INTERNATIONAL TROPICAL TIMBER ORGANIZATION

Technical Report

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REDUCING EMISSIONS FROM DEFORESTATION AND FOREST DEGRADATION

International Tropical Timber Organization
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Summary

Executive Summary

High rates of deforestation and forest degradation are among the serious environmental problems in Africa that are dwindling the level and quality of forest ecosystem services.Forest protected area management plays an important role in the global and nation level efforts of nature conservation. The Ankasa Forest Conservation Area is one of the most important protected areas in tropical forests of Western Africa. However, there is lackof information on the quantity and value of ecosystem services provided by the forest conservation area.The main objectives of this study were, therefore, to estimate the economic values of selected ecosystem services (timber, non-timber forest products, carbon, and soil nutrients) of the Ankasa Forest Conservation Area and the direct on-site REDD+ (Reducing Emissions from Deforestation and Degradation) opportunity costs of maintaining the conservation area from possible changes to other land uses commonly practiced by rural communities around the conservation area. Biophysical data from experimental sample plots and social-economic data from household survey were used to estimate the economic value of selected provisioning, regulating, and supporting ecosystem services of the conservation area. A number of ecological modeling techniques were used to estimate the quantities of selected ecosystem services. The concepts of ecosystem services and total economic value were applied as a conceptual framework whereas the revealed preference method of valuation was used for valuing the ecosystem services. The direct on-site REDD+ opportunity costs were estimated using the method of Net Present Value and using the microeconomic concept of opportunity cost. The Key findings of the study are presented below.

Provisioning services (Timber and Non-timber forest Products)

The standing volume of trees with diameter at breast height greater than or equal to 5 cm in the conservation area was about 627 m3/ha with stumpage value of about 364 $/ha, of which about 29% in volume and 46% in value was accounted by commercial timber species. The aggregate volume of trees for the whole conservation area was estimated at about 32.8 million m3 with a total stumpage value of about $ 19.1 million.

Rural households around the Ankasa Forest Conservation area extract non-timber forest products (fuel wood, wood for local construction, food (wild fruits, bush meat, snail, and mushrooms), and medicinal plants) from the land uses outside the conservation area. The total farm gate value of these ecosystem services was estimated at about 451 $/household/year, with fuel wood accounting about 67% of the value. If we divide this value by the average land size per household, we get a per hectare value that would be used for estimating the value of such ecosystem services that would be derived by rural communities from the Ankasa Conservation area, had there not been use restriction.Accordingly, the conservation area could provide the above non-timber forest products worth of about $ 2.8 million per year.

Regulating services (Carbon stock in biomass and soil)

The Ankasa Forest Conservation area stores carbon that amounts about 1230 tCO2e/ha and worth about 7257 $ at the weighted average price of 5.90 $/tCO2e of the international voluntary carbon market for the year 2012. The carbon in biomass, which is the sum of above ground tree biomass, root biomass, non-tree vegetation and litter, accounted about 78 % whereas the remaining was the stock of carbon in soils up to a depth of 60 cm. The carbon stock in biomass and soils of the whole conservation area was estimated at about 64.3 million tCO2e and worth of about $ 380million.

This value is equivalent to 15.6 times the aggregate stumpage value of the standing volume of trees in the conservation area. This study did not take into account the carbon sequestration services of the forest, which is an important component of the climate regulating service provided by the conservation area as a global public good.

Supporting services (Soil Nutrients and Biodiversity)

Nitrogen, phosphorous, and potassium nutrient contents in soils are important for plant growth and development. The nitrogen nutrient content in the Ankasa Forest conservation area was more than the minimum threshold level recommended for a healthy plant growth and development. The available nitrogen in the soil up to a depth of 60 cm was about 327 kg/ha in excess of the threshold level. This extra stock valued using the replacement cost method was estimated to worth about $ 25. The extra available nitrogen stock in the conservation area was estimated at about 17 thousand tons of nitrogen which worth about $ 1.3 million valued at a market price of commercial fertilizer in Ghana.

However, it was found that phosphorous and potassium nutrient contents in the soils of Ankasa were below the threshold levels required for plant growth. The available phosphorous and nitrogen nutrients in the soils up to a depth of 60cm were less by about 15 kg and 190 kg per hectare than the corresponding threshold levels respectively. This implies that supplementing these deficiencies with commercial fertilizer would require about $ 0.5 for phosphorous and about $12 for potassium on per hectare level. For the whole conservation area this would mean about $ 0.63 million worth of commercial fertilizer would be needed to increase the potassium nutrient content to the threshold level and about $ 26 thousand worth of additional commercial fertilizer to increase the soil phosphorous contents to the threshold level.

The conservation area is rich in biodiversity of tree species and plant species of non-timber forest products sources. A total of 108 tree species with diameter greater than or equal to 5 cm and 32 plant species of non-timber forest product sources were identified growing in inventoried plots with a total area of about 1 ha and 0.09 hectare respectively.

Cultural services (Tourism, research and education)

Although the Ankasa Forest Conservation area is rich in both plant and animal biodiversity and has great potential for eco-tourism, the development and benefits from eco-tourism from the forest so far are very insignificant. Over the period from 2002-2012, there was almost constant trend in the number of tourist arrivals to the conservation area. An average of 1326 tourist arrivals and revenue of $ 4121 per annum from the entrance fees was recorded for the same period. There were only 24 researchers and 18 student researches that were visiting the conservation area for research and educational purposes over a period of 11 years (2003-2013). In relative terms, the conservation area was able to derive an annual revenue of only 0.09 $/ha from tourist and foreign researchers arrivals.

REDD+ Opportunity Cost (PV of net income from cocoa farming and agroforestry)

Conserving the Ankasa Forest conservation area form possible conversions to other land uses, which are commonly practiced by rural communities around the conservation area, could result in emission reductions units in the range of about 605-803 tCO2e/ha. This emission reduction level refers only to the difference in stock of carbon in biomass and soils between the conservation area and each alternative land use on per hectare basis. The emission reduction level would be higher if we consider the difference in carbon sequestration service of the conservation area and each alternative land use, which is likely to be a positive value.

However, these levels of emission reduction units entail opportunity cost. The direct on-site opportunity cost of conserving the Ankasa Forest Conservation area for the next 30 years (until 2042) from conversion to the other land uses were estimated to range from between 9663-23353 $/ha in net present value depending on the type of the alternative land uses change. The lowest opportunity cost was estimated for pure cocoa farming as an alternative land uses and the highest opportunity cost was for an agroforestry land use that integrates local food crop production, rubber and coconut plantations on wet and non-wetlands. More than 90% of the opportunity cost was accounted by forgone net income from food crop production by rural communities.

The direct on-site REDD+ opportunity cost was, thus, estimated at in the range of about 12-39 $/CO2e in net present value for conserving the Forest Conservation Area for the next 30 years, which is equivalent to 0.4 -1.29 $/tCO2e per year. This result was based on a 3% discount rate and would be less if we consider a 7.26% discount rate which represents the real discount rate for Ghana. At this discount rate the direct on site opportunity cost was in the range of about 7-24 $/tCO2e.

The aggregate NPV (at 3% discount rate) of the direct on-site opportunity cost of conserving the whole conservation area for the next 30 years was estimated in the range of $ 505 million $ 1.22 billion, which is equivalent to 16.8 40.7 million $/year, with corresponding emission reduction levels of 42 million tCO2e and 31.6 million tCO2e respectively as a global public good. The range of annual opportunity cost is equivalent to 0.04-0.10% of Ghanas 2012 Gross Domestic Product.

Summary

Introduction

1. Introduction

According to the Millennium Ecosystem Assessment, ecosystem services are classified into four broad categories, namely, provisioning, regulating, supporting, and cultural services (MEA, 2005). Forest ecosystems as natural capital and the ecosystem services they provide make significant direct and indirect contributions to the global economy and human welfare. Forests in Africa play a significant role in biodiversity conservation and providing a number of ecosystem services and in climate change adaptation and mitigation; the sustained provision of ecosystem services can help people to adapt to the effects of changing climate while the carbon stored in the forests can contribute to climate change mitigation. However, the growing human population and the associated increasing demand of land for crop and livestock production (for both subsistence and commercial activities), human settlement, and production of biomass energy are among the major drivers for the degradation of forest resources.

Despite international and national environmental movements for conserving forest landscapes, the area of old-growth tropical forests continues to decline as the demand for rent from tropical forest land and resources increase (Ghauzoul and Sheil, 2010). In 2005 about half of the tropical humid forest contained about 50% or less tree cover, and that at least 20% of this biome was subject to timber extraction over the period 2000 to 2005 (Asner et al., 2009). Much of the global and national conservation efforts rely on protected area management. At the global scale there are over 100, 000 terrestrial protected areas accounting 12% of the land area (Chape et al. 2003), with the greatest coverage in the tropics. In the tropical moist forest zones a total area of about2.5 million km2 (2003 value), which accounts 23.3% of the land surface in this zones, was under some sort of national conservation designation (Chape et al. 2003, Ghauzoul and Sheil, 2010). Protected areas in tropical moist forests of Western and Central Africa constitute about 8.7% of the land area. The Ankasa Forest Conservation Area (FCA)that covers 523 km2in Western Ghana is one of these protected areas in tropical moist forests of Western Africa.

