THE ECONOMICS OF
LAND DEGRADATION

An Economic Valuation of agroforestry and land restoration in the Kelka forest in Mali

Assessing the socio-economic and environmental dimensions of land degradation

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Executive summary

The Kelka forest in the Mopti region of Mali is important for the provision of ecosystem services like carbon sequestration and maintenance of the hydrological cycle. The Kelka forest area occupies more than 300, 000 hectares with 15 villages within and around its boundaries. The forest resources and soil fertility of the forest are in continuous decline due to a combination of climatic and human induced factors. For example, the availability of firewood has halved over the past 15 years due to a lack of adequate forest and land management.

Sustainable land management interventions that can reverse the current trend of forest and land degradation are increasingly necessary, but large scale interventions need to be grounded in solid assessments of their potential economic and financial value to the local and the global society. To address this need, the paper presents an ex-ante cost benefit analysis of large-scale agroforestry and reforestation in the Kelka forest to inform decision-makers about the value and importance of changing current land use practices. The economic valuation uses 'productivity change', 'avoided cost', 'replacement cost', and 'market based' valuation methods. The analysis is based on high-resolution remote sensing techniques, an explicit spatially distributed hydrological model, and a crop growth model, developed to assess the impact of land use change on firewood availability, soil moisture, carbon sequestration, and nitrogen fixation.

Using different discount rates, results indicate that the benefits of large-scale agroforestry and/ or reforestation are significantly higher than the costs of implementing the restoration options over a 25 year time horizon. Different options for incentivizing agroforestry and restoration of the Kelka forest are discussed.

Table of contents

The economics of land degradation

Sustainable land use is a prerequisite for ensuring future water, food, and energy security. Given the increasing pressure on land from agriculture, forestry, pasture, energy production, and urbanization, urgent action is needed to halt land degradation and restore already-degraded lands. The United Nations Convention to Combat Desertification (UNCCD) was established in 1994 to specifically address desertification. The convention was born as a result of the 1992 Rio Earth Summit, which highlighted climate change, biodiversity loss, and desertification as the greatest challenges facing sustainable development. All three challenges have been attributed to failures in, markets, and policies. The UNCCD's core emphasis is on securing productivity and resilience of land for the well-being of dryland inhabitants, particularly in drought-prone areas. In 2007, a ten year strategy for the convention was adopted with a more explicit goal for its 195 parties, *"to forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas in order to support poverty reduction and environmental sustainability"* (UNCCD 2012). The ten year strategy is supported and implemented through key stakeholder partnerships with the aim of mainstreaming sustainable land management (SLM) into decision-making policies and practices.

The UNCCD definition of desertification is land degradation (linked to the loss of productivity of land) in drylands with the exception of hyper arid areas. Although there appears to be a general consensus amongst the parties to the convention that drylands, particularly in Africa, face severe impacts of desertification, land degradation, and drought (DLDD), land degradation is not restricted to drylands. The far-reaching impacts of DLDD affect both livelihoods and ecosystems globally, resulting in the loss of critical ecosystem services ranging from carbon sequestration to losses of fertility and nature conservation. The impacts of DLDD are local but can also be experienced off-site, e.g., when deforestation or poor management of land upstream results in siltation of dams downstream. Impacts of DLDD can be cross-border or even inter-continental, e.g., dust storms where the dust is generated on one continent and travels with prevailing winds and manifests as a dust storm on another continent. The importance of an international convention on desertification becomes strikingly apparent when considering these off-site/cross-boundary impacts that result from DLDD.

In 2013, the 2nd Science Conference of UNCCD was held in Bonn, Germany, to discuss and showcase scientific contributions on the theme *"Economic assessment of desertification, sustainable land management, and resilience of arid, semi-arid, and dry sub-humid areas"*. Throughout the conference, scientists and practitioners presented robust methodologies and evidence to suggest that preventing DLDD can be more cost effective than restoring degraded land. However, there are significant data gaps in the biophysical and economic data and methodologies need to be extensively tested to identify the most efficient methods to collect and compile the data required to fill these gaps. It is evident that the field of economic assessment of SLM is still, emerging but nonetheless an important one.

Central to the debate on the economics of DLDD is the concept of land degradation neutrality (LDN). LDN is a novel idea that was presented in the outcome document from Rio+20 and adopted by UNCCD (UNCCD 2012). Its aim is to secure the productivity of land and natural resources (such as soil) for sustainable development, food security, and poverty eradication. In principle, LDN would translate into avoided degradation of productive land and restoration of already degraded lands to obtain a degradation-neutral outcome. Cost-benefit analyses of SLM is an important approach in strengthening the case for investments in improved land management practices, and is one of the steps necessary to achieve land degradation neutrality.

Promoting SLM and effectively communicating the nexus of benefits derived from SLM has been at the heart of the work of IUCN's Global Drylands Initiative (GDI). GDI is further collaborating with the IUCN Global Economics and Social Science programme (GESSP) that provides technical expertise in the domain of ecosystem service valuation. The SLM nexus highlights the inter-linkages between climate, biodiversity and land, where synergies between the three UN conventions (UNCCD, United Nations Framework Convention on Climate Change [UNFCCC], and the United Nations Convention on Biodiversity [UNCBD]) lie, and where a large portion of IUCN's dryland work is focused. IUCN brings communities and multiple government sectors together to enable more coherent resource planning at the ecosystem level for SLM in the drylands.

IUCN - GDI and GESSP have a history of using economic valuations to demonstrate the benefits of ecosystems and SLM strategies specifically applicable to drylands. To strengthen these existing economic assessments, IUCN has built relationships with other initiatives who share similar goals and objectives, such as the Economics of Land Degradation (ELD) Initiative. The ELD Initiative highlights the potential benefits derived from adopting SLM practices, using quantitative ecosystem valuation studies. Through funds from the ELD Initiative, IUCN carried out an assessment of the economic costs and benefits of SLM and its natural resource governance interventions over several years in Jordan, Mali, and Sudan. These three country studies provided a detailed analysis of the costs and benefits of interventions, information on non-market values of ecosystem services, improved understanding of the value of ecosystem services to local livelihoods, and improved monitoring and evaluation for total ecosystem assessments. The studies demonstrated that long and short term social, economic, and environmental benefits can be derived from adopting SLM practices on a wide scale. These studies also informed the development of policy recommendations which will feed into on-going dialogue with policy- and decision-makers in these regions. Hence, IUCN hopes these studies have provided a fresh insight with innovative methodologies and new data, plus a more comprehensive review of the diversity of ecosystem services that are important in drylands.

01 Introduction

Poverty alleviation and food security are major concerns in Sahelian countries, characterized by low rainfall and significant climate variability (Day et al. 1992; OCDE, 2002; Liebenow et al. 2012). Mali is located in the Sahelian belt of West Africa with about two thirds of the country in the Sahara desert. The majority of livelihoods in Mali are dependent on rainfed agriculture, systems which are vulnerable to events such as droughts, storms, and floods. The frequency of such events are expected to rise over the coming decade (IPCC, 2013), leading to highly variable harvests and decreased productivity.

Alternative income sources and livelihoods are therefore of utmost importance for households of Mail, including in the Kelka forest of the Mopti region. Alternative income sources often derive directly from natural harvested resources such as fuel wood and non-timber forest products (NTFP) (Liebenow et al. 2012). Unfortunately, the resource base is under growing pressure from land degradation. Natural factors, such as repeated droughts and climate change, and anthropogenic factors, such as high population growth, competition for resources between different users, and forest overexploitation, constitute major threats to many important ecosystems in Mali (Barrow et al, 2012). Challenges and constraints of sustainable forest management pertain to the lack of appropriate valuation of the natural resources, inadequate forms of institutional arrangement, and practices resulting from misperceptions of the local population regarding the impact agroforestry practices have on crops.

The Kelka forest is an important habitat with a high diversity of acacia species (Diallo and Winter, 1996; Deme, 1998) and an important refuge for wildlife. The forest for example is the main source of energy for cooking for a population of about 60,000 people distributed in 15 communities. However, it has been undergoing observable forest resource depletion over the past years (Ba and Nimaga 2010); anecdotal evidence from local communities points to a halving of wild products over the last 15-years. Additionally, the population in the 15 villages residing within/around the Kelka forest is particularly vulnerable to food insecurity due to the fragility and infertility of the land, and the impacts of an uncertain climate (Barrow et al, 2012). Therefore, it is expected that properly designed land use interventions can bring significant benefits to livelihoods and stability in the area. In several other semi-arid areas, such as Niger and other Sahelian African countries, agroforestry and reforestation have been recommended in particular, as effective strategies to reverse land degradation (Nkonya, 2004; Pender, 2006).

IUCN has supported Community Forest Management in Kelka Forest in the dry region of Mopti for more than a decade. The core of the work has been on enabling local communities produce Community Environmental Management Plans (CEMP), with the goal of outlining priorities and agreeing on an action plan in natural resource management of the forest landscape. The CEMP is a tool used by IUCN to strengthen community ownership of restoration and agroforestry initiatives which have been identified as important by the communities. The communities around the Kelka forest developed a ‘Local Convention’ to support the sustainable management of the forest as one of their key resources. IUCN’s has been involved in supporting the creation and adoption of the ‘Local Convention’, using the CEMPs to strengthen the process by bringing about change in the governance and land tenure arrangements. The key objective is the adoption of SLM practices through reforestation and agroforestry by local communities supported by various policy and governance structures.

To rigorously assess the potential contribution from agroforestry and reforestation initiatives to societal wellbeing, the authors undertook an ex-ante economic valuation of agroforestry and land restoration intervention scenarios, compared to the present situation in the Kelka forest in the region of Mopti, Mali. The goal was to demonstrate how specific intervention scenarios can result in improved provision of ecosystem services at both local (community) and global levels. This was done through a cost-benefit analysis of the expansion of forest plot restoration and agroforestry as a means to halt land degradation. It involved estimating both the market (timber) and non–market benefits (regulating ecosystem services) associated with forest ecosystem services.

Based on an analysis of agroforestry interventions in 57 developing countries, Pretty et al. (2006) showed that agroforestry practices can result in increased yields and land preservation in the long-run. Similarly, Niles et al. (2002) showed that land restoration coupled with sustainable agricultural practices on existing land in developing countries can bring additional revenue in terms of better yields and fuelwood. Such benefits can be achieved through low-cost farmer-managed natural regeneration (FMNR) methods (Haglund, 2011).

When considering climate regulation, reforestation is globally beneficial, as it significantly mitigates atmospheric carbon (Lal, 2002; Niles et al. 2002; Ringius, 2002). For this reason, afforestation and reforestation has been recognized by the UN as a climate change mitigation strategy (UNFCCC, 2001) and is for example eligible under the Clean Development Mechanism (Cowie et al., 2011) of the Kyoto Protocol (IPCC, 2007) as an emission reduction project. This justifies why authors focused on agroforestry and forest restoration as specific SLM interventions in the Kelka landscape. An intervention scenario (agroforestry and reforestation also referred to as restoration) is considered and compared to the current scenario (baseline) that reflects the current situation of the Kelka forest. The baseline scenario is business as usual.

