H' = -\sum p_i \ln p_i$ where p_i is the proportion of individuals of species i in the community (Magurran, 1988)
[4] The last row indicates significance between total values of SLM and CLM. Within columns different superscripts indicate significance between land use types.

Appendix 3: Biophysical information for SLM technologies not documented with WOCAT

Pasture reserve, Touba Ndar Fall, GAA Barkédji

Characteristics of vegetation at the SLM site "pasture reserve" in Barkédji, Senegal[1]

Canopy cover (%)	13 [3.8]
Herbaceous cover (%)	68 [4.5]
Tree height (m)	3 [0.2]
Tree DBH (cm)	8 [0.4]
Percent trees damaged	10 [6.4]
Percent dead trees	6 [2.1]
Number of trees ha^{-1}	257 [55.8]
Number of regenerating trees ha^{-1}	462 [213]
Shannon diversity index	2.03 [0.07]

[1]Standard errors are given in parenthesis. Sample size was n=5.

Density per ha of mature trees and regeneration at the SLM site "pasture reserve", Barkédji, Senegal[1]

Species	**No. ind. ha^{-1}**	**No. regeneration ha^{-1}**
Guiera senegalensis	39.8 [21.0]	17.6 [9.6]
Combretum glutinosum	38.4 [19.0]	35.0 [27.4]
Grewia bicolor	32.0 [8.8]	257.8 [110.7]
Acacia macrostachya	30.2 [16.3]	19.2 [10.0]
Pterocarpus lucens	24.0 [10.7]	-
Boscia senegalensis	20.8 [3.2]	9.6 [3.9]
Commiphora africana	17.6 [15.7]	113.2 [63.5]
Combretum micranthum	17.6 [5.9]	1.6 [1.6]
Pterocarpus erinaceus	8.0 [8.0]	-
Sclerocarya birrea	6.4 [3.9]	-
Combretum nigricans	6.4 [3.0]	-
Adenium obesum	4.8 [3.2]	-
Dicrostachys cinerea	3.2 [3.2]	3.2 [3.2]
Feretia apodanthera	1.6 [1.6]	-

Species	No. ind. ha^{-1}	No. regeneration ha^{-1}
Balanites aegyptiaca	1.6 [1.6]	1.6 [1.6]
Anogeissus leiocarpus	1.6 [1.6]	-
Acacia ataxacantha	1.6 [1.6]	-
Combretum aculeatum	1.6 [1.6]	3.2 [3.2]
Total	**257.2 [55.8]**	**462 [213]**

[1] Standard errors are given in parenthesis. Sample size was n=5.

<u>Small grove, Lompoul-sur-Mer, GAA Lompoul</u>

Characteristics of vegetation at the SLM site “small grove”, Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	22 [6.1]
Tree height (m)	4 [0.4]
Tree DBH (cm)	13 [0.1]
Percent trees damaged	0
Percent dead trees	0
Herb cover (%)	40 [0]
Number of trees (ind. ha^{-1})	183 [39.8]
No. ind. ha^{-1} (regeneration)	20 [19.9]

[1] Standard errors are given in parenthesis. Sample size was n=5.

Density per ha of mature trees and regeneration at the SLM site “small grove”, Lompoul, (northern littoral of Senegal)[1]

Species	No. ind. ha^{-1}	No. ind. ha^{-1} (regeneration)
Acacia raddiana	159.2 [31.8]	0
Balanites aegyptiaca	15.9 [0]	0
Neocarya macrophylla	8.0 [8.0]	0
Jatropha chevalieri	0	15.9 [15.9]
Annona senegalensis	0	4.0 [4]
Total	**183.1 [39.8]**	**19.9 [19.9]**

[1] Standard errors are given in parenthesis. Sample size was n=5.

Appendix 4: List of species tested for the stabilization of sand dunes

List of species tested for the fixation of sand dunes along the northern littoral of Senegal (source: Maheut & Dommergues (1959)).