With the growing global interest on tropical forests for climate change mitigation and adaptation, the coverage of protected areasis expected to grow. The Global Climate Change Mitigation and adaptation financing mechanisms like, the Clean Development Mechanism (CDM), Payment for Ecosystem Service (PES) and Voluntary Carbon Market Mechanisms, and REDD+ are manifestations for the growing demand for the climate change mitigation role of forests. However, generating revenues from such financing mechanism through selling ecosystem services of existing or future protected areas requires data on the quantity and value of the forest ecosystem services. Moreover, based on the common sense that you cant manage what you dont measure, valuation of forest ecosystem services is important for sustainable forest management and conservation. In this regard, there has been a growing number of studies on valuation of ecosystem services at different special scales as a decision making tool for moving towards sustainable management and conservation of natural resources (European Communities, 2008; Braat, et al., 2008; Barbier, 2007; CBD, 2007; OECD, 2006; Berry, Olson & Campbell, 2003;Costanza, et al., 1997). Specifically, valuation of forest ecosystem services has been recognized as an important tool that can aid decision makers to evaluate trade-offs between alternative land uses and forest management regimes as well as caurses of social actions that change the use of forest ecosystems and the services they provide (MEA, 2005).

Thus, this study aimed at quantifying and valuing the ecosystems services of the Ankasa FCA and at estimating the direct on-site REDD+ opportunity costs of maintaining the conservation area from conversion to competing land uses.

Applied Methodology

1. Materials and Methods

1.1. Theoretical framework

1.1.1. Typology of forest ecosystem services

With the growing need for understanding and communicating the ecological, economic, social, and cultural values of forest ecosystem services, a number of conceptual frameworks for guiding valuation of these services have been realized over nearly the last two decades since the 1990s. The four categories of ecosystem services, namely provisioning, regulating, cultural, and supporting services, introduced by the Millennium Ecosystem Assessment are the results of one of such efforts and are widely accepted as a frame work of analysis in the contemporary valuation of ecosystem services (Figure 1). This framework provides a standard and internationally accepted conceptual structure through which all aspects of the utility of natural resources to sustainable livelihood and development can be understood (Noel and Soussan, 2010).

Figure 3 1: Typology of forest ecosystem services (Adapted from MEA, 2005).

1.1.2. Quantifying the forest ecosystem services

In the economic literature about valuation of environmental services and the application of cost benefit analysis of land use changes, it is important to identify the stakeholders affected by the project for which the valuation and/or cost benefit analysis is to be made. Discussion with stockholders is very important for determining the valuation objectives, selecting the most important ecosystem services to be valued, and determining the best competing land use against which cost benefit analysis will be carried out.

Valuation of forest ecosystem services then requires quantifying the identified ecosystem services at spatial and temporal scales. Generating such data requires the expertise of different scientific disciplines. It is possible to make a sound valuation exercise if only the physical quantities of the ecosystem services are derived from scientific studies of respective disciplines. Such an interdisciplinary approach entails a greater level of accuracy in the estimated values since it allows minimizing the use of generalized assumptions and hence reduces the associated uncertainties and errors in the valuation exercise.

Both primary and secondary data sources can be used for quantifying the ecosystem services of forest resources. The primary data sources could be field experiments by different scientific disciplines (at different levels e.g. forest biome, forest stand, plot, tree, species, etc.. levels), household surveys, expert opinions from interviews, and ground based input data for mapping ecosystem services at a wider spatial scale using GIS and remote sensing methodologies. The other sources of data are secondary data which may include official statistics on ecosystem services and published works from the literature.

1.1.3. Valuation methodologies

Once the physical quantities of ecosystem services are determined, converting to monetary values using the appropriate valuation method is the next step. The question of how to value these ecosystem services has become a focal issue in a number of discussions and is of direct relevance for the study. Forest resource and the ecosystem services they provide have value both as a stock or natural capital as well as in terms of the flow of yields of economically important ecosystem services they provide. A conceptual framework of valuation that distinguishes between values of assets (forest as natural capital stock) and products (flow value of forest ecosystem services) is essential to integrate such data into the national account (green GDP) of a country. A stock is a quantity existing at a point in time and a flow is a quantity per period. Stocks, flows, and their relationship are crucial to the operation of both the natural and economic systems (Common and Stagl, 2007).

Valuation of forest ecosystem services has been a challenging task for the fact that forests provide a number of non-traded ecosystem services for which market prices do not exist. For some traded goods and services of forest ecosystem services, market prices may not reflect the true scarcity of the services because of market imperfections. In the effort of addressing such critical valuation problem, the concept of Total Economic Value (TEV) has emerged over the last two decades following the work of Pearce (1993) (Table 1). According to the concept of TEV, the values of forest ecosystem services can be classified into two main categories: use values and non-use values. The use values further include direct use values (DUV), indirect use values (IUV), and option values (OV).

Table 3 1: Description of components of the Total Economic Value of Forest ecosystem Services

Value	Sub-value	Description	Examples
Use	Direct	Goods and services that directly accrue to the consumers either from direct use or interaction with the environmental resources and services.	Timber, fuel wood, recreation etc
	Indirect	Functions of forest ecosystems that accrue indirectly support and protection to economic activity and property.	Carbon sequestration, fixing and cycling of nutrients, soil erosion protection, water purification etc
	Option	Future uses of the forest or its biodiversity resources and other functions.	Genetic resources, old growth forests
Non-Use	Existence	The intrinsic values that non-users are willing to pay purely for the existence of the resource without the intention of directly or indirectly using the resource in future.	The demand of non-users for conservation of tropical rainforests, endangered wild animals like tiger etc...
	Bequest	Peoples willingness to pay for ensuring that forests will be preserved for the welfare of future generations.	Biodiversity; areas of scenic beauty

Source: Adapted from Pearce, 1993; CBD, 2007.

Direct and indirect use values of forest ecosystem services are relatively more easily quantified than option and non-use values. In the valuation literature, the common methods to value forest ecosystem services can be classified into revealed preference and non-revealed preference approaches (Table 2).

Table 3 2: Description of methods for valuing forest ecosystem services

Methods Sub-methods Description Examples

Revealed preference Market price Market prices Valuation of an ecosystem service using its market price. Timber, fuel wood, park entrance fees for tourists.

Production function Effect on production Determining the value of an ecosystem service by considering its role in production of other marketed goods and services. Upper water shade catchment protection services of forest to agricultural production, hydropower production, and irrigation at the bottom of the catchment.

Surrogate market approach Travel cost The method involves estimating the recreational value of forest ecosystem services by measuring the money and time that people spend to reach and visit the specific ecosystem. Value of an ecosystems scenic beauty, presence of wildlife, opportunities for sporting activities.

Hedonic pricing The method involves deriving the difference in the market price of a non-ecosystem good due to the existence of a specific environmental attribute. Effect of proximity to forested areas on property prices, wage rates etc

Cost based approach Opportunity cost This technique values the benefits of environmental protection (conserving a forest) in terms of what is being forgone as a net benefit from alternative land use. Conversion of forest to Shifting cultivation for subsistence or commercial agriculture.

Replacement cost This involves estimating the expenses of replacing an ecosystem services with a man-made product, infrastructure, or technology. Cost of commercial fertilizer to counteract nutrient loss due to soil erosion.

Averted expenditure The value of an ecosystem service can be inferred from the expenditure on technologies required to reduce the negative impacts of the missing or degraded service. A forest near urban areas providing air purification service through absorbing dust particles and pollutants. Such services can be inferred from what people spend on preventive technologies used to avoid the health impacts of the pollutants.

Damage cost The method involves valuing an ecosystem services role in protecting other assets. Catchment protection services of controlling downstream siltation and avoided productivity loss in agriculture.

Stated preference Contingent valuation Involves deriving the value of non-marketed ecosystem services by asking consumers directly about their willingness to pay (WTP) for a specific service or their willingness to accept compensation (WTA) for the loss of a service. Value of biodiversity, value of conserving a forest for the welfare of future generation. The method involves collecting survey data and complex econometric modeling.

Conjoint analysis The method asks respondents to consider the status quo and a specific hypothetical scenario, with participants choosing between various environmental services at different prices or costs. Used for all services that cannot be valued using stated and cost-based approaches. The method involves collecting survey data and complex econometric modeling.

Choice experiment The characteristics of the ecosystem service are explicitly defined; vary over choice cards along with a monetary metric. Then, individuals have to choose different combinations of characteristics of the ecosystem service over other combinations at various prices. Used for all services that cannot be valued using stated and cost-based approaches. The method involves collecting survey data and complex statistical and econometric modeling.