The rest of the document is organized as follows: the next section describes the study area, the baseline and an alternative future land use scenario which aims to reverse the current trend in land use degradation. With a baseline (no change), and an integrated 'reforestation and an agroforestry' scenario defined, the following chapters show how different biophysical models are used to predict how key ecosystem services are affected by land use changes. The biophysical changes are then translated into economic values using a combination of avoided costs, replacement cost, market prices. and productivity change valuation approaches. Using these approaches, the value of large-scale restoration is estimated in terms of increased firewood availability, increased carbon sequestration, the value of improved soil moisture at the farm level, and the value of increased nitrogen fixation over a 25 year time horizon (25 years is a standard time horizon used in cost benefit analysis and therefore facilitates comparability of estimates with other studies). Costs over the same time horizon were deducted to yield a Net Present Value (NPV) of the land use intervention at different discount rates. Finally, recommendations are provided to assist decision-making for the governance of land and related resources, and to address problems related to food security and poverty alleviation in the rural areas of Mali.

[1] Restoration and reforestation will be used interchangeably throughout the document

02

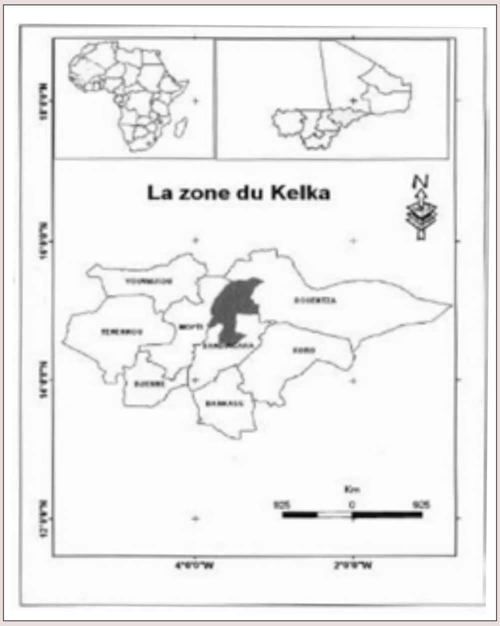
The study area and valuation scenarios

Study area

The study area is the Kelka forest, located in the Mopti Region of Mali. Mopti is semi-arid to arid, with an average annual rainfall of 516 mm (Afrique Nature International, 2009). Moreover, the rainy season is concentrated in only 4 to 5 months long, with considerable intra-seasonal variability resulting in dry spells and water logging. Annual mean temperature is 28 oC and the average potential evapotranspiration is around 200 mm per month (ClimWat, 2011). Soils are predominantly arenosols of the deep uniform sandy loam type (FAO, 1974). There are four main vegetation types including Gallery Forest, Savannah Woodland (most predominant), Savannah Shrub, and Steppe Shrub (Barrow et al. 2012). The most abundant species of trees are *Acacia nilotica, Acacia raddiana and Acacia albida*. A few baobab trees are scattered over the landscape, and there are also large patches of bare ground.

FIGURE 1

Map of the study watershed within the Kelka forest in the Mopti Region, Mali



The desire of the local population to manage their resources and control levels of exploitation has been manifested in the creation of a multi-village institution based in Batouma, which acts to control natural resource use within the forest. Natural resource management principles of the Kelka are elaborated through a process of dialogue, participation, and engendering responsibility among the populations of the 15 villages involved. However, as argued by Hesse and Trench (2000), its powers are limited. While government departments are supportive of projects piloting community based management and reforming outdated legislation, new legal texts tend not to go far enough and ultimately control is maintained by the government (further discussed in the conclusion). For more details on the socio-economic aspects of the Kelka forest the reader is referred to Barrow et al., 2012.

A baseline socio-economic household survey was conducted in a community named Batouma located 87 km from Sévaré, Commune of Dangol Boré, Cercle of Douentza, in Mopti Region. The results were then extrapolated to the Kelka forest as a whole. This community was selected because of its central position in the Kelka area, previous experience with soil restoration interventions, and accessibility. The biophysical analysis underlying the economic valuation of hydrological services was undertaken in a specific watershed (Batouma ko) within the Kelka forest covering the 15 villages. Local populations are heavily reliant on fragile agricultural systems and diminishing forest products (Bocoum et al., 2003), but the soils are poor for agricultural production because they are heavily eroded. Farmers in the area are thus engaging in alternative farming strategies by cultivating different crops. A shifting farming system is increasingly observable, moving from largely sorghum monocropping to a mixture of sorghum, millet, and rice cultivation.

Valuation scenarios

This section presents a potential future land use restoration scenario. It has two components: reforestation on degraded public land and a focus on the contribution of agroforestry to societal well-being. These two land use interventions are compared with the current baseline land use scenario that is used to predict how the landscape and its ecosystem services may evolve over the next 25 years in the absence of changes away from current land use management regimes. This section also depicts the main assumptions underlying the different scenarios.

Baseline scenario: current land and resource use patterns

To establish the baseline land use scenario, authors created a land use and land cover map (*Figure 2*). The baseline scenario was built (as much as possible) on the observable patterns of the current state of land and resources. Detailed digital image classification of Landsat 8 Images from December 2013 as well as detailed interpretation of Google Earth Professional (high resolution) and references to available land use maps from FAO were essential in the construction of the present land use and land cover data of the study area. This was augmented by a field visit and discussions with the local community members.

The vegetation cover is made of important tree species, mainly *A. nilotica*, *A. raddiana*, and *A. albida*. These are found on a vegetation mosaic of grassland, shrubland, and forests. The high Normalized Difference Vegetation Index (NDVI) was used to identify different vegetation types. On this basis, different landscape types were defined as agricultural areas, and mosaics of potential flood zones were observed and validated using Google Earth data.

Agroforestry practices are poorly adopted in the area. Tree plantation and crop fields are separated due to the perception that trees attract birds, which have a negative impact on sown seeds and harvest[2]. Tree density in fields is approximately 10 trees/ha, which is the legal minimum density. Under the baseline scenario, it is assumed that there will be no further uptake of agroforestry over a 25 year time horizon in the absence of deliberate

[2] *This information came out from the focus group discussion organized in the village.*

TABLE 1

Land use and land cover statistics within the watershed study area in Kelka, Mopti for the baseline and forest landscape restoration scenarios

<table>
<tr><th>Scenarios</th><th>Baseline</th><th>Forest landscape restoration scenario</th></tr>
<tr><td>Land use</td><td>Area (ha)</td><td>Area (ha)</td></tr>
<tr><td>Agriculture</td><td>29 314.9</td><td rowspan="2">Agroforestry (10 x 10 m spacing)
47 353.5</td></tr>
<tr><td>Agriculture on potential flood zones.</td><td>18 038.5</td></tr>
<tr><td>Bare area with rugged rocky mountains</td><td>31 899.9</td><td>31 899.9</td></tr>
<tr><td>Bare areas</td><td>31 597.1</td><td rowspan="3">Reforestation
125 530.7</td></tr>
<tr><td>Degraded grasslands</td><td>75 611.4</td></tr>
<tr><td>Sparse vegetation</td><td>18 322.1</td></tr>
<tr><td>Settlements community</td><td>239.1</td><td>239.1</td></tr>
<tr><td>Shrubs patches on the rocky mountain</td><td>15 569.9</td><td>15 569.9</td></tr>
<tr><td>Vegetation mosaic of grassland, shrubland and forest</td><td>89 609.24</td><td>89 609.24</td></tr>
<tr><td>Water body</td><td>2 182.5</td><td>2 182.5</td></tr>
</table>

interventions to encourage it. It is also assumed that forest woody biomass will continue to halve every 15 years (Katile, personal communication, 2014).

Forest landscape restoration scenario

IUCN defines forest landscape restoration as a process that aims to regain ecological integrity and enhance human wellbeing in a landscape that is, or once was, dominated by forests and woodlands and which continues to yield forest-related goods and services (Reitbergen-McCracken et al., 2007). At the outset of this study, and in line with the Walde Kelka association's aspirations working on in the area, it was stipulated that a viable land restoration option could involve the introduction of native acacia trees in agroforestry schemes and the reversal land degradation on public forestland through reforestation. The justifications hereof and further detail on the proposed forest landscape restoration scenario is provided in the following.

a. Agroforestry component

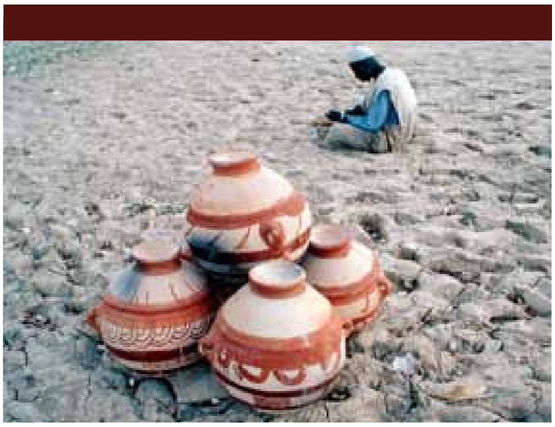
To estimate the potential societal net-benefits associated with agroforestry adoption, authors constructed a future land use scenario in which it is assumed that all areas under agriculture of the study area will be integrated with agroforestry (47 353.53 ha). Based on the literature (Poschen, 1986) and interviews with farmers, *A. albida* is the most preferred multipurpose agroforestry tree, and is considered to be a highly valuable tree species in semi-arid zones, not only as a source of firewood, but also because of its capacity to improve soil fertility through nitrogen fixation (Le Houerou, 1985; CTFT, 1986; Poschen, 1986). Furthermore, it intercrops well with all major crops (e.g., millet, maize sorghum) in agricultural systems.

Integrating this species with conventional agricultural land uses may also enhance soil moisture and water percolation to enhance the consistency of stream flows throughout the year, including the summer months when streams often run dry (Calder et al., 2007). The future land use scenario incorporates a 10m x 10m spacing of *A. albida* trees which is an optimal spacing for firewood production (Belachew, 2012), as it is recommended to leave enough space between trees for effective intercropping (Schroth, 1995). This scenario results in approximately 100 trees/ha instead of the baseline legal minimum of 10 trees/ha.

b. Restoration component

The temperature, rainfall, and soil types present within the study area are all suitable for *A. nilotica*, *A. raddiana*, and *A. albida* tree species. In Mali, the concept of forest has a very broad dimension, which includes the concept of 'forest lands'. Forest land extends to grassland areas as well. The degradation of forest lands is a major concern for policy makers in the country. In fact, several vegetation types have been degraded due to extensive use during the dry season and unsustainable forest resource use (Barrow et al., 2012). In particular, grasslands in the Kelka constitute previous forested areas that have been degraded in recent decades. This is in line with the argument made by Trotter et al (2005) who showed that reforestation may prove an attractive alternative land use option on marginal grasslands.