Acacia adstringens	*Eucalyptus sp.*
Acacia nilotica	*Faidherbia albida*
Albizia lebbeck	*Ipomoea pes-caprae*
Anacardium occidentale	*Melaleuca leucadendron*
Aphania senegalensis	*Parinari macrophylla*
Borassus flabellifer	*Pithecellobium dulce*
Cassia bicapsularis	*Pithecellobium saman*
Cassia occidentalis	*Portulacaria afra*
Cassia siamea	*Schizachyrium pulchellum*
Casuarina equisetifolia	*Sporobolus spicatus*
Chrysobalanus orbicularis	*Tamarix articulata*
Coccoloba uvifera	*Trachylobium verrucosum*
Cocos nucifera	
Combretum aculeatum	
Dodonaea viscosa	

Appendix 5: Biophysical characteristics of the agroforestry plot, Mabouye Niayes (Lompoul)

The following tables present data for one out of the five agroforestry plots in Mabouye Niayes, whose owner had been interviewed during the LADA assessment.

Characteristics of vegetation at the plot of the SLM technology ”agroforestry with *Neocarya macrophylla* and *Faidherbia albida*”, referred to in the documentation of this technology, p. 103, in Lompoul, (northern littoral of Senegal)[1]

Canopy cover (%)	3.1
Tree height (m)	4 [0.3]
Tree DBH (cm)	22 [1.6]
Percent trees damaged	0
Percent dead trees	0
Herb cover (%)	40
Number of trees (ind. ha^{-1})	40
Number of regeneration (ind. ha^{1})	15

[1] Standard errors for average tree height and DBH in this plot are given in parenthesis.

Density of mature trees and regeneration in the plot of the SLM technology ”agroforestry with *Neocarya macrophylla* and *Faidherbia albida*”, referred to in the documentation of this technology, p. 103, in Lompoul, (northern littoral of Senegal)

Species	**Origin**	**No. of trees ha^{-1}**	**No. of regeneration ha^{-1}**
Neocarya macrophylla	ind	25.3	-
Acacia raddiana	ex	5.9	-
Calotropis procera	ind	4.5	1.5
Sclerocarya birrea	ind	1.5	-
Dialium guineense	ind	1.5	-
Prosopis africana	ind	1.5	-
Maytenus senegalensis	ind		13.4
Total		**40.2**	**14.9**

Appendix 6: Distribution of trees into diameter classes in Barkédji and Lompoul

Barkédji

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site "homegarden", Barkédji

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Azadirachta indica	0	0	0	8	0	0
Balanites aegyptiaca	31	0	0	0	0	0
Calotropis procera	0	4	0	0	0	0
Citrus limon	0	0	28	0	0	0
Combretum glutinosum	0	0	0	0	2	0
Eucalyptus camaldulensis	0	16	0	0	0	0
Euphorbia balsamifera	0	0	0	0	0	0
Lawsonia inermis	0	0	0	0	0	0
Moringa oleifera	0	2	0	0	0	0
Piliostigma reticulatum	0	0	0	2	0	0
Prosopis juliflora	0	0	51	0	0	0
Tamarindus indica	0	0	4	0	0	0
Ziziphus mauritiana	41	0	20	0	0	0
Total	**73**	**22**	**102**	**10**	**2**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site "homegarden, project GPF", Barkédji

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Azadirachta indica	0	0	2	2	0	0
Balanites aegyptiaca	0	0	2	0	0	0
Bauhinia rufescens	0	0	2	0	0	0
Combretum glutinosum	0	0	0	2	0	0
Eucalyptus camaldulensis	0	0	0	2	0	0
Lawsonia inermis	0	0	6	0	0	0
Leucaena leucocephala	0	0	0	2	0	0
Mindioli (local name)	0	0	2	0	0	0
Moringa oleifera	0	0	2	0	0	0

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Prosopis juliflora	4	4	0	51	0	0
Sclerocarya birrea	0	0	0	2	0	0
Ziziphus mauritiana	0	0	4	0	0	0
Ziziphus mucronata	0	0	7	0	0	0
Total	**4**	**4**	**26**	**61**	**0**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site “agroforestry with *A. senegal*”, Barkédji