Adapted from Garrod and Willis, 1999; CBD, 2007; Noel and Soussan, 2010.

Valuation of forest ecosystem services has been a challenging task for the fact that forests provide a number of non-traded ecosystem services for which there are no market prices. For example, in the 2008 interim report of The Economics of Ecosystems and Biodiversity (TEEB) (European Communities, 2008), it is argued that:

It will be possible to make a quantitative assessment in biophysical terms only for part of the ecosystem services those for which the ecological production functions are relatively well understood and for which sufficient data are available. Due to the limitation of our economic tools, a still smaller share of these services can be valued in monetary terms. It is therefore important not to limit assessments to monetary values, but to include qualitative analysis and physical indicators as well.

Therefore, valuation is part of the multiple approaches that should be used for assessing the contribution of forest ecosystem services to human welfare. The following figure indicates the multiple approaches that can be used for assessing the contribution of forest ecosystems to human welfare.

Figure 3 2: Multiple approaches for assessing the contribution of Forest Ecosystem Services (Source: P. ten Brikn, Workshop on the Economics of Global Loss of Biological Diversity, 5-6 March 2008, Brussels. Cited in European Communities, 2008).

1.1.4. Opportunity costs of land use change

As part of the global effort for mitigating the increase in concentration of GHGs in the atmosphere and the associated impact on the global climate, there has been developments in the Science and Policy of Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+), with the plus indicating related objectives like biodiversity conservation, enhancement of forest carbon, and poverty reduction, (Angelsen et al., 2009; Hansen et al., 2009). The UNFCCC and several national and state governments have been working on the development of REDD+ crediting mechanism that would reward REDD+ efforts in tropical countries with issuance of emission/sequestration credits that could be traded in carbon markets (IETA, 2012). REDD+ entails costs which can be classified as opportunity, implementation, and transaction costs(Figure 3). REDD+ Opportunity costs refermainly to the forgone economic benefits of alternative land use and to some extent social and cultural costs which are not easily measured in economic terms (White et al., 2011).

Figure 3 3: Classification of REDD+ Costs (Source: White et al., 2011).

According to White et al. (2011) data on REDD+ opportunity cost estimates are important for five basic reasons. First, except for remote locations which may entail large implementation and transaction costs, opportunity costs of REDD+ are assumed to account for the largest share of the total cost of avoiding deforestation and forest degradation (Boucher, 2008a; Pagiola and Bosquet, 2009; Olsen and Bishop, 2009; White et al., 2011). Secondly, opportunity costs of REDD+ provide insights on the major drivers of deforestation and forest degradation, impacts REDD+ programs on the different social group and hence derive policies mechanism that can take into account the interests of marginalized groups (Pagiola and Bosquet, 2009, White et al., 2011). Third, the opportunity cost information can be used as a basis for designing fair compensation for the affected groups from changes in land use practices as part of REDD+ program. In areas where natural forest protected areas are efficiently managed opportunity cost estimate, which refers to the loss of income to nearby communities arising from use restrictions, is important for policy makers to understand the impacts of a REDD+ conservation policy (White et al., 2011).

1.2. Study area

The study was conducted in the Ankasa FCA (Figure 4) in of the Jomoro and Ellembelle Districts of the Western Region of Ghana. The conservation area is located at about 330 Km west of Accra and very close to the border with Côte DIvoire. According to information from the management plan of the forest the conservation area covers a total area of 523 km2 and includes the 349-km2 Ankasa Forest Reserve in the south and the 174-km2 Nini-Suhien National Park in the north. The conservation area is the only wildlife protected area in Ghana that is located in the wet evergreen tropical high rainforest belt. Apart from the forest reserve, which was selectively logged until 1976, the Ankasa FCA is in an almost intact state. The conservation area is rich in biodiversity and contains over 800 vascular plants species, 639

butterfly species, and more than 190 species of birds. It is also hometo a number of charismatic, rare and endangered species, including forest elephant, bongo, leopard, chimpanzees and possibly up to eight species of forest primates.

1.3. Data collection

The economic values of timber, non-timber forest products, carbon stocks in biomass and soils, soil nutrient losses, and crop production were estimated on per hectare basis of two forest land use types, namely the Ankasa FCAs and other land uses surrounding the conservation area. The major land uses around the conservation area include cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland. Moreover, the extent of tree biodiversity and the diversity of plant species used as non-timber forest products (for medicinal, food, local construction and other use) for both land uses categories were assessed. These ecosystem services were selected based on their importance in climate change mitigation and adaptation as well as the ease of empirical measurement.

1.3.1. Reconnaissance survey

In order to achieve the objectives of the study, first a reconnaissance survey was conducted for three days in May, 2013. The aim of the reconnaissance survey was to generate basic information on:

the major land uses/covers outside of the forest reserve,

the types of crops cultivated by rural households living around the conservation area, and accessible routes in the conservation site that can be used for lying sample plots of the main survey.

The survey was held through physical observation and discussion with the Manager and staffs of the Ankasa FCAHead Quarter, and community leaders of rural households residing around the conservation area. Accordingly:

Five major land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) were identified as land uses outside of the conservation area).

A list of crops cultivated by rural households

Five routes to the conservation area, each close to one rural community living around the conservation area, were identified. These routes and/or the close by rural communities are locally called Old Ankasa, Odoyefe, Domeabra, Navrongo, and Kusasi.

Based on the physical observation of the study site and the above information, we refined the biophysical and household survey designs proposed for the collection of selected ecosystem services of the conservation area and the neighboring land uses.

We applied both plot level biophysical data collection survey design and household survey to collect data on the physical quantities of selected ecosystem services of the conservation area as well as each of the five land uses outside of the conservation area. The following sections describe the plot level and household survey designs and the corresponding data of ecosystem services collected using the survey designs.

1.3.2. Plot level survey

A total of 21 nested circular plots (Figure 5) were set in the Ankasa FCA using a stratified systematic random sampling method. First, the southern part of the conservation area which is called the Ankasa Forest Reserve was stratified into five (old-Ankasa route, Odoyefe route, Domeabra route, Navrongo route, and Kusasi route) based on accessibility. For each stratum, we selected a random point at a location about 200 to 500 meters from the boundary to inside of the reserve and set the first nested circular plot. From the first plot onwards, 2 plots were lied systematically at distance of 1-2 km to the North direction along the routes of Odoyefe, Navrongo, and Kusasi whereas to the East direction along the route of Domeabra. In the case of the Old-Ankasa route, which is the main gate to the park and has a forest road, we were able to set a total of 9 plots. In addition, a total of 25 sample plots (five plots per each of the major land uses) were set outside of the forest reserve using the same sampling procedure. Figure 3-5 shows the design of the nested circular plot and the measurements that were undertaken in the small, medium, and large radii of the plot.

Figure 3 5: Design of nested circular plot and measurements of ecosystem services

The inventory of Non-timber forest product species was undertaken in 18 of the 21 sample plots of the Ankasa FCA and 10 of the 25 sample plots of the other land uses outside of the conservation area.

The non-tree vegetation includes all the ground vegetation plus trees with less than 5cm diameter. The measurement for this biomass class was undertaken in a 1mX1m random quadrant in the small circular plot. The non-tree vegetation in the quadrant was harvested destructively and the fresh weigh was measured in the field. A sub sample was taken and measured in the field as well and the oven dry weight of the sub sample was determined at the FORIG lab. The samples were put in the oven at a temperature 105 0C and measured after every 24 hours until we observe a constant weight. The dry to wet ratio of the each sub-sample was calculated and used to determine the dry weight from of the non-tree vegetation per quadrant by multiplying the ratio with the total wet weight of the sample from each quadrant. We applied the same procedure for determining the dry weight of litter biomass per quadrant. In the case of both non-tree vegetation and litter biomass samples, we took measurements in 6 of the 21 plots in the conservation site and 7 of the 25 plots in the other land uses.

Soil samples were taken from a random point at about 1m from the center of the nested plot. For each plot, a total of 3 soil samples were taken using soil augur from three soil depth classes (0-20 cm, 20-40cm, and 40-60cm) by taking one sample from each soil depth class. We took soil core samples of each soil depth class for a total of 8 plots out of the 21 plots in the conservation site and for another 8 plots out of the 25 plots of the other land uses. A total of 138 (21X3 + 25X3) soil samples were analyzed at the Soil Research Institute of Ghana for determining the soil carbon and organic matter content, and contents of soil nutrients, specifically total nitrogen, available phosphorous and potassium. The core samples were dried in oven up to a constant weight and the fine soil are separated from the non-soil parts (stones and gravels). The dry weight of the fine soil was used to determine the soil bulk density.