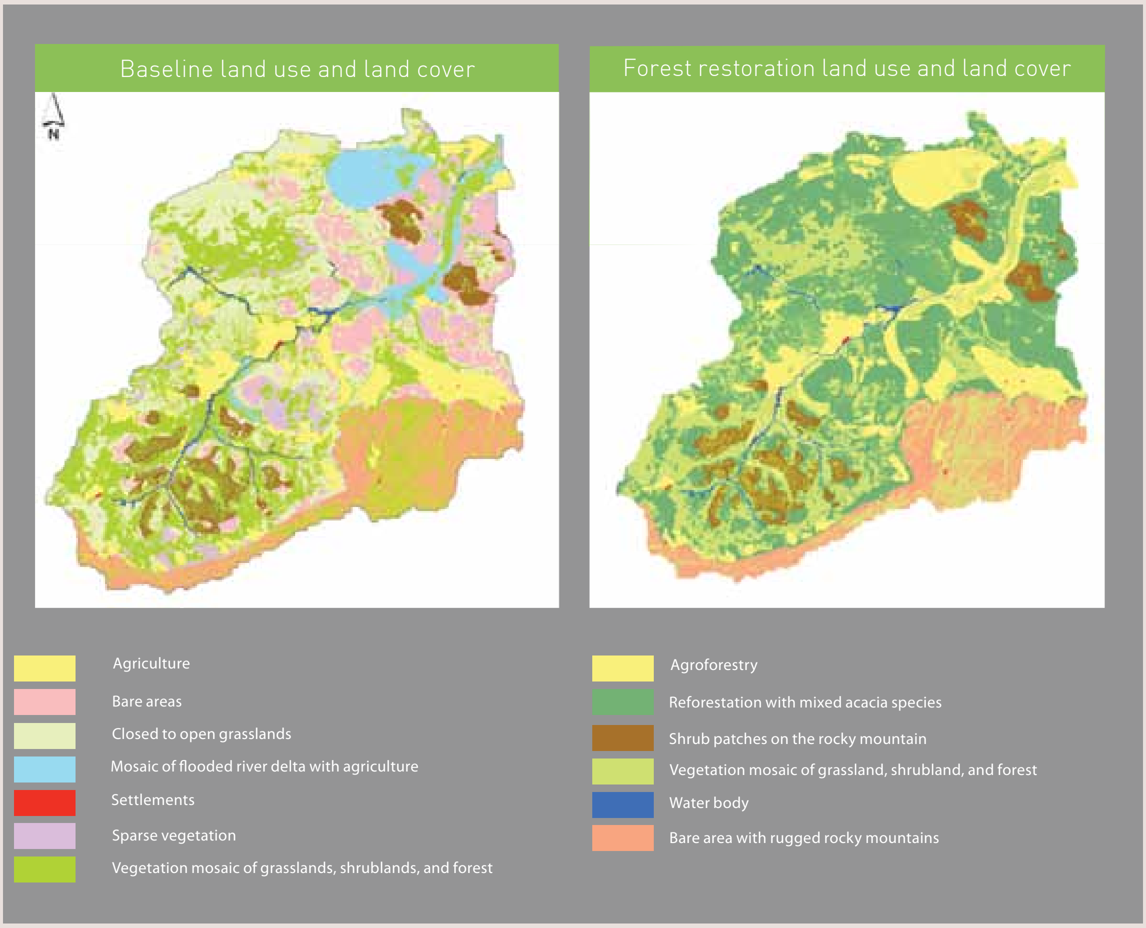
Consequently, the following criteria are considered for creating future reforestation component: bare areas, degraded grasslands, and sparse vegetation areas will be established or restored with different acacia trees based on the following repartition: 40 per cent *A. nilotica*, 50 per cent *A. raddiana*, and 10 per cent *A. albida* [3]. These proportions are based on the rough estimation of community members during the field visit. It is assumed that this corresponds to the natural balance between acacia species in the area. A spacing of 3 x 3m is assumed. This spacing is reduced as compared to agroforestry land because no intercropping is assumed on non-agricultural lands. Also, this spacing seems adequate based on the reforestation experience of the Near East Foundation in the area. *Figure 1* shows the land use maps.



[3] These proportions are based on Kelka community members' own assessment of the natural repartition of acacia species elicited during a field visit to the village of Batouma in February 2014.

FIGURE 2

Land use and land cover map of the baseline and forest landscape restoration scenarios in the Kelka forest watershed, Mopti



03

Methodology and context

For the economic valuation, an eclectic methodology combining different methods was used to capture various benefits of forest restoration. High-resolution remote sensing was combined with ArcSWAT (Soil and Water Assessment Tool) and a crop growth model (AquaCrop). AquaCrop has a strong water component integrated within the economic analysis of key regulating and provisioning ecosystem services provided by the Kelka forest. SWAT is a river basin or watershed scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over a long timeframe.

The model is physically based, computationally efficient, and user friendly; it enables users to compute the long-term impacts of interventions. ArcSWAT, an ArcGIS extension of SWAT, is a graphical user interface for the SWAT model (see Myint (2014) for detailed results). AquaCrop is a crop growth model developed by FAO to estimate crop yields under different agro-climatic conditions. The yield is estimated as harvest index multiplied by the total biomass which is a function of evapotranspiration during the growing period (Steduto et al., 2009). It has been used in several studies in Africa (Ardakanian and Walter, 2011; Khoshravesh et al., 2013), and has four main components:

- Climate: rainfall, temperature, evapotranspiration and CO_2 concentration;
- Soil component: number of soil horizon, thickness, soil water content, total available water, level of soil saturation;
- Crop characteristics: crop water productivity, harvest index, etc., and;
- Crop management component: field management (mulching, bonding, etc.) and irrigation.

For a detailed description of AquaCrop see Steduto et al, 2009. Further details can also be found in *Appendix B*.

Associated costs (implementation and surveillance) were also considered, as well as the constraints and perceptions that may hinder activities geared towards implementing reforestation or agroforestry.

To collect relevant baseline information for the study, authors developed a field sampling design to estimate the availability and household dependency on forest resources, and conducted

TABLE 2

Socio-economic and geographic data (baseline statistics) from the smallholder survey in Batouma

Variable	Mean (std dev)	Variable	Mean (std dev)
Number of households	85	Grain millet yield in 2014 (kg/ha)	259 (302)
Age of household head	40.5 (14.1)	Heads of sheep owned	1.2 (1.2)
Number of people per household	7.6 (5.8)	Heads of goat owned	2.1 (2.9)
Number of working adults per household	3.6 (0.7)	Heads of cow owned	0.6 (1.1)
Literacy of household head	0%	Heads of donkey owned	0.8 (0.8)
Studies after primary school	0%		
Household head born in the same village	56%		
Area of farmland owned (ha)	5.2 (10.6)		
% used for agriculture (principally millet)	55%		
% under fallow	24%		
% other uses (forest, pasture, etc.)	21%		

expert interviews to estimate the costs of agroforestry and reforestation. Authors then visited the field site, met with key stakeholders, implemented the field survey, and gathered socioeconomic data. The community had about 90 households, and a total of 85 household heads were interviewed, of which 10 households had female household heads. Of those 85 questionnaires, 75 were completed and exploited for this study.

The economic valuation framework

To estimate the benefits associated with these forest landscape restoration interventions, both direct and indirect use values have been estimated. These include: 1) the direct use value associated with higher firewood availability; 2) indirect use value associated with increases in agricultural yields due to nitrogen fixating and soil moisture enhancing acacia trees on farm land, and; 3) carbon sequestration: a global indirect use value associated with avoided damages such as global warming. On public land, the benefits of nitrogen fixation and soil moisture retention derived from reforestation efforts are less obvious than on individually owned farmland where the farmer can individually enjoy greater yields. Therefore, the benefit of agroforestry was valued in terms of the contribution from all four ecosystem goods and services to the individual farmer, whereas for forestation only the benefit of enhanced firewood and carbon sequestration was valued. While, the carbon is locally sequestrated, the benefits will be enjoyed at the global level, because a unit of carbon sequestered in Mali is taken out of the global atmosphere. That is why mechanisms are implemented at the international level to incentivize projects with important carbon sequestration potential (CDM, 2013).

It should be noted that even if supplied at an individual farm level, firewood is an externality at the community level unless innovative institutions are put in place to ensure it is privately enjoyed. Presently, the prevailing social norm dictates that firewood anywhere in a community is a common good even when found on private land. Although agroforestry and reforestation will provide other valuable NTFP, the current analysis focuses on timber products, as these are the only provisioning services that can be reliably quantitatively estimated. Therefore, as a word of caution, the true total economic value would be greater than this study suggests (e.g., Arrow et al., 1993). It would also include wider water regulating services, control of land erosion, improved habitat that enhances biodiversity, etc. Aggregate benefits of ecosystem restoration efforts found here should therefore be seen as lower bound estimates.

The values of firewood and nitrogen fixation are estimated using market value. The value of carbon sequestration is estimated using the avoided cost method, while the value of soil moisture and water infiltration is estimated through their effects on yield (market based method). An ex ante analysis is conducted on these values: more detail is given on the different methods in subsequent sections.

Finally, enacting agroforestry practices and reforestation on public land involves costs including **implementation costs** (how much does it cost per hectare to prepare the land and plant the trees), **opportunity costs** (what are the benefits forgone with using that land), and possible recurrent **management costs** (such as surveillance costs).

Biomass

Biomass (associated with crop, wood, and fodder) is an essential variable to consider in forestry studies, because it is directly linked to important valuation parameters such as carbon sequestration, nitrogen fixation, and quantity of wood collected. From the analyses in this study, authors attempted to estimate the benefits from woody, fodder, and crop biomass. Previous studies have suggested that there is a positive linear correlation between the biomass growth of acacia trees and the age of the trees (Okello, 2001). Moreover, the United Nation Clean Development Mechanism advocates the use a linear growth projection for trees and shrubs for the purpose of estimating carbon sequestration and storage from reforestation projects (CDM, 2013). A similar assumption has been used by IPCC (2003) when trees are between 0 to 20 years of age. The following paragraphs briefly present the literature on the different acacia species in the area to determine the growth rate of each, which is important as it is the central component of the overall methodological approach as presented in *Figure 3*.

A. albida is generally a highly appreciated agroforestry species because it intercrops well

TABLE 3

A. albida biomass for different spacing (Okorio and Mahembe, 1994)

Spacing (m x m)	Total Wood Biomass (tons)	Number of trees per ha (trees/ha)	Biomass per tree (kg/tree)	Biomass acquired per year (kg/tree/yr)
4 x 4	28.3	625	255 (302)	7.5
5 x 5	18.7	400	1.2 (1.2)	7.8
6 x 6	12.4	278	2.1 (2.9)	7.4

with agriculture crops and is important for nitrogen fixation (Poschen, 1986). It is a medium weight wood with a density reported between 580 to 730 kg/m3 at 12 percent moisture content. *Table 3* shows *A. albida* biomass for different spacing densities, based on the study by Okorio and Maghembe (1994) in semi-arid areas of Tanzania and the author's own calculations.

For different spacing, the observable difference in biomass is less than 5 per cent. These results strongly suggest that wood biomass is a linear function of the number of trees and that the growth rate is about 7.6 kg/tree/yr.

A. nilotica is generally found in water abundant areas such as river banks and waterlogged areas (Prota, 2014). *A. nilotica* is important for river bank protection and firewood production. The wood density is 700 kg/m3. Biomass yield estimates vary widely according to the study and the site conditions. Average timber biomass yields for plantations on dry sites of 3 to 6 m^3/ha/yr, with 700 to 1000 trees/ha have been reported (Prota, 2014). Maguire et al. (1990) claim that Acacia plantations can produce up to 40 tons of dry-weight of total above-ground biomass/ha/yr in Pakistan. Also wood densities from 650 up to 1170 kg/m^3 at 15 per cent moisture content have been reported (Prota, 2014). Given the wide range, it has been decided to use average density and a biomass yield of approximately 6 kg/tree/yr.

A. raddiana is a subspecies of *Vachellia tortilis* (Kyalangalilwa et al. 2013). V. *tortilis* is a drought resistant tree and an important species for fuel wood production, but does not intercrop well with agricultural crops because of its wide root system. It prefers flat alluvial areas and is known for its high water use. On the other hand, *A. raddiana* can source water from deep aquifers 40 to 50 meters below ground. It is a heavy wood with a density of 580 to 900 kg /m^3 (Goudzwaard, 2014). A 12 year old, 3m X 3 m spaced *A. raddiana* plantation could produce 54 tons/ha of fuel wood annually (Hines and Eckman, 1993). This results in a value of about 48.6 kg/tree at 12 years old, indicating that *A. raddiana* grows by 4 kg /tree/yr.