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Acacia raddiana	2.6	0	0	0	0	0
Acacia senegal	6.5	30.7	0.9	0	0	0
Balanites aegyptiaca	15.7	2.0	2.8	0.7	0	0
Bauhinia rufescens	0.4	0.2	0	0	0	0
Combretum glutinosum	3.7	0	0	0.4	0	0
Faidherbia albida	0	0	0	0	0.2	0
Grewia bicolor	0.7	0.2	0.4	0	0	0
Guiera senegalensis	6.1	0.2	0	0	0	0
Piliostigma reticulatum	1.3	0	0	0.2	0.2	0
Ziziphus mauritiana	5.7	0.2	0.2	0.2	0	0
Total	**42.7**	**33.6**	**4.4**	**1.5**	**0.4**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site “parkland”, Barkédji

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Balanites aegyptiaca	0	0	0	0.5	0	0
Combretum glutinosum	1	1	0	1	0	0
Faidherbia albida	0	0	0	0	1	0
Piliostigma reticulatum	0	0	1	0	0	0
Sclerocarya birrea	0	0	0	0.5	1	0
Sterculia setigera	1.5	0	0	0	1.5	0
Total	**2.5**	**1**	**1**	**2**	**3.5**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site “natural grove”, Barkédji

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Acacia macrostachya	11	85	32	11	0	0
Acacia seyal	32	64	372	11	0	0
Anogeissus leiocarpus	64	0	0	0	0	0
Combretum glutinosum	53	53	11	0	0	0
Combretum micranthum	21	11	0	0	0	0
Combretum nigricans	11	11	0	0	0	0
Commiphora africana	11	0	0	0	0	0
Feretia apodanthera	53	74	0	0	0	0
Grewia bicolor	85	53	21	0	0	0
Guiera senegalensis	11	32	0	0	0	0
Lannea acida	0	0	0	11	0	0
Pterocarpus erinaceus	0	32	11	11	0	0
Stereospermum kunthianum	11	11	0	0	0	0
Total	**361**	**425**	**446**	**42**	**0**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site “pasture reserve”, Barkédji

Species	**<2**	**2-9.9**	**10-19.9**	**20-39.9**	**40-79.9**	**≥80**
Acacia ataxacantha	0	2	0	0	0	0
Acacia macrostachya	19	16	14	0	0	0
Adenium obesum	0	0	3	2	0	0
Anogeissus leiocarpus	0	0	0	2	0	0
Balanites aegyptiaca	2	0	2	0	0	0
Boscia senegalensis	8	21	0	0	0	0
Combretum aculeatum	3	0	0	0	0	0
Combretum glutinosum	35	32	8	0	0	0
Combretum micranthum	2	16	2	0	0	0
Combretum nigricans	0	5	2	0	0	0
Commiphora africana	113	6	13	0	0	0
Dichrostachys cinerea	3	3	0	0	0	0
Feretia apodanthera	0	2	0	0	0	0
Grewia bicolor	258	29	3	0	0	0
Guiera senegalensis	18	35	5	0	0	0
Pterocarpus erinaceus	0	8	0	0	0	0
Pterocarpus lucens	0	0	0	0	0	0
Sclerocarya birrea	0	0	0	0	0	0
Total	**460**	**173**	**51**	**3**	**0**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the CLM site “extensive pasture”, Barkédji

Species	**<2**	**2-9.9**	**10-19.9**	**20-39.9**	**40-79.9**	**≥80**
Acacia raddiana	14.7	21.5	5.2	2.4	0.8	0.0
Acacia senegal	1.2	4.4	0.0	0.0	0.0	0.0
Adenium obesum	2.4	0.8	0.0	0.4	0.0	0.0
Balanites aegyptiaca	0.4	0.4	0.0	0.0	0.0	0.0
Combretum aculeatum	0.4	0.4	0.0	0.0	0.0	0.0
Combretum glutinosum	6.4	3.2	0.8	0.4	0.0	0.0

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Commiphora africana	0.8	0.8	0.8	0.0	0.0	0.0
Grewia bicolor	2.8	0.8	0.0	0.0	0.0	0.0
Guiera senegalensis	3.6	5.2	1.2	0.0	0.0	0.0
Leptadenia pyrotecnica	0.0	0.4	0.0	0.0	0.0	0.0
Pterocarpus lucens	0.4	0.4	2.0	0.8	0.8	0.0
Sclerocarya birrea	0.0	0.8	0.0	0.0	0.0	0.0
Total	**33.1**	**39.0**	**10.0**	**4.0**	**1.6**	**0.0**