1.3.3. Household survey

Based on the information from the reconnaissance survey, a structured household survey questionnaire was designed to collect data household demographic characteristics, land size, plot area and cultivated crops on each of the plots by the household, gross annual income from the crop production, input costs of the crop production, consumption and sale of non-timber forest products, and farm gate prices for crops, non-timber forest products, and market prices of agricultural inputs. The aim of the household survey was to generate data on net income from agroforestry food crop production per hectare and income from NTFP uses per household for estimating the REDD+ opportunity cost of the conservation area. Accordingly, stratified random samples of 63 rural households (12 to 13 household heads per rural community) were selected from the five rural communities living around the conservation area. A team of 3 enumerators were trained on the survey questionnaire and the survey was administered in June 2013. The data entered and analyzed using SPSS 16.00 software.

Presentation of the Data

Data analysis

Based on data from the experimental plots, the household survey, and secondary data sources, the economic values of the following ecosystem services of the Ankasa Forest Conservation area and the surrounding land uses were estimated on per hectare basis. These ecosystem services are:

Provisioning services: Timber and Non-timber forest products

Regulating services: Carbon stock in biomass and carbon stock in soils both converted to carbon dioxide equivalent.

Supporting services: Soil nutrient cycling (Nitrogen, Phosphorous, Potassium); biodiversity (tree species diversity, non-timber forest product species diversity)

Cultural services: tourism, research and educational services of the Ankasa forest reserve.

The following sections provide details on the methods used to estimate the economic values of each of the above ecosystem services.

Estimates of the economic value of the provisioning ecosystem services

Stumpage value of timber species

Based on the plot level inventory data, on the species, name of sample trees and information from the Forestry commission of Ghana on the major tropical timber species, the sample trees of each plot were classified into timber and non-timber species. For the timber species, the volume of the timber for each sample tree was calculated using Wongs (1989) volume equation, which is a power model that uses DBH as a single predictor variable and widely used in tropical inventory. We specifically used Wongs (1989) volume model developed for Tropical Forests and given by Volume (m3/tree) = 0.004634DBH2.201, where DBH is tree diameter in cm.After determining the volume of each sample commercial tree species the total volume in the small, medium, and large radii of the nested plot were calculated as the summation of the trees in each radius class. The corresponding results were multiplied by the expansion factors of 198.94, 49.74, and 19.99 respectively and summed to convert in to hectare level values for each commercial timber species. Finally, the mean values for the Conservation Area and the other land uses were determined.

To estimate the economic value of each commercial timber species, the per hectare volume estimates for each species were multiplied by the average stumpage prices of the species. The stumpage prices for the different commercial timber species were obtained from the Forestry Commission of Ghana (Damnyag et al., 2011) and the prices were converted to $ at the official exchange rate of 1 $ = 2.0095GHc as of June 2013.

Estimates of Non-timber forest products

The estimation of the economic value of non-timber forest products was based on data from both the plot level and household surveys. The plot level survey was held to identify plant species that are used as non-timber forest product sources. Therefore, for both the conservation area and other land uses, the abundance and names of plant species used for medicinal, food, food and medicinal, local construction and ornamental purposes, fodder and other local uses were identified.

The household survey was used to assess the level of consumption and farm gate value of major non-timber forest products by rural households living around the Ankasa FCA. Accordingly, the average annual consumption levels per household and the corresponding farm gate values for the following major non-timber forest products were estimated based on the household survey data.

Fuel wood (for home consumption and for sale)

Wood for local construction (wood for house and other local construction, wood for making beds for drying crops, Canes, Rattan)

Food (Wild fruits like mango and avocado, bush meat, snail, mushrooms)

Medicinal plants

Estimating the economic value of the regulating service

Carbon storage in Biomass

In order to estimate the economic value of avoided emission of carbon that is currently stored in forest biomass we considered the carbon stock in standing trees greater than 5cm DBH, root of these standing trees, understory non-tree vegetation which includes ground floor vegetation and trees with less than 5cm DBH, and litter. The study did not take into account the biomass dead trees.

To determine the above ground dry biomass for trees greater than 5cm DBH, the Brown et al. (1989) allometric model developed for Wet Tropical forest zone was used. Among the three models developed by Brown et al. (1989) for the wet forest zone, we selected the model that uses DBH and tree height (H) as predictor variables and given by Y (Kg/tree) = exp(-3.3012 + 0.9439ln(DBH2H). In the case of coconut trees, we applied the model of Frangi and Lugo (1985) that uses only tree height as a predictor variable and given by Y = 4.5 + 7.7H. By using these models the aboveground dry biomass of each sample tree was estimated and the results for all the trees within each radius class of each nested sample plot was summed to convert the values to a per hectare level using the corresponding expansion factors. Finally, the mean dry biomass in kilo gram per hectare was calculated for the conservation area and the other land uses. The root biomass per hectare was estimated by multiplying the dry aboveground biomass with conversion factors (root to shoot ratios for tropical wet forests) of 0.205 for trees with dry above ground biomass less than 125 tons per hectare and 0.235 for dry aboveground biomass exceeding 125 tons per hectare (Monkay et al., 2006). To determine the dry weightsof the non-tree vegetation as well as the litter biomass the dry weights per quadrant as described in section 3.2.2 were converted to per hectare values after adjusting for the basal area ofstanding trees.

The dry biomasses factors of 0.46 for trees less than 10cm DBH, non-tree vegetation and litter biomasses and 0.49 for trees above 10cm DBH (Hughes et al., 2000) were used to convert the dry biomass into carbon. The resulting carbon content in tons per hectare for each of biomass component was multiplied by the conversion factor of 3.67 (i.e. the ration of the molecular weights of carbon dioxide molecule to carbon atom) to obtain the tons of carbon dioxide equivalent (tCO2e) per hectare (Olschewski and Benitez, 2005).

The weighted average price of $5.90/tCO2e in the voluntary carbon market for the year 2012, which is reported by Forest Trends Ecosystem Marketplace on the State of the Voluntary Carbon Markets 2013, was used to convert the estimated tCO2e per ha for each biomass component to their corresponding monetary values.

Carbon storage in Forest Soils

Based on the results of the laboratory analysis of the 138 soil samples analyzed for their organic carbon content at the Soil Research Institute of Ghana, the data on the soil bulk density, and following Mekuria et al. (2011) the soil organic carbon stock per hectare for each soil depth class was estimated using the following equation:

SOC (t/ha) = (% C X 10-2) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

Where, SOC is the soil organic carbon stock, C is the soil organic carbon content, Bd is soil bulk density respectively. The stock of soil carbon was multiplied by the conversion factor of 3.67 to obtain into tCO2e per hectare.

Estimating and describing the supporting ecosystem service

Estimating the value of soil fertility

The replacement cost method was applied to estimate the value of soil fertility loss. The method allows the estimation of the value of an ecosystem service by estimating the cost of replacing with an alternative or substitute good or service (Bishop, 1999). The method is widely used because it is relatively simple to use provided that data on nutrient loss is available (Bojö, 1996; Damnyag, 2011). In order to estimate the replacement cost of soil fertility loss we applied the following procedures.

First the available nutrient in the soil was determined on per hectare level based on the results of the laboratory analysis of the 138 soil samples analyzed for their nitrogen, phosphorous, and potassium contents at the Soil Research Institute of Ghana, the data on the soil bulk density, and following Mekuria et al. (2011) the available stocks of total nitrogen (TN), phosphorous (P), and potassium (K) for each soil depth class were estimated using the following equations:

TN (t/ha) = (% TN X 10-2) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

P (t/ha) = (Pppm X 10-6) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

K (t/ha) = (Kppm X 10-6) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

Second, we estimated the corresponding threshold stock levels using the minimum soil property threshold levels (0.1% TN, 10 ppm of P, and 100 ppm of K) considered as moderate for plant growth and reported for assessing forest soil health (Amacher et al., 2007).Then, the nutrient loss for each soil nutrient was estimated by subtracting the available stock from the calculated threshold level. The results were then multiplied by the corresponding nutrient-to-fertilizer conversion ratios derived from a 50 Kg commercial fertilizer of NPK 15-15-15 to obtain the equivalent commercial fertilizer required to replace the nutrient loss (Niskanen, 1998; Nahuelhual et al., 2006; Damnyag et al., 2011). Finally, we estimated the replacement cost for each nutrient loss by multiplying the equivalent commercial fertilizer required to replace the nutrient loss by the annual average market price of the fertilizer in Ghana market.We obtained the monthly average prices of NPK 15-15-15 fertilizer in Ghana for the year 2012 from www.AfricaFertilizer.org and accordingly the annual average market price was 499.49 $ per ton for the year and this value was used in the calculation.