It is suggested that in acacia species used for fuel wood, natural thinning is adequate and additional thinning is not justified (Prota, 2014), and this was confirmed in key informant discussion.

Based on information mentioned above, *Equation 1* was used to estimate biomass at difference stages:

$$\text{Biomass } T = R \times T \times A / a \qquad \text{(Equation 1)}$$

, where *R* is the forest growth rate, in terms of both above and below ground biomass growth per year, *T* is the time horizon considered for biomass calculation (in years), *a* is the area per tree, and *A* is the total area being considered.

The average below to aboveground biomass ratio for sub-tropical dry forests is reported as 1.27 in IPCC (2003). The formula for the forest growth rate *R*, therefore becomes:

$$R = 1.27 \times \text{Above ground biomass Growth per year} \qquad \text{(Equation 3)}$$

TABLE 4

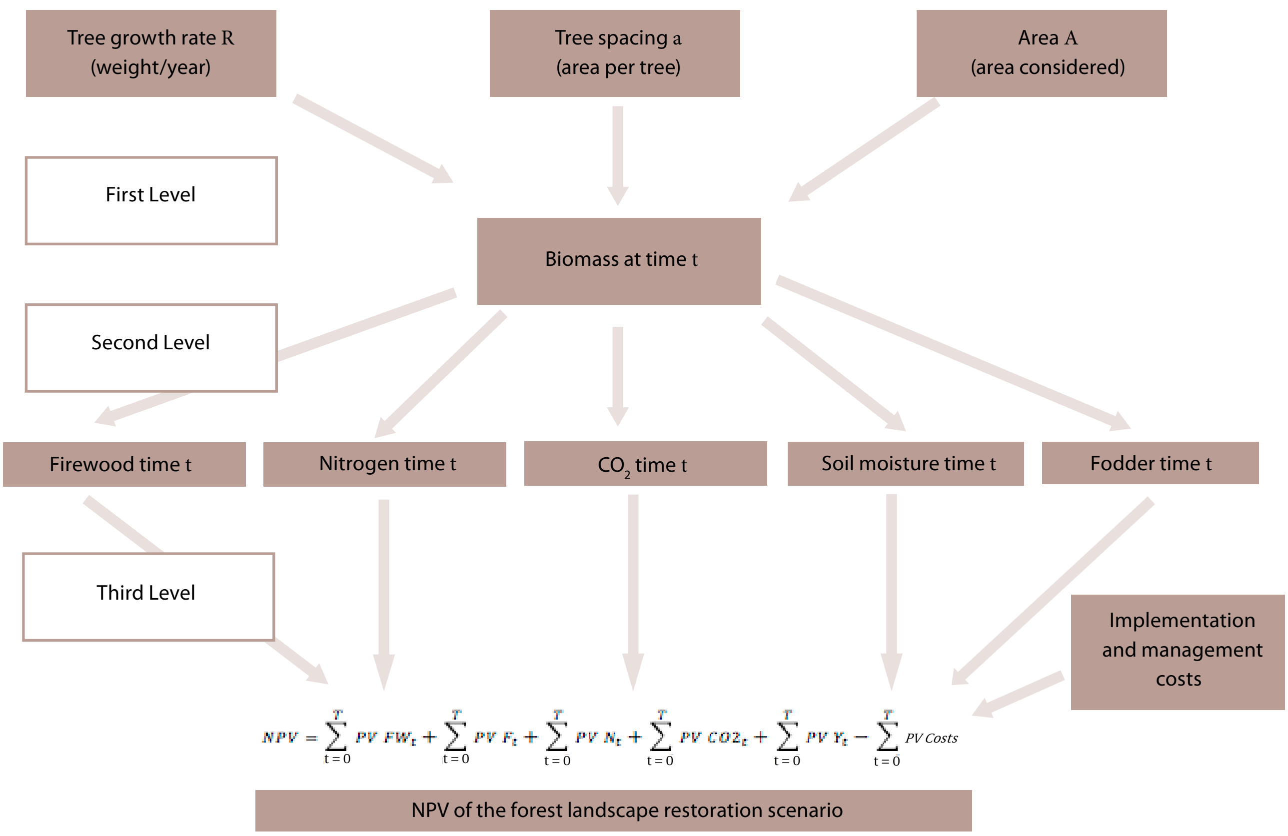
Summary of tree growth and density assumptions used in the alternative scenario

Agroforestry land			
Tree type	Tree growth rate (kg/tree/year)	Proportion (%)	Spacing
Acacia albida	7.6	100	10m x 10m
Reforestation land			
Tree type	Tree growth rate (kg/tree/year)	Proportion (%)	Spacing
Acacia albida	7.6	10	3m x 3m
Acacia nilotica	6.0	40	3m x 3m
Acacia raddiana	4.0	50	3m x 3m

Figure 3 shows the overall methodological approach of the NPV calculation and illustrates the different steps. Knowing the area, the spacing and the biomass growth rate (first level of the figure), the biomass of the trees can be calculated year by year (second level of the figure). The biomass is a fundamental element as it allows calculation of the other key variables. Other relevant valuation components (firewood, nitrogen, carbon, and soil moisture) are calculated based on the biomass (third level of the figure). Finally, the valuation of firewood, nitrogen, carbon, and soil moisture plus the costs of agroforestry and reforestation are used to calculate the NPV (fourth level of the figure).

FIGURE 3

Overall methodological approach (main variables are described in Table A1 in Appendix A)



Firewood for agroforestry and reforestation

Communities in the Kelka are highly reliant on forest products. In the face of low agricultural productivity, forest products - especially firewood - provide complementary income to community members. Collection is restricted to dead wood, and firewood collected in the forest is sold to commercial dealers who export it to major cities like Bamako. However, the forest is under threat due to insufficient restoration and conservation practices. During the smallholder survey implementation in February 2014, several community members revealed that while it took one hour to collect seven heaps of firewood 15 years ago, today they need to spend up to 2 hours to gather the equivalent amount of resources.

Interventions that promote agroforestry and restoration of bare or degraded land can help improve the resource base. The present value benefit of the baseline scenario is compared with the alternative scenario, considering different discount rates. In doing so, it is assumed that the quantity of dead firewood that can be collected (for a given period of work time) is proportional to the quantity of biomass available (IPCC, 2003). For reasons explained below, only the contribution of dead wood to household firewood production from A. albida agroforestry was valued, although in practice it is also feasible for the individual farmer to prune trees for additional firewood. The mathematical formulation used to estimate the present value of enhanced firewood supply is demonstrated in *Appendix C*. Results are reported in *Table 6*.

Value of fodder from *A. albida* agroforestry

A. albida can provide important source of animal fodder. For example, a wood savanna in which *A. albida* is the dominant tree species, has been found to able to stock 20 animal units per km^2 as compared with 10 units when *A. albida* is not present (Giffard, 1964). According to FAO (1980) a full-grown *A. albida* tree can produce more than 100 kg pods per year. Cisse and Kone (1992) reported pod production of between 125 and 135 kg/tree/yr in Senegal and Sudan, respectively.

To take advantage of forage production, pruning of smaller branches and twigs for fodder is therefore commonly practiced in *A. albida* agroforestry systems (FAO, 1999). Firewood is another valuable product that may be derived from the pruning of *A. albida*, but since pruning for firewood compromises the value of fodder production (FAO, 1999), it was assumed here that the farmer optimizes for fodder production at the expense of less firewood.

In estimating the benefits, authors assumed that fodder production increases linearly with tree age, up till 130 kg/tree in year 25 when the tree has reached maturity (Cisse and Kone 1992). However, the production of firewood is optimized for 100 trees planted per hectare of land (Belachew, 2012), in accordance with the scenario modeled in this paper. At 100 trees/ha (at 10 x 10 m spacing), the total fodder produced over the 25 year time horizon for one hectare of *A. albida* agroforestry amounts to 145 tons. Pods may be harvested during dry season when fodder is scarce and used to feed animals or sold on local markets (e.g., in the town of Kona). Either way, the resource may appropriately be valued using local farm gate market prices (Vedeld et al., 2004).

The value of *A. albida* fodder is estimated using market value. According to the smallholder survey and an interview undertaken with Amadou Katile, general secretary of the Walde Kelka Association during the field visit in February 2014, a bag of fodder (weighing about 15 kg) is sold at 35 XOF (West African CFA Franc) (0.07 USD)[4] in the local market of Kona. The present value formula used to value the benefit of additional fodder production (assuming constant prices) is shown in *Appendix D*.

Nitrogen fixation

As earlier mentioned, Acacia species are known for their ability to fix atmospheric nitrogen. This property can be efficiently exploited with success in agroforestry systems, as it has been in other agroforestry systems around the world (e.g., Danso et al. (1987)).

Unfortunately, accurate measurement of nitrogen fixation in large field-grown trees is virtually impossible. Thus, attempts to quantify nitrogen fixation in natural ecosystems and to understand its role in them are still at an early stage (Vitousek et al., 2002). The existing literature only estimates seedling quantities. For example, Kiriinya (1988)

[4] Using a 2014 exchange rate of 500 XOF to the US dollar. The same conversion rate is used throughout the text.

analyses nitrogen concentration in seedlings, without specifying how the results could be applied for mature trees. Similarly, Dommergues (1987) mentions the figure of 20kg N_2/ha/yr. Dommergues (1987) does not specify the density at which the trees were spaced, but since 100 trees/ha, which is common in agroforestry systems, we make the assumption that 20 kg of N_2 is fixated, for a tree density of 100 trees/ha. It is further assumed that this is the fixation rate for mature trees of 25 years old, and that nitrogen fixation is proportional to the biomass as suggested by Dommergues (1987). The resulting implication is that 1 ton of A. albida can fix about 1.32 kg of N_2 per year.

To estimate the value of enhanced nitrogen fixation, the 'replacement cost method' was used - that is, the cost associated with replacing soil nitrogen through the purchase of inorganic fertilizers was estimated. This is done according to the formula shown in *Appendix E*. Results are reported in *Table 6*.

Carbon sequestration and storage

To estimate the societal value associated with enhanced carbon sequestration in the alternative forest landscape and land use scenario, authors firstly assumed that the quantity of carbon sequestered is assumed to be directly proportional to and equal to half the total annual amount of above and below biomass, following IPCC Tier 1 guidelines. The annual increase in biomass for each tree species is estimated based on literature as shown in the earlier section on biomass. The equation converting above and below ground biomass to carbon sequestration is shown in *Appendix F.*

Secondly, authors used the social cost of carbon (SCC), reported in IWG (2013) to estimate the value of the avoided damage caused by one ton of carbon dioxide. These damages include decreased agricultural productivity, damage from rising sea levels, and harm to human health related to climate change. The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change.

The SCC figures have been estimated by the White House Interagency Working Group (IWG 2013), using Integrated Assessment Models (IAMs), which integrate a simplified climate model and a simplified economic model into a cohesive numerical model to capture the feedback effects between the two. Using a methodology specified in the 2010 Technical Support Document (IWG, 2010), the White House Interagency Working Group performed SCC estimates for three IAMS: DICE-2010 (Nordhaus 2010); FUND 3.8 (Anthoff and Tol 2012) and PAGE09 (Hope 2011) .