Distribution of trees into diameter classes (no. ind. / ha) for the CLM site “conventional agriculture”, Barkédji

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Acacia albida	0	0.08	0	0	0.16	0
Acacia ataxacantha	0	0	0	0	0	0
Acacia nilotica	0.08	0.00	0.08	0	0	0
Acacia raddiana	0.31	0.31	0.70	0.70	0.31	0
Acacia senegal	0.00	0.08	0.08	0	0	0
Acacia seyal	1.09	0.08	0	0.08	0	0
Adansonia digitata	0	0	0	0	0.16	0.23
Azadirachta indica	0	0	0	0.16	0.08	0
Balanites aegyptiaca	7.47	1.40	1.09	1.32	0.16	0
Combretum glutinosum	0	0	0.16	0	0	0
Combretum micranthum	0	0.08	0	0	0	0
Feretia apodanthera	0	0.08	0	0	0	0
Grewia bicolor	0	0	0.08	0	0	0
Guiera senegalensis	0.16	0	0	0	0	0
Prosopis juliflora	0	0	0.08	0.08	0	0
Ziziphus mauritiana	0.08	0	0	0	0	0
Total	**9.18**	**2.10**	**2.26**	**2.33**	**0.86**	**0.23**

Lompoul

Distribution of trees into diameter classes (no. ind. / ha) for the CLM site “pasture”, Lompoul, (northern littoral of Senegal)

Species	**<2**	**2-9.9**	**10-19.9**	**20-39.9**	**40-79.9**	**≥80**
Acacia raddiana	0	8	37	8	0	0
Commiphora africana	0	0	3	3	0	0
Faidherbia albida	0	3	0	0	0	0
Maytenus senegalensis	0	3	0	0	0	0
Total	**0**	**13**	**40**	**11**	**0**	**0**

Distribution of trees over diameter classes (no. ind. / ha) for the SLM site “small grove”, Lompoul, (northern littoral of Senegal)

Species	**<2**	**2-9.9**	**10-19.9**	**20-39.9**	**40-79.9**	**≥80**
Acacia raddiana	0	64	92	4	0	0
Annona senegalensis	0	0	4	4	0	0
Balanites aegyptiaca	0	0	0	16	0	0
Jatropha chevalieri	16	0	0	0	0	0
Neocarya macrophylla	4	0	0	0	0	0
Total	**20**	**64**	**96**	**24**	**0**	**0**

Distribution of trees into diameter classes (no. ind. / ha) for the SLM site “agroforestry”, Lompoul, (northern littoral of Senegal)

Species	**<2**	**2-9.9**	**10-19.9**	**20-39.9**	**40-79.9**	**≥80**
Acacia raddiana	0.2	0	0.9	0	0	0
Adansonia digitata	0	0	0	0	0	0.2
Anacardium occidentale	0	0	0	0.2	0.2	0
Azadirachta indica	0	0	0	0.2	0	0
Calotropis procera	7.2	2.3	1.2	0	0	0
Cocos nucifera	0	0	0	1.9	0	0
Dialium guineense	0	0	0	0.2	0	0
Elaeis guineensis	0	0	0	0.7	1.4	0

Species	<2	2-9.9	10-19.9	20-39.9	40-79.9	≥80
Faidherbia albida	0	0	0.9	1.4	0.5	0
Ficus gnaphalocarpa	0	0	0	0.5	0	0
Jatropha chevalieri	0.2	0	0	0	0	0
Mangifera indica	0	0	0	0.7	0	0
Maytenus senegalensis	2.1	0	0	0	0	0
Neocarya macrophylla	0	0	0.9	4.4	0	0
Prosopis africana	0	0	0	0.2	0	0
Sclerocarya birrea	0	0	0.2	0	0	0
Zanthoxylum zanthoxyloides	0	0.2	0	0	0	0
Total	**9.8**	**2.6**	**4.2**	**10.5**	**2.1**	**0.2**

Appendix 7: Electronical Appendix on Data-CD

a) Data of the vegetation assessment in Barkédji and Lompoul

b) WOCAT questionnaires QT and QA

c) LADA field manuals part 1 and 2

d) Example of a WOCAT 4-page Case Study

e) Thesis (.pdf and .doc)