Describing biodiversity of trees and non-timber forest product source plants

In order to obtain a quantitative and qualitative description of the level of tree biodiversity as well as the diversity of plant based sources of non-timber forest products, tree species biodiversity and species diversity of plants and of non-timber forest product source were determined for the conservation area as well as the land uses outside the conservation area. Using the sample plot level inventory on the tree species and the non-timber forest product plant species, we calculated species diversity. Out of a wide range biodiversity indices available in the literature (Magurran, 1988), we applied the Shannon index (H), which has been proposed to estimate biodiversity in carbon sequestration projects (Ponce-Hernandez, 2004; Henry et al., 2009). Shannon index was calculated by multiplying the abundance of a species (pi) by the logarithm of this number:

H_j= -_(i=1)^mp_ij ln(p_ij)

Where H is the Shannon index for the trees in small, medium and large diameter classes or for non-timber forest product use type or for land use type j depending on the scale of analysis.

p_(ij=n_ij/N_j)

Where ni is the number of subjects from the species I and N is the total number of subjects within plot j.

Estimating REDD+ Opportunity Cost of the Conservation Area

In order to estimate the opportunity cost of keeping the Ankasa FCA sustainably and hence avoid and/or reduce emissions from the likely deforestation from conversion to other competing land uses, we estimated the opportunity costs in terms of income loses to rural communities living around the conservation area arising from use restriction. Based on the date from the reconnaissance survey and the main plot level and household surveys, and the results of the valuation of ecosystem service of the conservation area and land uses around, we estimated the REDD+ opportunity cost of reducing emissions (in terms of $/tCO2; $/tCO2/ha; and $/tCO2/ha/yr) from potential conversions of the conservation area to four land use change options using the following procedures.

First, we identified four major land uses that represent the major livelihood basis of rural communities living around the conservation area. These land uses are:

Cocoa farming: refers to cocoa farms mixed with agro forestry food crops and some timber trees.

Agroforestry_1: refers to land use that integrates local food crop production, cocoa farming, rubber plantation, and coconut plantation on both wetlands and non-wetlands.

Agroforestry_2: refersto land use that integrates local food crop production, rubber plantation, and coconut plantation on both wetlands and non-wetlands.

Agroforestry_3: refers to land use that integrates local food crop production, cocoa farming, rubber plantation, coconut plantation and fallow lands on both wetlands and non-wetlands.

Figure 3 6: Ankasa Forest Conservation area (at the center) and land uses close to the conservation area (from left to right on top are wetland, cassava farm, cocoa farm. whereas from left to right in the bottom are rubber plantation, fallow land, and coconut plantation).

Second, four major types of ecosystem services were identified as source of income that can represent the direct on-site opportunity cost of not converting the Conservation area to either of the above four land use change options. This ecosystem services are commercial timber, timber for local uses, non-timber forest products, and crops (cocoa, Cassava, other crops (plantain, banana, yam, maize, coconut, palm, garden egg, okro, and pepper)). The flows of benefits and costs of producing each of these ecosystem services and hence the net benefits from each of the four land use options as well as the corresponding potential values from the forest reserve were estimated as follows.

Timber:the volume and stumpage values ($/ha) of commercial and non-commercial timber species were estimated based on the methods described in section 3.3.3.1 above and we took these values as net benefits from timber with the fact thatstumpage price is the price of the standing timber and does not include harvesting costs. For the Ankasa FCAand Cocoa farming, we took directly the estimated results. However, in the case of the land use options Agroforestry_1 to Agroforestry_3, the values were calculated by taking the weighted averages of the results of the different land uses included under each Agro forestry category. For example, the in the case of Agroforestry_1 the volume of timber refers to the weighted average of the volumes of timber per ha for the cocoa farm, coconut plantation, rubber plantation, and wetlands which are estimated based on the plot level inventory data in the study area.

NTFP: household level of annual consumption and farm gate values of NTFPs (Fuel wood for home consumption and for sale, wood for local construction, food, and medicinal plants) were estimated based on the data from the household survey as described in section 3.3.1.2 and the values were taken as net benefits from NTFP extraction with the assumption of zero labor cost of extraction. In order to convert these values to per hectare values we divided the values by the average land size per household with the assumption that households derive most of these products from the land that belongs to them. This assumption is based on our observation in the study area, the results of the household survey, as well as the ease of practicality in collecting data on NTFP harvesting through household survey than area based inventory. Furthermore, we did the following assumption in accounting the flows of NTFP to the four land use options and the conservation area. For the conservation area we assumed no income from NTFPs to nearby rural communities based on the fact that extraction of NTFP from the conservation area is illegal and completely prohibited. For the cocoa farming we considered income from food and medicinal plant NTFPs whereas for the three agroforestry types of land uses we considered incomes from all types of the NTFPs.

Crops: In order to account for net farm income of rural households, the questionnaire was designed to collect the following farm income accounting information. Each respondent was asked about the name and size of each plot of land he/she has been cultivating over the past 12 months in two production seasons. For each plot respondents were further asked to provide information on crop types cultivated in each season and identify them into major (dominant) cropand minor crops, the total harvest of the major crop and each of the other minor crops from the plot per season, and the inputs (hired labor, fertilizer, pesticides, and insecticides) used for each plot per season. The data was analyzed using SPSS 16.00 and the mean production per plot was estimated for each crop type for each season, the result was then multiplied by the average annual farm gate price of the specific crop to get the gross value of output per crop per plot. The results of gross outputs for the crops cultivated in a plot were summed to get the total value of crops per plot. The net income per plot was calculated by subtracting the total input costs, which was calculated by the quantity of input used by the price of inputs, from the total value of crop output from that plot. We classified the results of all plots (143 plots which in total cover an area of 499 hectares) by the major crop types (cocoa, Cassava, other crops (plantain, banana, yam, maize, coconut, palm, garden egg, okro, pepper) and estimated the mean output quantity and value, input costs, and net income per ha/year for each of these classes and their aggregate. In the assignment of the flows of costs and benefits of cocoa production over the time, we considered only costs of cocoa production and land preparation for the first four years of the discounting period with the assumption that if the conservation forest is to be converted to cocoa farm it will require at least 4 years for the cocoa trees to provide crops.

Third, for each land use type we estimated the total carbon stock per ha as a sum of carbon in biomass and soil and converted the result to tCO2 equivalent as described in section 3.3.2. Finally, based on the results of the above procedures we estimated the present value of the direct opportunity cost of conserving the Ankasa FCA using the following equation:

NPV_JA=_(t=0)^T[({timNB_Jt-timNB_At }+{ntfpNB_Jt-ntfpNB_At }+{cropNB_Jt-cropNB_At }) (1-r)^(-1)]

NPV_JA=(_(t=0)^T[({timNB_Jt-timNB_At }+{ntfpNB_Jt-ntfpNB_At }+{cropNB_Jt-cropNB_At }) (1-r)^(-1)])/[tCO_(2_A)-tCO_(2_J)]

NPV_AJt=_(t=0)^T[(B_jt-C_jt) (1+r)^(-t)]

Where:

NPVAJ is the opportunity cost in $/tCO2 emission reduction from not converting A, which refers the Ankassa Forest Conservation area, to land use J (where J = 1 4, representing the above four land use options).

timNB is net benefit (benefit minus cost) from timber

ntfpNB is the net benefit from non-timber forest product extraction

cropNB is the net benefit from crop production

tCO2A is the stock of carbon in Ankassa forest in terms of tons of carbon dioxide equivalent

tCO2J is the stock of carbon in the alternative land use J in terms of tons of carbon dioxide equivalent

r is discount rate

t is time in years (t = 0, 1, 2, T and T = 5, 10, 20 and 30)

We applied two real discount rates (3% and 7.26%). The 3% is the discount rate for Annex I countries, which are the main buyers of carbon credits, whereas the 7.26% real discount rate was calculated for Ghana using national average nominal interest rate, i , of 15.5% (www.tradingeconomics.com; Bank of Ghana, 2012) and the expected inflation rate following (Fisher, 1930) as: r= (i-)/(1+).

Current consumer price and/or general price indices are often used as an estimate of future inflation. However, these indices reflect the general development of all prices, which might either over estimate or underestimate the future price development of the specific project outputs. Therefore we used data for five years (2014-2018) inflation forecasts for Ghana available online from www.economywhach.comand calculate an expected inflation rate of 7.69% and hence the real discount rate of 7.26%.

The project duration over which the economic analysis has to be carried out is another important parameter that has to be chosen. This is related to the issue of permanence, which refers to the question of How long do payments to families and other incentive measures need to be maintained to ensure that emissions reductions are permanent? Based on international experience in forestation projects for Clean development mechanism and official carbon accounting rules (UNFCCC, 2003) and related studies (Olschewski and Benitez, 2005; Mekuria et al., 2010), and with the objective of providing portfolio of accounting periods for possible decisions by potential buyers of carbon credits we selected four accounting periods, which are 5 years, 10 years, 20 years, and 30 years.