Soil moisture and ground water percolation

The value of soil moisture is estimated through the additional value of the crop yield surplus it brings about. Soil moisture is calculated for the baseline and future scenarios using the SWAT model. The AquaCrop model was then used to estimate crop yield for both scenarios. As previously explained, AquaCrop is a FAO developed agronomic model with a strong water component designed to simulate crop growth from sowing to harvest on a daily time scale (Steduto et. al., 2009). It simulates the crop growth process as a function of the climate and the soil parameter, and has been validated in various conditions in the Sub-Saharan Africa context (see Khoshravesh et. al., 2013 for example). *Appendix B* shows the parameterized values for AquaCrop and SWAT.

The soil water profile is assumed to be at field capacity at the beginning of crop growing the season. SWAT simulations (Myint 2014[5]) indicate that there will be an increase in the level of soil moisture by 2.1mm, increasing from 19.7mm in the baseline scenario to 21.8 mm in the restoration scenario *(Table B1, Appendix B)*. In running the model, it was assumed that the main crop in the area (millet) efficiently uses water. Given this, simulations from the crop-growth model shows that enhanced soil moisture from *A. albida* agroforestry may increase yields by 24 kg/ha, over and above the baseline scenario of 259 kg/ha in the area. That is equivalent to a 9 per cent increase in yields.

The forest landscape restoration will also enhance the recharge of the shallow groundwater aquifer. The SWAT model outputs shown in *Table B3* in Appendix B shows that groundwater recharge will increase by an average of 198 m^3/ha (or 19.8 mm), from 152 m^3/ha in the baseline scenario to 350 m^3/

[5] *Myint 2014. Biophysical Analyses to study the changes to Ecosystem Services following the implementation of Sustainable Land Use Practices in Sudan, Mali, and Jordan. Accessible at: http://cmsdata.iucn.org/downloads/final_report_eld_18july__2_.pdf.*

ha in the forest landscape restoration scenario. In order to attach a shadow value to the additional water generated, authors estimated the value of using it in the production of millet as part of a supplementary irrigation scheme. The method is a variant of the Change in Net Income (Hearne and Easter, 1997; Johansson, 2005). Using this approach, the simulated crop-growth model indicates that by using an additional 198 m^3 of water/ha of cultivated land it would possible to double agricultural yields to 463 kg/ha. In that case, the implied proxy for the shadow value of water is 0.31 USD/m^3 (155 XOF/m^3) based on a market price of 0.3 USD/kg for millet. This is likely to be an upper bound estimate to the extent that it does not reflect the behavior of farmers in the area (few farmers irrigate) and does not account for supply costs of water.

Considering the possibility that the increased percolation into shallow groundwater can be used for the supplementary irrigation of millet crops, it is possible to double yields to 463 kg/ha (relative to the baseline scenario of 204 kg/ha) without enhanced soil moisture or supplementary irrigation schemes. These effects are not likely to be realized until several years after the trees have been planted. It is therefore assumed that the effects will gradually be realized in 20 years. Also, as trees in agroforestry systems occupy space that would otherwise be cultivated, yield per hectare will be reduced. It is assumed that on average, an area of 5 m^2 around the tree will not be productive (because of the shade and the root system). This is accounted for in estimations of total yield per hectare in the alternative land use restoration scenario. The present value formula used to estimate the value of enhanced soil moisture in agroforestry production systems is shown in *Appendix G*. The beginning of the rainy season is the best period to start restoration or agroforestry activities, due to water scarcity in the dry season.

Implementation and management costs

The advantage of the reforestation of mixed acacia species (*A. nilotica, A. raddiana, and A. albida*) is that seeds are readily available in the wild and the cost of attaining them is thus negligible. Furthermore, acacia trees do not require any special management after five months (or once the trunks attain a certain height, as they are indigenous to the region. Thus, the main costs associated with reforestation efforts on public lands refer to the initial time investment associated with planting and watering the trees. Costs were estimated based on the narrative of a member of the Walde Kelka Association (Katile, Amadou, personal communication, 2014) and estimated on the basis of a previous experience of the Walde Kelka close to the village of Batouma in 1998.

More specifically, a project was developed using 5 ha of various acacia species with an average spacing of 3 x 3 m. It involved two different phases of planting and watering up until germination, followed by surveillance to avoid damage by free roaming livestock. It was found that it took 62 children (<18 years of age) and 31 adults each working 20 days for approximately one hour per day, to do land scarification, plant seeds, and irrigate them until germination. Adults are assumed to be twice as productive as children. Land scarification is done by using hoes in the zone where the acacia seeds are to be planted. As the first five months are critical for the survival of acacia trees, reforestation efforts subsequently involved 12 adults protecting the area from wandering animals for approximately 10 hours a day for 4 months.

To approximate the costs associated with reforestation, authors valued the time spent by community members per hectare on these activities. Household labour is valued as opportunity costs, estimated by what may be earned in the income-garnering activity, namely firewood collection. On this basis, the opportunity cost in terms of foregone firewood collection ranges between 1.1 to 1.7 USD (551 to 827 XOF) per day according to the smallholder survey that was conducted in Batouma. An average value of 1.4 USD (690 XOF) was used in this calculation. Villagers work about 10 hours a day, thus the opportunity cost per hour for an adult is 0.14 USD (69 XOF). It was assumed that children's opportunity costs are half this value. *Table 5a and 5b* show how the costs were calculated.

The reforestation experience near Batouma, although it was not based upon the principles of FMNR methods, also had relatively low associated costs and was based on locally-led initiatives developed through the CEMPs. FMNR is a low-cost approach that allows quick regeneration of forests and agroforestry sites through protection and management of indigenous species (Haglund, 2011).

TABLE 5A

Planting and watering implementation cost until germination

Until germination (planting and irrigation) 5 ha							
Number of persons	Number of days	Number of hours/day	Number of hours	Per hour opportunity cost XOF	Total cost	Cost per ha XOF	Cost per ha in USD
62	20	1	1240	68.9	85,477	17,095	34

TABLE 5B

Surveillance implementation cost

Number of persons	Number of days	Number of hours/day	Number of hours	Per hour opportunity cost XOF	Total cost	Cost per ha XOF	Cost per ha in USD
12	80	10	96,00	68.9	661,760	13,235	265

The method has proved to be successful on a large scale in semi-arid areas of Niger (Water Vision, 2014).

Implementation and management costs associated with A. albida agroforestry

To ensure survival and increase To ensure survival and increase the production of trees in reforested lands, Sahelian farmers commonly water seedlings, protect or fence seedlings, and prune trees (FAO 1999). As such, establishing a successful A. albida agroforestry system requires investments in terms of time and capital inputs for fencing. Due to the cash constraints of farmers in the Mopti area, fencing is rarely adopted. Moreover, because farmers are in the field during the rainy season after trees have been planted, ensuring that no damage is made from browsing animals can be done whilst working in the field. Surveillance costs are therefore assumed to be negligible for agroforestry restoration. The major implementation costs are therefore associated with the planting and watering of trees until they can germinate in the first year, using the same assumptions as outlined in *Table 5a*.

Yearly A. albida management costs associated with pruning and collection of fodder

The purpose of pruning A. albida trees may include wood, fodder and mulch production, improved fruit production, reduction of shade on understory crops, longer tree lifespans, and control of parasitic plants such as *Tapinanthus spp.* in affected species (FAO 1999). As found in the earlier section on the value of fodder from *A. albida* agroforestry, this paper estimates the value of such prunings through its contribution to livestock fodder.

Farmers prune acacia trees and gather pods to feed to their livestock daily in the dry season when most other trees are leafless (and when fodder is most scarce). It takes one hour to harvest four bags of fodder (7.5 kg). According to previously outlined assumptions, fodder production is considered directly proportional to the age of the tree, up until the age of 25 when the tree reaches maturity. Every year, each tree therefore produces an additional 5.2 kg of fodder, reaching a maximum of 130 kg/tree during its lifespan. For the sake of illustration, by the 25th year, 1733 hours ((100 trees * 130 kg)/7.5 kg) is spent on pruning for fodder per hectare. It is assumed that farmers are able to collect all the fodder available from their A. albida trees in the dry season. As when estimating implementation and surveillance costs above, household labour is valued at its opportunity cost, namely what may be earned through an equivalent time spent collecting firewood.

Finally, no felling costs are incorporated in this analysis, since except for very old trees, which no longer pollard properly, *A. albida* trees are not normally felled (Laike 1992). *Appendix H* shows how the present value of implementation and management costs have been estimated.

04

Results and discussion

Results

On the basis of this cost-benefit analysis, the NPV of Kelka to the local communities as well as to society as a whole is estimated as the sum total of the value of enhanced firewood production, carbon sequestration, nitrogen fixation, soil moisture and water infiltration, less the implementation and management costs, for three different discount rates. The results are presented in *Table 5* and the formula used to calculate the NPV is shown in *Appendix I.*

Table 7 shows the cost-benefit ratio to the individual farmer of adopting *A. albida* agroforestry. Only private benefits and costs are included. Private benefits include, fodder, firewood (dead woody biomass), yield increases through enhanced soil moisture, and the value of nitrogen fixation.

To achieve these community plans and implement the 'Local Convention', the project had to first focus on building the capacity of members of the Walde Kelka Association (elected officials and municipal officers including representatives of the communities). Walde Kelka would then be a support platform to train communities further on establishing management plans. Given the weakness of local natural resource rights, strengthening of local governance, for example by strengthening implementation of the local convention, is a priority.

Value of forest landscape restoration in the Kelka

The results presented in the previous section suggest that the net present benefits of agroforestry and reforestation efforts in the Kelka outweighs the net present costs for discount rates of 2.5, 5, and even 10 per cent.

Agroforestry provides the highest per hectare return on investment. When accounting for the contribution of firewood, fodder, increased soil moisture and nitrogen fixation, the results suggest that farmers may enjoy between 5.2 to 6 USD of benefits for every dollar invested. It is worth noting however that cash-constrained farmers often have very high personal discount rates in excess of 10 per cent (Barbier, 2000). Real personal discount rates of smallholder farmers between 15 and 70 per cent have been reported in the literature (Cuesta et al., 1994; Brent, 1989). If such rates apply to the farmers in this area, it is unlikely that farmers will ever switch directly to agroforestry farming systems. However, a phased approach to agroforestry adoption, such as FMNR can help reduce the implementation costs and hereby make adoption more likely.

The benefit cost ratio of the integrated agroforestry and reforestation scenario, is in the order of 1.7 to 3 USD. This corresponds to a net present value of between 300 and 1,300 USD/ha (0.015 -15.5 million XOF/ha) over a 25 year time horizon, equivalent to an annuity value of the present value of future benefits of between 18 to 62 USD/ha/year (9,000 - 31,000 XOF/ha/year). If it had been possible to account for the value of enhanced availability of non-timber forest products and bush meat (biodiversity, more largely) in this valuation study, the NPV would inevitably have been higher.

Finally, it is noteworthy that the societal value of forest landscape restoration scenario is significantly larger when integrating the global benefits from enhanced carbon sequestration. In that case, forest landscape restoration provides up to 13 dollars of benefits for every dollar invested (at a discount rate of 5 per cent), equivalent to an annuity value of 428 USD/ha/year (214,000 XOF/ha/year). The welfare estimates associated with carbon sequestration however are highly sensitive to the discount rate used. Because a large portion of climate change damages are expected to occur many decades into the future, the present value of those damages is highly dependent on the discount rate.