Analysis and interpretation of the data and results

4. Results

4.1. Economic values of selected ecosystem services

4.1.1. Provisioning services: timber and non-timber forest products

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imber:Table 4.1 describes the total volume and stumpage values per hectare for the commercial and non-commercial timber in the study area. The Ankassa Forest Reserve contains 627.35 m3of standing volume of timber per hectare with a mean stumpage value of 364.26 $/ha. Commercial timber species (Annex A1) account 28.73% in volume and 45.99% in value of total standing timber per hectare. Among the commercial timber species, low value species accounted the largest proportion (76.52%) in volume per hectare whereas the high value timber species accounted the largest share (54.68%) in value per hectare. In the case of off-reserve land uses, the total standing volume and stumpage value of timber was 279.59 m3/ha and 131.22 $/ha respectively. This indicates that the Ankasa Forest Reserve has 247.76 m3/ha more standing timber volume than the average standing volume of timber in off- reserve land uses. In terms of value this corresponds to a difference of 233.04 $/ha.

Table 4 1: Volume and Stumpage value of commercial and non-commercial timber species by land cover

Species category	Forest reserve		Off-reserve land uses*	
	Volume in m3/ha Mean (SE)	Value in $/ha Mean(SE)	Volume in m3/ha Mean(SE)	Value in $/ha Mean(SE)
	Mean (SE)	Mean (SE)	Mean (SE)	
High value commercial timber	28.59 (13.97)	91.6 (44.57)	0.70 (0.70)	3.49 (3.49)
Medium value commercial timber	13.73 (10.53)	9.87		

(7.23) 5.80
(4.66) 6.45
(4.60)
Low value timber species 137.92
(21.25) 66.06
(12.03) 98.78
(39.81) 44.59
(17.78)
Total timber species 180.24 167.53 105.28 54.52
Other tree species for local uses 447.11
(60.55) 196.73
(26.64) 174.307
(41.88) 76.696
(18.43)
Total timber 627.35 364.26 279.59 131.22

*refer Annex A2 for details on the corresponding data for the land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) whose values are aggregated as off-reserve land use.

Non timber forest products:non timber forest product extraction from the Ankasa Forest Reserve is illegal and prohibited. The results of the level of annual consumption and farm gate values of NTFP extraction per household are described in Table 4.2 below therefore refer to the extractions from the off-reserve land uses. Households in study area reported that they were extracting non timber forest products (for fuel wood, wood for local construction, for food, and medicinal uses) with an average gross farm gate value of 451.27 $/household over 12 months from May 2012 to June 2013 from the off-reserve land uses .The farm gate value of fuel wood accounted the largest share (66.54%) of the gross farm gate value of all the NTFPs extracted whereas medicinal plant extraction accounted the least (only 2.19%). If we divide the values of the NTFP per household by the average land holding size of sample households in the study area (8.42 ha per household) to get a proxy at per hectare level, it implies that households extracted NTFP of with an average value of 53.59 $/ha/yr from the off-reserve land uses.

Table 4 2: Household consumption levels and farm gate values of major NTFPs from the Off-reserve land uses in rural areas around the Ankasa FCA.

NTFP	% of HHs using the NTFP (N=63)	Unit	Consumption in Unit/HH/Yr		Farm Gate Value in $/HH/Yr		Farm Gate Value in $/ha/Yr *
			Mean	SE	Mean	SE	
Fuel Wood:					300.29	51.20	35.66
Fuel wood for home consumption	100.00	Kilo gram	1193.10	123.63	243.04	39.48	28.86
Fuel wood for sale	11.10	Kilo gram	116.42	64.21	57.25	37.19	6.80
Wood for local construction:					90.54	22.68	10.75
Wood for local construction	66.70	Pieces	87.86	16.49	40.61	8.35	4.82
Wood for making beds for drying crops	44.40	Pieces	71.96	39.46	28.73	18.35	3.41
Canes	14.3	Pieces	21.00	12.60	6.91	4.10	0.82
Rattan	22.20	Pieces	26.65	9.51	14.291	5.48	1.70
Food:					50.45	13.82	5.99
Wild fruits (mango, avocado, ...)	23.80	Pieces	63.22	20.73	16.26	5.87	1.93
Bush meat (antelope and other animals)	11.10	Number	1.48	0.81	11.57	6.27	1.37
Bush meat (Rodents)	22.20	Number	7.13	2.53	19.43	8.14	2.31
Snails	14.30	Number	52.17	47.61	2.62	1.43	0.31
Mushrooms	6.30	Pieces	80.51	79.35	0.57	0.57	0.07
Medicine:					9.90	5.18	1.18
Medicinal plants	19.00	Pieces	13.95	6.03	9.90	5.18	1.18
Total					451.27	63.76	53.59

*the per hectare values were calculated by dividing the per household values by 8.42 hectares which is the average land size per household.

4.1.2. Regulating services: Carbon stock in biomass and soils

Carbon stock: Forests store carbon in biomass and soil through the processes of photosynthesis and decomposition of organic matter respectively. Table 4.3 describes the total carbon pool in terms of CO_2 equivalent and the corresponding market value for the Ankassa Forest Conservation and the off-reserve land uses. TheAnkasa forest stores 1229.93 tCO2e/ha and has a value of 7256.78 $/ha. Biomass carbon accounts the bigger share (78.37%) of the total carbon pool of the forest as well as its value whereas the carbon in the forests soils up to a depth of 0.6 meters accounts the remaining 21.63% both in quantity and value. In the case of biomass carbon, above ground tree biomass stores59.55% of the total carbon pool of the forest and tree root biomass accounts 12.72% of the total carbon pool of the forest. Non-tree vegetation and litter biomass together account the remaining 6.09% of the total carbon pool. The top soil (0-0.2 m depth) stores more carbon than the soils at higher depth classes. The carbon in the top soil accounts 11.82% of the total carbon pool of the forest reserve whereas the soils in the last two depth classes accounted only 6.81% and 3% of the total carbon pool respectively.

Table 4 3: Stocks and values of carbon in biomass and soils of Ankassa Forest Conservation Area and Off-reserve land uses

Ecosystem service	Land Uses						
	Forest Reserve	Off reserve					
		Cocoa	Coconut	Rubber	Fallow	Wetland	Total
No. Plots	21	5	5	5	5	5	25
Biomass carbon in tCO2e/ha							
AGB	732.46 (97.54)	94.16 (14.74)	45.96 (8.62)	387.38 (252.18)	209.42 (28.03)	516.82 (155.76)	250.75 (65.41)
Root biomass	156.47 (22.57)	19.30 (3.02)	9.42 (1.77)	79.41 (51.70)	42.93 (5.75)	105.95 (31.93)	51.40 (13.41)
Non tree vegetation biomass	56.98 (20.96)	0.00	17.39	9.89 (2.59)	43.08	21.02 (3.16)	20.37 (5.10)
Litter Biomass	18.00 (6.36)	8.41	2.20	6.35 (0.56)	10.06	7.00 (1.25)	6.77 (0.96)
Total	963.91	121.87	74.97	483.01	305.49	650.79	329.29
Value of tCO2e biomass carbon in $/ha	5687.07	719.06	442.97	2849.77	1802.37	3839.65	1942.84
Soil carbon in tCO2e/ha							
Top 0-20 cm depth	145.37 (20.62)	153.90 (29.84)	105.67 (27.06)	134.94 (17.46)	208.80 (90.26)	93.30 (24.82)	139.32 (20.63)
20-40 cm depth	83.76 (10.07)	82.48 (20.39)	80.67 (28.33)	98.04 (18.92)	116.95 (35.09)	46.54 (18.32)	84.94

(11.28)
40-60 cm depth 36.89
(7.60) 68.56
(25.78) 45.40
(12.90) 50.43
(22.12) 59.20
(15.55) 12.40
(4.34) 47.20
(8.24)
Top 0-60 cm depth 266.02 304.95 231.75 283.42 384.93 152.24 271.46
Value of tCO2e of soil carbon in $/ha 1569.51 1799.15 1367.28 1672.15 2271.95 898.21 1601.58
Total carbon pool in tCO2e/ha 1229.93 426.82 306.72 766.43 690.43 803.03 600.75
Value of total carbon pool in $/ha 7256.58 2518.21 1809.62 4521.92 4073.55 4737.86 3544.42

For the land uses outside of the forest reserve, the study found a total carbon pool of 600.75 tCO2/ha with a value of 3544.42 $/ha as a weighted averages of the corresponding values for the five major land uses of the off-reserve. Among the five land uses off-the reserve, wetlands store the highest carbon on per hectare basis followed by rubber plantations and fallow lands whereas coconut plantations store the least. In terms of biomass carbon, the same trend was observed whereas in terms of soil carbon pool we observed a different ranking of the five land uses. Fallow lands store the highest carbon in soil on a per hectare basis followed by cocoa farms and rubber plantations whereas wetlands store the least carbon in soil.

Comparing the Ankasa forest reserve with the off-reserve land uses indicates that the total carbon pool and its value for the Ankasa forest reserve are more than twice the carbon pool and value for the off-reserve land uses on a per hectare level. The difference is totally accounted by the difference in biomass carbon pool between the two land uses. In the case of soil carbon, however, we found the opposite. The off-reserve land uses on average store a little more carbon than the soils in Ankasa Forest Reserve on per hectare basis. But the differences in soil carbon pool at each of the soil depth classes between the Ankasa forest reserve and the Off-reserve sites were not statistically significant at 1% level (top soil: df =44, t=0.206, p=0.84; soil depth 20-40cm: df=44, t=-0.077, p=0.94; soil depth 40-60cm: df=44, t=-0.906, p=0.37).

4.1.3. Supporting services: Soil Nutrients and Biodiversity

4.1.3.1. Replacement cost of soil nutrient loss

Nitrogen is an important nutrient for plant growth. A minimum threshold level of 0.1% of nitrogen nutrient is considered as moderate for plant growth and reported for assessing forest soil health (Amacher et al., 2007). Table 4.4 below describes the replacement costs of soil nitrogen, phosphorus, and potassium nutrient losses for the Anakasa Conservation area and the off reserve land uses. The available nitrogen nutrient in the Off-reserve land uses was larger by 137.37 Kg/ha than the nitrogen nutrient in the soils of the Ankasa Forest reserve. However, in both the Ankasa forest reserve and the off-reserve land uses, the available nitrogen in soils was much greater than the threshold level implying no replacement cost for this particular nutrient at a threshold level of 0.1% nitrogen content in soil. The negative replacement costs of 22.47 $/ha for the Ankasa Forest reserve and 33.73 $/ha for the off reserve land uses imply the value of the extra stocks of available nitrogen in soil which can be considered as benefits. But if we consider a threshold level of 0.2% of nitrogen content, which Damnyag et al. (2011) used in their study as a threshold level required for the growth of Agroforetry crops in Ghana, the available soil nitrogen will be less than the threshold in both land uses. At this threshold level, the replacement cost of nitrogen nutrient loss was estimated at 139.49 $/ha for the Ankasa Forest Reserve whereas the replacement cost for the off reserve land uses was 131.18 $/ha (Annex A3).

Phosphorous nutrient content available in soils of both the Ankasa FCA and the off-reserve land uses were below the threshold level of 10 milligram per kilogram of soil. The available phosphorous nutrient in the soils up to a depth of 0.6 meters were nearly equal in both site with about only 0.11 kg/ha higher in the soils of the off-reserve land uses than the Ankasa FCA.Thus, a replacement cost of 0.49 $/ha is required to increase the soil phosphorous content to the threshold level of 10 mg/kg for each of the two land uses. In the case of the five off-reserve land uses, cocoa farm exhibited the highest available phosphorous in kg/ha and lowest replacement cost in $/ha followed by rubber plantation and coconut plantations whereas fallow lands had the lowest available phosphorus in kg/ha and highest replacement cost in $/ha (Annex A3).

Table 4 4: Replacement costs of soil nutrient loss in Ankasa Forest Conservation and Off-reserve land uses

Nutrient Type by land use (n=sample size) Available nutrient in soil by soil depth in cm (N in %; P in mg/kg; K in mg/kg) (SE) Available nutrient in Kg/ha Nutrient loss * in kg/ha Nutrient-fertilizer conversion ratio Price per nutrient ($/kg) at 0.499 $/kg of

fertilizer Replacement cost ($/ha)
0-20 20-40 40-60 Average
Forest Reserve (n=21)
Nitrogen(N) 0.19
(0.02) 0.10
(0.01) 0.05
(0.01) 0.11 2513.92 -326.58 0.150 0.075 -24.47
Phosphorous (P) 3.99
(0.72) 3.15
(0.61) 2.23
(0.49) 3.12 6.89 14.98 0.066 0.033 0.49
Potassium (K) 17.71
(1.67) 11.85
(0.98) 10.14
(1.18) 13.24 29.11 189.62 0.125 0.062 11.79
Off-Reserve **(n=25)
Nitrogen(N) 0.20
(0.02) 0.11
(0.01) 0.05
(0.01) 0.12 2651.29 -450.22 0.150 0.075 -33.73
Phosphorous (P) 4.20
(0.50) 2.98
(0.41) 2.37
(1.46) 3.19 7.00 15.01 0.066 0.033 0.49
Potassium (K) 25.93
(5.30) 19.26
(4.19) 10.90
(1.23) 18.70 41.07 179.03 0.125 0.062 11.13

*nutrient loss was calculated as the available nutrient minus the threshold level nutrient, which is calculated for the sites at threshold soil properties of (N= 0.1%, P=10 mg/kg; and K = 100 mg/kg), as described in section 3.3.3.1.

** refer Annex A3 for details on the corresponding data for the land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) whose values are aggregated as off-reserve land use.

Potasium nutrient content available in soils of both the Ankasa FCA and the off-reserve land uses were also below the threshold level of 100 milligram per kilogram of soil. The available potassium nutrient in the off reserve land use soils up to a depth of 0.6 meters was 11.96 kg/ha higher than the available potassium nutrient in soils of the Ankasa Forest reserve. Thus, the replacement cost was higher for the Ankasa Forest Reserve by 0.70 $/ha than what is required to increase the soil potassium content of the off-reserve land use to the threshold level of 100 mg/kg. In the case of the five off-reserve land uses, fallow lands contain the highest available potassium in kg/ha and require the lowest replacement cost in $/ha followed by cocoa farm and coconut plantation whereas wetlands had the lowest available potassium in kg/ha and highest replacement cost in $/ha (Annex A3).

4.1.3.2. Biodiversity: Tree species diversity and NTFP source plant species diversity

Biodiversity conservation in forests and other land uses is important for sustainable supply of all of the other ecosystem services. Table 4.5 describes tree species diversity in the Ankasa FCA and the Off-reserve land uses of the study area. A total 108 tree species with DBH 5cm of which 60 tree species were with DBH  30 cm were identified growing in 21 plots, which sum up an to area of 1.051 hectare, in the Ankasa FCA. Out of the total 406 individual trees greater than 5 cm diameter identified in the 21 plots (Annex A4.1), Diospyros sanza-minika is the main species accounting 4.4% of the total number of individual trees. In the case of trees of small and medium size classes, a total of 62 tree species with small diameter (5 cm  DBH < 15 cm)and 54 tree species with medium size class (15 cm  DBH < 30 cm) were identified growing in 21 plots within the4m and 8m radius nested plots respectively. The total area of all of the small radius nested plots was of 0.106 hectare whereas it was 0.422 hectare for the medium radius nested plots.

In the case of off-reserve land uses, a total only 39 tree species with DBH 5cm of which 12 tree species were with DBH  30 cm were identified growing in 25 plots, which sum up to an area of 1.251 hectare. Out of a total 346 individual trees greater than 5 cm diameter identified in the 25 plots, Theobroma cacao and Hevea brasiliensisare the two dominant species that account 22.30% and 21.10% respectively. In the case of trees of small and medium size classes, a total of 24 tree species with small diameter (5 cm  DBH < 15 cm) and 23 tree species with medium size class (15 cm  DBH < 30 cm) were identified growing in 25 plots within the 4m and 8m radius nested plots respectively. The total area of all of the small radius nested plots was of 0.126 hectare whereas it was 0.503 hectare for the medium radius nested plots.

The Shannon indices of each of the diameter classes for the Ankasa forest reserve are higher than the corresponding figures for the off-reserve land uses. This indicates that the Ankasa forest reserve is much richer in tree biodiversity than the off-reserve land uses. Moreover, the abundance of trees in the former land use is much higher than the off-reserve land uses. In the case of the five land uses of the off-reserve, fallow land is the richest in tree biodiversity followed by wetland whereas the other three land uses were almost mono-species.

Table 4 5: Biodiversity of tree species by diameter class in the Ankasa FCA and Off-reserve land uses.