In reality, the implementation of forest landscape restoration is subject to a number of potential obstacles, whether reforestation on public lands or agroforestry on private lands. First, initial financial costs of implementation are high if farmers are

TABLE 6

Calculation of the net present value of agroforestry and reforestation (in USD)

		r = 2.5%			r = 5%			r = 10%		
		PV per ha	Per ha annuity value	PV whole watershed	PV per ha	Per ha annuity value	PV whole watershed	PV per ha	Per ha annuity value	PV whole watershed
	Benefits									
A	Increased firewood (Ag*)	**107.7**	5.8	5,100,000	**73.9**	5.2	3,500,000	**38.0**	1.7	1,800,000
B	Increased firewood (Re*)	**321.0**	17.4	40,300,000	**220.7**	15.7	27,700,000	**114.7**	5.2	14,400,000
C	Increased nitrogen fixation (Ag)	**308.3**	16.7	14,600,000	**211.2**	15.0	10,000,000	**109.8**	5.0	5,200,000
D	Increased soil moisture (Ag)	**557.5**	30.3	26,400,000	**382.2**	27.1	18,100,000	**196.4**	8.9	9,300,000
E	Enhanced shallow aquifer recharge (Re + Ag)	**158.5**	8.6	27,400,000	**120.9**	8.6	20,900,000	**78.7**	3.6	13,600,000
F	Enhanced availability of animal fodder (Ag)	**408.0**	22.1	19,320,000	**296.5**	21.0	14,040,000	**166.0**	7.5	7,860,000
G	Enhanced carbon sequestration (Re)	**18,774.7**	1,019.0	2,356,800,000	**3,995.8**	283.5	501,600,000			
H	Enhanced carbon sequestration (Ag)	**5,790.5**	314.3	274,200,000	**1,220.6**	86.6	57,800,000			
	Costs									
I	Agroforestry implementation costs	**33.8**	1.8	1,600,00	**33.8**	2.4	1,600,000	**33.8**	1.5	1,600,000
J	Agroforestry management costs	**200.8**	10.9	9,510,000	**145.9**	10.4	6,910,000	**81.7**	3.7	3,870,000
K	Reforestation implementation costs	**298.7**	16.2	37,500,000	**298.7**	21.2	37,500,000	**298.7**	13.6	37,500,000
	Net benefits									
	Kelka smallholder farmers (from Ag only)									
A+C+D+F-I-J	Net benefit	**1,147.0**	62.2	54,310,000	**784.0**	55.6	37,130,000	**395.0**	17.9	18,690,000
(A+C+D+F)/(I+J)	Benefit-cost ratio	**5.9**			**5.4**			**5.2**		
	Kelka forest communitites (from Ag + Re)									
A+B+C+D+E+F-I-J-K	Net benefit	**1,328.0**	72.1	84,510,000	**827.0**	58.7	48,230,000	**289.0**	13.6	9,190,000
(A+B+C+D+E+F) / (I+J+K)	Benefit-cost ratio	**3.0**			**2.7**			**1.7**		
	Global society (from Ag + Re)									
A+B+C+D+E+F+G+H-I-J-K	Net benefit	**25,893.0**	1,405.4	2,715,510,000	**6,043.0**	428.8	607,630,000	**289.0**	13.6	9,190,000
(A+B+C+D+E+F+G+H)/(I+J+K)	Benefit-cost ratio	**49.5**			**13.6**			**1.7**		

**The total area dedicated to each is 46,353.5 ha (agroforestry) and 125,530.7 ha (restoration), which are referred to as Ag and Re respectively.*

expected to switch from current practices to agroforestry in one move. Local populations may not have the necessary financial means to undertake such large-scale restoration activities. Secondly, the Kelka forest is not classified as a protected forest. Since the forest is a de facto open-access resource, people outside the Kelka communities can harvest tree products for their personal benefits. The resulting 'tragedy of the commons' has discouraged Kelka communities from fully engaging in forest landscape restoration. Thirdly, because benefits such as carbon sequestration and ground water infiltration are external to the individual household, they are most like ignored in household decision-making processes. Strong institutional arrangements would therefore be necessary to ensure that communities have sufficient incentives to engage in forest landscape restoration, beyond their own backyards. Indeed, one of the reasons that that the benefit cost ratio of adopting agroforestry is greater than that deriving from the integrated agroforestry and reforestation intervention, is that farmers are able to appropriate a greater share of the products and ecosystem services produced by the trees on their farm, relative to when tree planting efforts occur on public lands.

While lack of cash can explain low adoption agroforestry adoption rates, another significant constraint to the uptake of agroforestry in the area relates to the farmers' perception that trees attract wildlife, particularly birds that could subsequently damage crop yields. While there is no scientifically conclusive evidence to suggest this is indeed the case, such deep-rooted beliefs would need to be challenged through appropriate extension services in order to be overcome.

To address some of the above-mentioned institutional issues, there have been over a decade of IUCN interventions in the Kelka. These have focused on supporting and strengthening the 'Local Convention' established 15 years ago by local stakeholders. The objective of the 'Local Convention' was to enhance community management rights of the forest resources and identify mechanisms that would ensure that the sharing of the benefits is equitable and acceptable for the different stakeholders. This also involved providing rights to women and other vulnerable groups. The convention has been partially applied to strengthen local resource rights and targeted support, on raising awareness of the convention and enabling local partnerships (community-government) to boost implementation. CEMPs were developed with the various communities within the Kelka to prioritise and establish forest management, e.g., establishing sustainable harvesting rules or the setting up of compensation schemes to communities for actively engaging in forest landscape restoration.

Perceptions and constraints influencing the likelihood of locals adopting agroforestry and engaging in reforestation initiatives

The household survey undertaken as part of this project revealed that all farmers are aware of soil fertility problems. The common solution in the community is to bring additional organic matter to the land. Unfortunately, this solution doesn't yield expected returns because of the difficulty in collecting enough organic material. Increased awareness around soil fertility benefits from agroforestry may make local populations more receptive to adopting such agricultural systems. There is a need to work with farmers to experiment with FMNR through on-farm trials in the area for demonstration purposes. The success of such demonstrations will strongly determine the likelihood of local farmers to adopt integrated crop-tree systems. A complementary option is to progressively educate local community on the fertility improvement role that *A. albida* trees can play in agricultural systems by communicating to them results obtained in other semi-arid areas (e.g., in Niger) (Water Vision, 2014). Although *A. albida* was used here because its potential as an agroforestry tree has been extensively studied, other native acacia species can also be experimented with.

The primary perceived constraint to reforestation is the need to water young trees to ensure survival (mentioned by 83 per cent of the respondents). The second major constraint is impacts from wandering animals that do not allow young tree seedlings to develop. The lack of appropriate equipment and knowledge to protect trees were also mentioned as important barriers to forest landscape restoration. Education and awareness raising could be of value in showing farmers how to natural regenerate selected trees on their crop lands, although policy and attitudinal barriers over rights to these trees still need to be further examined. This may be an area where the local convention can play a critical role.

Finally, the fieldwork undertaken for this study revealed an additional barrier at the cultural level hindering agroforestry development; while farm crops are considered the private ownership of the household having planted them, resources from trees on the cropland, such as wood and forage resources, are considered communal property. This makes it difficult, or at least socially unacceptable, for the individual farmer to exclude other community members from the use of wood and tree forage resources, making it even more important to engage the 'Local Convention' to delineate rules and boundaries to prevent these unfavourable situations.

Limitations and perspectives

Due to security concerns in the study area, the total time dedicated for fieldwork (including the focus groups and questionnaire administration) was only four days. This situation did not allow for enough time to thoroughly investigate some aspects, such as the possible willingness of the population to engage in the commercial exploitation of acacia plantations besides the collection of dead wood (presently, only eucalyptus plantations are used in rotations for commercial exploitation involving the tree-felling). Nonetheless, intensive information collection was made during the visit to the Batouma community, permitting the analysis above.

This economic valuation does not represent a comprehensive account of the benefits from agroforestry and reforestation. For example, there are several diffuse benefits from agroforestry associated with improvements in the physical, chemical, and biological properties of the soil that may not have been accounted for in our consideration of nitrogen fixating and soil moisture improving properties only.

Reforestation on degraded grassland may also enhance nitrogen fixation and lead to more healthy soils for the future. This 'option value[6]' is not considered here. Moreover, benefits associated with increased wildlife (habitat for gazelles, baboons, and bees for pollination and honey production) (Barrow et al., 2012) that could result from forest landscape restoration have not been taken into account because of the difficulty of establishing clear cause-effect relationships.

IUCN and its partners have supported communities to process and market wild fruits from reforested land, providing further incentives for sustainable management and protection; this provides an insight into the potential additional value of biodiversity. Therefore, the NPV estimates here represent lower bound benefit estimates rather than comprehensive net-benefits.

The study was based on simulated climatic data on the basis of observations of temperature, wind, and rainfall data, for the past 20 years in the Kelka forest. It does not consider the possible influence of future impacts of climate change in the area. Projections predict a decrease in rainfall over time, but with overall increased rainfall variability (IPCC, 2014). The uncertain impact of such changes on the estimated net present values has not been accounted for here.

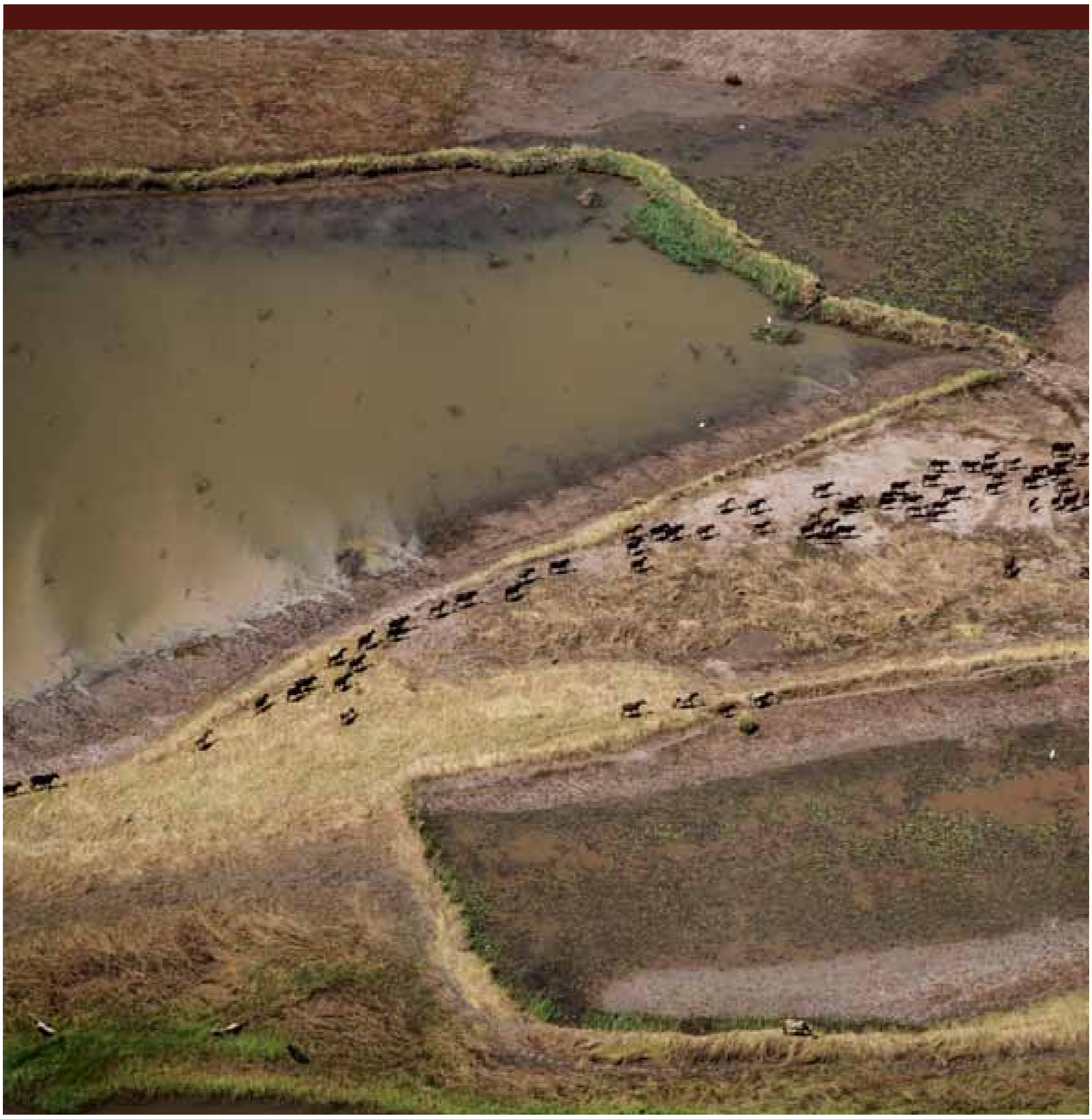
The value of enhanced shallow groundwater recharge was estimated using a crop growth model that uses water as an input assuming that the additional water infiltrated to the shallow groundwater aquifer as a result of forest landscape restoration is used in the production of millet. The value of the enhanced yields is then used as a proxy for the shadow value of irrigation water. In using this approach, authors did not consider supply cost of water (e.g., irrigation equipment), neither the actual behavior of the farmers in the area. The estimate is therefore likely to be an overestimate of the true economic net value of water in the Kelka forest.

Finally, the assumption that such a large area like the Kelka forest is restored homogenously across the entire area at the same time should be viewed as an abstract way of conceptualizing the global impact of intervention rather than a real implementation program. However, this conceptualization exercise is useful at the level of a large catchment in order to help better capture the hydrological processes that result from forest landscape restoration interventions. In particular, a high density of vegetation is required for there to be any observable change in the hydrological regime in terms of improved soil moisture and aquifer recharge. This implies that if only a few hectares are restored or used in agroforestry

[6] Option value is the value that people place on having the option to enjoy something in the future, although they may not currently use it.

systems, expected benefits may not materialize. On the other hand, large-scale restoration efforts like the one presented here may have general equilibrium effects, e.g., pushing down prices on firewood, in which case the benefit estimates of firewood are overestimated. On the other hand, with increasing scarcity of woody biomass and population pressures in surrounding areas, it is unlikely that overall demand relative to supply will increase over time. In that sense, doing ex-ante cost benefit analysis of an uncertain future is a challenging undertaking.

Preliminary results of this analysis have been presented in a workshop including participants from regional administrative authorities, technical services, NGOs, and members of the Walde Kelka Association in Sévaré, September 2014. As recommended by workshop participants, considering the importance of pastoralism in the area, a more thorough investigation of the benefits for livestock and the values of grassland restoration would be the logical next step from the study. Also, a next analysis would need to look more carefully at the potential climate change adaptation strategies offered by large-scale landscape, e.g., through changes to the micro-climate and the frequency and impacts of droughts. Finally an in-depth analysis of the accompanying policy measures will be required. The workshop did not reveal any major political constraints.



05 Conclusion

The degradation of the natural resource base of local communities is a major threat for sustainable development (Guissé, 2013). Estimating the value of such resources and the interventions necessary to promote their restoration represents a first step in the fight against poverty and land degradation. Benefits including access to increased firewood supply and fodder, enhanced soil fertility (increased soil moisture and nitrogen), and carbon sequestration were estimated in this analysis. The study demonstrates that the benefits of large-scale landscape restoration from acacia reforestation and agroforestry in the Kelka area largely outweigh the costs both at the local and global levels when discounted at 2.5, 5, and 10 per cent for a time horizon of 25 years. This implies that such landscape interventions are largely justified.

This analysis also shows that benefits outweigh costs over a 25 year time horizon at the level of the individual farmer. Benefits to cost ratio vary from 5.2 to 6 in agroforestry systems depending on the discount rate (*Table 6*). However, trees that are integrated in cropping systems are perceived to compete with agricultural productivity, as trees are believed to attract grain-eating birds. This is a deep-rooted perception that cannot be overcome through simple communication. Thus, in order to be able to promote agroforestry practices, as recommended by this study, there is a need to practically demonstrate the usefulness of agroforestry practices to smallholders in the Kelka. Appropriate approaches to agroforestry should be considered, particularly the low cost options provided by FMNR, to avoid propping up extension with unrealistic subsidies.

Some of the benefits of landscape restoration accrue to a broader stakeholder group, e.g. global citizens benefitting from carbon sequestration. These however, do not incur the costs associated with delivering that ecosystem service. It may therefore be legitimate that local populations are incentivized through benefit transfer mechanisms. This will represent a win-win situation where both local and international communities enjoy shared benefits. Appropriate mechanisms to move in this direction still need to be explored. There are also significant benefits associated with SLM practices, to be provided at the domestic level (e.g., water infiltration and soil stabilization). Farmers benefit directly from SLM and therefore any incentives should be carefully considered for their long term viability, not only for short term expediency.

A priority is to expand work on FMNR to work with farming communities towards natural regeneration. This is likely to require awareness raising, exposure to other sites, and some level of training. If additional incentives are required, as suggested in Seyler (1993), farmers willing to engage in agroforestry practices could be exempted from some rural taxes. Farmers trained in silvicultural techniques could also serve as local forestry extension service providers. Even with these incentives, as mentioned in the section on perceptions and constraints influencing the likehoold of locals adopting agroforestry and engaging in reforestation initiatives, work also needs to be done at the socio-cultural level to:

1) challenge the perception that trees attract crop-damaging birdlife, and;
2) ensure farmers can legitimately appropriate the benefits that on-farm trees provide in the absence of outsider encroachment of perceived 'public resources'.

As for reinforcing community management rights over forest resources, one of the main challenges faced is that the Walde Kelka Association has no legal right to sanction people who do not obey the rules and regulations established by local institutions, despite the fact it derives its legitimacy from the involvement of traditional leaders (Hesse and Trench 2000). The incompleteness of the Malian decentralization process, in the sense that it is not flexible enough to recognize locally defined management plans or local forest convention, is arguably the ultimate obstacle to the establishment and enforcement of local regulations. As sanctions for disregarding local conventions remain the responsibility of the State, incentives for local SLM are absent (Hesse and Trench 2000). Similar problems associated with lack of tenures over rangeland resources, were found in a parallel ELD study in Jordan (Westerberg and Myint 2014).

In Mali, a possible solution may come from an enhanced decentralization process that empowers local institutions and is an inclusive collaboration between the forest administration, elected communes, and Kelka local stakeholders. The fact that the Kelka forest covers three different rural communes makes it necessary to encourage close collaborative platforms for the realization of large -scale reforestation.

There is a pressing need to halt land degradation and the depletion of resources in the Kelka, as well as in other sensitive areas in the semi-arid West African regions. When communities are more aware of and sensitive to resource depletion problems, the implementation of interventions will be easier. The survey here revealed that the population within the Kelka forest area is well aware of the challenges and ready to engage in activities that may improve the natural capital of the area and the ecosystem service dividends it provides.

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Appendices

Appendix A - Costs and prices

Nitrogen price

The price of a kilogram of pure nitrogen can be estimated from the price of a bag of nitrogen fertilizer (PSS, 2014). A 50 kg bag of nitrogen fertilizer contains 23kg of pure nitrogen and 27 kg of other inert materials. It costs between 12,500 and 13,500 XOF (FAO, 2007). The price of 1kg of nitrogen is therefore between 543 and 587 XOF. 565 XOF/kg (1.13 USD/kg) is used for the calculations. It is not assumed that prices will change.

Millet price

Millet price is estimated from a market visit. The average price of millet is 150 XOF/kg (0.3 USD/kg). It was not assumed that the price will vary over time.

Firewood price

Firewood price is estimated to 15 XOF/kg (0.03 USD/kg) in rural areas that are 40 to 80 km from a major urban area, as is the case for the Kelka (Tangara, 2006). Therefore, this estimation is used here, and again no change in price is assumed.

TABLE A1

Description, value, and sources of different variables

Description	Variable	Value	Sources
Area per tree. (Calculated from the spacing between trees)	a	Agroforestry: 10m x 10m = 100m^2 Restoration: 3m x 3m = 9m^2	Assumptions based on common practice
Area under different types of land use	A	Agriculture = 29 314.99 ha Agroforestry = 47,353.53 ha Restoration = 125,530 ha	Estimated with high-resolution remote sensing and Google Earth Professional
Growth rate of trees	R	Different between acacia species *A. albida*: 7.55kg/tree/yr *A. nilotica:* 6kg/tree/yr *A. raddiana:* 4kg/tree/yr	Okorio and Maghembe (1994) Maguire et al. (1990) Hines and Eckman (1993)
Woody biomass at a given time	$Biomass_t$	$Biomass_t$= 1.27 × R × t × A / a	IPCC (2003)
Dead wood biomass (The quantity of dead wood collected by local population)	Dead wood	Dead wood = 0.11 × Biomass	IPCC (2003)
Nitrogen fixation	Nitrogen	Nitrogen = (1.32 × Biomass) / 1000	Dommergues (1987)
Carbon sequestration	CO_2	CO_2= 0.5 × 3.6663 × ΔBiomass	IPCC(2003)
Soil moisture	Soil moisture	Soil moisture = c × Biomass	SWAT
Present value for firewood	PV F_t		Calculated
Present value for nitrogen	PV N_t		Calculated
Present value for carbon	PV $CO2_t$		Calculated

TABLE A1 (CONTINUED)

Description, value, and sources of different variables

Description	Variable	Value	Sources
Present value for soil moisture (translated into yield)	$PV\ Y_t$		Calculated
Yield in the baseline scenario	Y	255 kg/ha	Smallholder survey in Batouma
Price for firewood	P_F	0.03 USD/kg	Tangara (2006)
Price for nitrogen	P_N	1.13 USD/kg	Survey
Price for carbon (economic damage)	SSC_t	Varies, see source	IWG (2013)
Price for a kg of millet yield (through additional soil moisture)	P_Y	0.3 USD/kg	Smallholder survey in Batouma
Intervention cost	CO_2	$CO_2 = 0.5 \times 3.6663 \times \Delta\text{Biomass}$	IPCC (2003)
Discount rate	r	2.5, 5, and 10 per cent	SWAT

Appendix B - Parameterization of the crop growth model AquaCrop and ArcSWAT

Parameters used in the AquaCrop model are specified below in *Table B.1* and *B.2*. Soil data was selected according to the data of the FAO database for the area.

TABLE B1

Soil parameters

Description	Sandy Loam
Thickness (m)	4
PWP (%)	10
FC (%)	22
SAT (%)	41
TAW (mm/m)	120
KSAT (mm/day)	500

Sources: FAO (1974) and Aquacrop database. Steduto et al (2009)

TABLE B2

Crop parameters

Region	Crop	Planting date	Harvest Index (%)	Sowing Density (plant/m^2)
Mopti	Millet	15/05	22	13.3

Sources: CropWat and Aquacrop database, Steduto et al (2009)

NB: For *Table B.2,* the Harvest index has been calibrated to reflect actual yield in the present scenario. Additional parameterization files are available upon request from the authors. Climatic data (rainfall, Evapotranspiration and temperatures) for the Mopti region were extracted from the FAO database ClimWat (ClimWat, 2001). No specific field management is considered.

ArcSWAT inputs and results

The Spatial Datasets required for the ArcSWAT model are the Digital Elevation Modal (DEM), Land Cover/Land Use Data, and Soil Data. Optional databases are Study Area Mask, Streams, User Defined Watershed, and User Defined Streams. It also requires monthly or daily Temperature (C), Precipitation (mm), Wind speed (m/s), Relative Humidity (fraction), and Solar (MJ/m^2) energy. Methodological details are provided in Myint (2014).

The temperature, solar, relative humidity and wind daily data from global weather data from Texas A&M University Texas A&M University and the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) was applied for the analyses. The detail of the climate data metadata is described in *Box B1*. The monthly rainfall data from Mopti was applied for the rainfall input data for the modeling. The water balance equation is illustrated in *Box B2*.

BOX B1

Climate Data	
South latitude	12.5
West longitude	33.5
North latitude	15.5
East longitude	36.5
Number of weather stations	90
Start date	12/1/1990
End date	12/31/2010
Start hour of day	12:00 AM

Data collected	
Temperature	°C
Preciptation	mm
Wind	m/s
Relative humidity	fraction
Solar	MJ/m^2

Source: Myint (2014)

BOX B2

Water-Balance Equation

$$Sw_t = Sw_{t-1} + \{R_t - Q_t - E_t - GWQ_t\}$$

Sw_t	Available water at time, t (today)
Sw_{t-1}	Available water at time, t-1 (yesterday)
R_t	Rainfall (today)
Q_t	Runoff (today)
E_t	Evapotranspiration (today)
W_t	Seepage loss (today)
GWQ_t	Groundwater runoff (today)

Source: Myint (2014)

TABLE B3

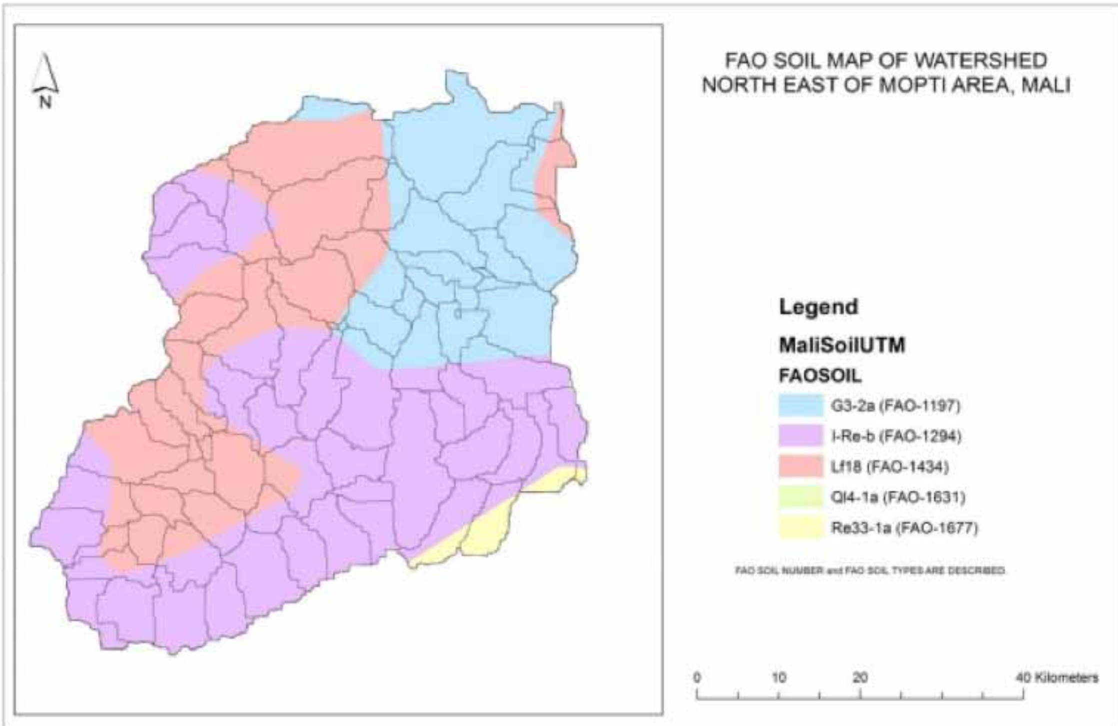
Hydrological differences between the forest landscape restoration scenario and the baseline scenario

Average annual basin values (1990-2010)	Volume per ha (m^3/ha)*
Surface runoff Q	-110.0
Lateral soil Q	-1.4
Groundwater (shallow aquifer recharge)	197.7
Revap (soil moisture)	21.2
Total water yield	89.8
Percolation out of soil	-39.1
Evapotranspiration	233.0
PET	1.0
Transmission losses	-4.6
Total sediment loading	0.9

*1 m^3 = 0.1 mm

FIGURE B1

FAO Soil Map
(from Myint, 2014)



Appendix C - Present value of enhanced fire-wood generation

According to IPCC (2003), the natural average dead live ratio in forests in semi-arid areas is 0.11. Based on that, the present value of firewood is estimated with the following formulas:

$$\Delta Firewood = 0.11 \times Above\ ground\ Biomass \qquad (C1)$$

$$PV\ FW_t = \frac{p_F(\Delta Firewood_{Alt} - \Delta Firewood_{Baseline})}{(1+r)^t} \qquad PV_{Firewood} = \sum_{t=0}^{T} PV\ FW_t \qquad (C2)$$

, where r is the discount rate, and T is the time horizon considered (here, T = 24 years).

Appendix D - Present value of enhanced fodder production

The present value benefit of enhanced fodder production is calculated using *Equation D1* and *D2*, where max fodder production of 130 kg/tree is reached in Year 25.

$$Fodder\ Value\ (t+1) = Unit\ price \times Fodder\ Production\ t_0 + \left(\frac{130}{25}kg\right) \times number\ of\ trees\ (D1)$$

$$Present\ Value\ Fodder = \sum_{t=0}^{T} \frac{(Fodder\ Value_{Alt}\ (for\ year\ t))}{(1+r)^t} \qquad (D2)$$

Appendix E - Present value of enhanced nitrogen fixation

To estimate the value of enhanced nitrogen fixation, we estimate the cost associated with replacing an equivalent quantity of soil nitrogen through the purchase of inorganic fertilizers, according to *Equation E1* and *E2*. The price information used is outlined in *Appendix A*.

$$\Delta Nitrogen = \frac{1.32\ N2/kg \times Biomass}{1000}, \qquad (E1)$$

$$PV\ N_t = \frac{p_N(\Delta Nitrogen_{Alt} - \Delta Nitrogen_{Baseline})}{(1+r)^t}, PV_{N_2\ Fixed} = \sum_{t=0}^{T} PV\ N_t \qquad (E2)$$

Appendix F - Present value of enhanced carbon sequestration

Following IPPC Tier 1 guidelines, the annual quantity of additional carbon sequestrated is estimated to be equivalent to 50 per cent of annual above and belowground biomass accumulation from reforestation and agroforestry. Carbon is subsequently converted to carbon dioxide by multiplying it with a conversion factor of 3.6663 (*Equation F1*). *Equation F2* is used to estimate the present value benefit of enhanced carbon sequestration, estimated as equal to the dollar equivalent of avoided damage associated with capturing carbon that would otherwise had been in the global atmosphere.

$$Total\ Biomass = Above\ ground\ biomass + Below\ ground\ biomass = 1.27 \times Above\ ground\ biomass \quad (F1)$$

$$\Delta CO_2 = 0.5 \times 3.6663 \times \Delta Total\ Biomass\ (F2)$$

$$PV\ CO2_t = \frac{ssc_t\left(\Delta CO_{2\,Alt} - \Delta CO_{2\,Baseline}\right)}{(1+r)^t}, PV_{CO_2\ Sequestrated} = \sum_{t=0}^{T} PV\ CO2_t \quad (F3)$$

, where r is the discount rate, T is the time horizon considered (here, T = 24 years).

Appendix G - Present value of enhanced soil moisture and ground water infiltration

The present value formula used to estimate the value of enhanced soil moisture, through its contribution to enhanced agricultural yields in agroforestry production systems is shown in *Equation G1.*

$$PV\ Y_t = \frac{p_Y\left(0.95\ \Delta Yield_{Alt} - \Delta Yield_{Baseline}\right)}{(1+r)^t}, PV_{soil\ moisture} = \sum_{t=0}^{T} PV\ Y_t \qquad (G1)$$

Appendix H - Cost of fodder production from agroforestry

The cost associated with implementing and managing the A. Albida agroforestry system is valued using the opportunity cost of household labour time.

The implementation cost of the agroforestry system relates to the time spent on surveillance, watering and planting of seeds in the first year, while the management cost relates to the yearly labour time dedicated to fodder pruning.

It is assumed that the pruning cost depends on the quantity of fodder to prune, which depends (linearly) on the age of the tree. Trees are assumed to reach full production at 25 years old. *Equation H1* allows us to calculate the pruning cost for one year.

$$Pruning\ costs\ (for\ year\ t) = \frac{Per\ tree\ pruning\ cost \times number\ of\ trees \times age\ of\ the\ tree}{25} \quad (H1)$$

The present value costs of implementing and managing the agroforestry system can thereby be calculated according to *Equation H2*:

$$Present\ value\ costs = Implementation\ cost_{t=0} = \sum_{t=0}^{24} \frac{Pruning\ costs_{\ t}}{(1+r)^t} \quad (H2)$$

Appendix I. Net present value of implementing the alternative restoration agroforestry scenario.

$$NPV = \sum_{t=0}^{T} PV\ FW_t + \sum_{t=0}^{T} PV\ F_t + \sum_{t=0}^{T} PV\ N_t + \sum_{t=0}^{T} PV\ CO2_t + \sum_{t=0}^{T} PV\ Y_t - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$
$$= \sum_{t=0}^{T} \frac{(Benefits_{Alternative\ t} - Benefits_{baseline\ t}) - Costs_{Alternative\ t}}{(1+r)^t} \quad (I1)$$

, where *FW* stands for firewood, *F* for fodder, *N* for soil nitrogen, *Y* for yields (from soil moisture and ground water percolation), and *C* for costs.

39

Acronyms and abbreviations

ArcSwat	Soil and water assessment tool
CEMP	Community environmental management plan
DEM	Digital elevation model
DLDD	Desertification, Land Degradation and Drought
ELD	Economics of Land Degradation Initiative
FAO	Food and Agriculture Organisation
FMNR	Farmer-managed natural regeneration methods
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GESSP	Global Economics and Social Science programme (IUCN)
GDI	Global Drylands Initiative (IUCN)
IAMs	Integrated assesment models
IPCC	Inter-governmental Panel on Climate Change
IUCN	International Union for conservation of nature
IWG	Interagency working group
LDN	Land degradation neutrality
NDVI	Normalized Difference Vegetation Index
NTFP	Non-timber forest product
NPV	Net present value
SCC	Social cost of carbon
SLM	Sustainable land management
UNCBD	United Nations Convention on Biodiversity
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
XOF	West African CFA Franc

List of figures

List of tables

List of boxes

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