Land use	Tree size	n(plot)	Number of Species	Shannon index	Main species
Forest Reserve					
	DBH  5 cm	21	108	2.40(0.08)	Diospyros sanza-minika
	5 cm  DBH < 15 cm	21	62	1.49(0.11)	Picralima nitida
	15 cm DBH < 30 cm	21	54	1.32(0.13)	Drypetes principum
	DBH  30 cm	21	60	1.60(0.11)	Heritiera utilis; Scytopetalum tieghemii
Other land uses					
	DBH  5 cm	25	39	0.54(0.14)	Theobroma cacao
	5 cm  DBH < 15 cm	25	24	0.38(0.11)	Hevea brasiliensis
	15 cm DBH < 30 cm	25	23	0.30(0.10)	Hevea brasiliensis
	DBH  30 cm	25	12	0.14(0.08)	Hevea brasiliensisHevea brasiliensis
Cocoa Farm	DBH  5 cm	5	2	0.08(0.08)	Theobroma cacao
	5 cm  DBH < 15 cm	5	2	0.08(0.08)	Theobroma cacao
	15 cm DBH < 30 cm	5	1	0.00	Theobroma cacao
	DBH  30 cm	5	0		
Coconut Plantation	DBH  5 cm	5	0		
	5 cm  DBH < 15 cm	5	1	0.00	Cocos nucifera
	15 cm DBH < 30 cm	5	1	0.00	Cocos nucifera
	DBH  30 cm	5	1	0.00	Cocos nucifera
Rubber Plantation	DBH  5 cm	5	1	0.00	Hevea brasiliensis
	5 cm  DBH < 15 cm	5	1	0.00	Hevea brasiliensis
	15 cm DBH < 30 cm	5	1	0.00	Hevea brasiliensis
	DBH  30 cm	5	1	0.00	Hevea brasiliensis
Fallow Land	DBH  5 cm	5	20	1.37(0.16)	Macaranga barteri; Musanga cercropioides
	5 cm  DBH < 15 cm	5	12	0.82(0.26)	Ficus sur
	15 cm DBH < 30 cm	5	11	0.94(0.16)	Macaranga barteri
	DBH  30 cm	5	1	0.00	Musanga cercropioides
Wetland	DBH  5 cm	5	18	1.26(0.23)	Raphia hookeri
	5 cm  DBH < 15 cm	5	11	0.99(0.15)	Anthocleista vogelli
	15 cm DBH < 30 cm	5	10	0.56(0.28)	Raphia hookeri
	DBH  30 cm	5	10	0.70(0.29)	Raphia hookeri

Table 4.6 describes the biodiversity in non-timber forest product plant sources in the Ankasa FCA and off-reserve land uses. In the Ankasa forest reserve a total of 32 plant species (Annex A5.1) that are source of non-timber forest products were identified growing in 18 plots which sum up an area of 0.09 hectare. In the case of the off-reserve land uses there were 29 plant species (Annex A5.2) of non-timber forest product sources growing in 10 plots that sum up and area of 0.05 hectare. The Shannon index for the diversity of the non-timber forest product source plant species of the Ankasa Forest reserve was higher than the

off-reserve land uses indicating a richer biodiversity in the former land use.

Table 4 6: Biodiversity of non-timber forest product source plants in Ankasa Forest Reserve and Off-reserve land uses

Land use	Use as a NTFP	n (plot)	Number of species	Shannon index	Main species
Forest Reserve	Medicinal	13	6	0.28(0.04)	Sphenocentrum jollyanum
	Food	13	9	0.24(0.06)	Chrysophyllum albidum
	Food and Medicinal	13	4	0.32(0.03)	Piper guineense
	Construction and ornamental	4	10	0.12(0.02)	Eremospatha hookeri; Strombosia glaucescens
	Other uses (resin, fodder, ...)	5	6	0.08(0.01)	Napoleonaea vogelii
	Total	18	32	1.03(0.22)	Sphenocentrum jollyanum
Other land uses	Medicinal	7	19	0.65(0.15)	Aframomum stanfieldii
	Food	7	5	0.14(0.04)	Elaeis guineensis
	Food and Medicinal	4	3	0.05(0.02)	Psidium guajava
	Construction and ornamental	1	3	0.04	Raphia hookeri
	Other uses (resin, fodder, ...)	3	1	0.02(0.01)	Baphia nitida
	Total	10	29	0.89(0.20)	Aframomum stanfieldii

4.1.4. Cultural services: Tourism, research and educational services

Tourism, recreation, research and educational services are most important cultural services that forests in general and conservation area forests in particular could provide.Despite the rich biodiversity in both plant and animal species found in the conservation area and the high potential for tourism development, the conservation area has not been used to tap such a potential that can contribute to the development of the country. Both the number of tourist arrivals the revenue from the sector that the conservation area was getting over the period from 2002-2012 indicate that the conservation area on average generated revenue of $4121 from 1326 tourist arrival per year. As figure 2 below shows, both the number of tourist arrivals and revenue from the sector was not showing a sign of increasing trend over the period from 2004 to 2009 but for the last three years there were improvements mainly on the revenue from tourist arrivals. In terms of the research and educational services that the conservation area could provide, over a period of 11 years from 2003-2013 there were only 24 researchers (21 foreign and 3 domestic researchers) and 18 student researchers (4 foreign and 14 domestic student researchers) who visited the conservation area for a short to medium term research works of 1 to 6 months duration. The conservation area was able to generate only 590.91 $/year from the foreign researchers and foreign student researchers with the former accounting 94% of the generated revenue.

Considering the total size of the conservation area which is estimated to be 523 km2, the revenues that the conservation area was generating from tourist and researchersvisitsare insignificant. For example the sum of the average revenues per year imply that the conservation area was generating only 9.01$/km2 or 0.09 $/ha from the tourist and foreign researchers arrivals.

Figure 4 1: Number of tourist arrivals at Ankasa FCA and revenue generated over the period 2002-2012. (Source: Ankasa FCA Management Headquarter).

4.2. REDD+ opportunity cost of the Ankassa Forest Reserve

Reducing Emissions from Deforestation and forest Degradation (REDD) entails opportunity costs, implementation and transaction costs. Opportunity costs include direct on-site costs, indirect off-site costs, and socio-cultural costs (White et al., 2011). Table 4.7 below describes the direct on-site opportunity costs of conserving the Ankasa FCA for the next 5 to 30 years. The difference in NPVs between converting and not converting the Ankasa forest to other land uses, which measures the direct on-site opportunity cost of conserving the forest, was highest for Agroforestry2 followed by Agroforestry1 but lowest for cocoa farm. The direct on-site opportunity cost of conserving the forest for the next 30 years ranges from 9662.69 $/ha to 23352.80 $/ha in net present values. Net income from crop production accounts more than 90% of this opportunity cost of conserving the Ankasa forest from conversion to any of the four alternative land uses. The details on net income from crop production in the off-reserve land uses can be seen in Annex A6. The remaining less than 10% of the opportunity cost is in terms of forgone net benefits from commercial and non-commercial timber and non-timber forest products.

The difference in total stock of carbon measured in carbon dioxide equivalent between the Ankasa forest and each of the four alternative land use measures the emission reduction units that can be realized from conserving the forest. As Table 4.7 shows, the emission reduction in tCO2/ha is the highest in the case of conserving the Ankasa FCA from conversion to cocoa farm whereas the lowest is in the case of conserving the forest from conversion to Agroforestry2.

The net present value of the direct on-site opportunity of conserving the Ankasa FCA for a period of 30 years at a discount rate of 3% ranges from 12.03 -38.63 \$/tCO2e , which implies that the forest can be conserved at a direct on-site opportunity cost of 0.40-1.29 \$/tCO2e/yr. If we take a higher discount rate, say 7.26% which is the real discount rate for Ghana calculated based on interest rate of 15.5% and average expected inflation rate of 7.69% (www.economywatch.org), the maximum direct on-site opportunity cost of conserving the forest for a period of 30 years was estimated at 0.81\$/tCO2e/yr in net present value, which is the forgone net benefit form not converting the forest to Agroforestry2. On the contrary if we assume a zero real discount rate which would imply a relatively stronger intergenerational equity, the maximum direct on-site opportunity cost would be only 1.94\$/tCO2e/yr in net present value terms.

Table 4 7: Direct on-site REDD+ Opportunity cost estimates for the Ankasa FCA.

Land use change options	Years	Difference in NPV of Forest Conservation Area and NPV of each land use change options by ecosystem service type in \$/ha					Emission Reduction in tCO2/ha	NPV of Opportunity costs at 3% real discount rate		NPV of Opportunity costs at 7.26% real discount rate		NPV of Opportunity costs at 0.00% real discount rate	
		Commercial timber	Non-Commercial timber	NTFP	Crops	Total		\$/tCO2e	\$/tCO2e/yr	\$/tCO2e	\$/tCO2e/yr	\$/tCO2e	\$/tCO2e/yr
Conserving Forest Reserve from Converting to:													
Cocoa farm	5	169.35	102.99	33.82	-75.12	231.04	803.11	0.29	0.06	0.22	0.04	0.35	0.07
	10	169.35	102.99	63.00	2376.25	2711.59	803.11	3.38	0.34	2.56	0.26	4.14	0.41
	20	169.35	102.99	109.87	6314.88	6697.09	803.11	8.34	0.42	5.36	0.27	11.73	0.59
	30	169.35	102.99	144.75	9245.60	9662.69	803.11	12.03	0.40	6.75	0.23	19.23	0.64
Agroforestry1 (Food crops, Cocoa, Rubber, Coconut, and wetlands)	5	116.70	120.11	252.74	1914.25	2403.80	654.18	3.67	0.73	3.31	0.66	3.97	0.79
	10	116.70	120.11	470.76	5616.19	6323.76	654.18	9.67	0.97	7.84	0.78	11.34	1.13
	20	116.70	120.11	821.05	11564.12	12621.98	654.18	19.29	0.96	13.28	0.66	26.06	1.30
	30	116.70	120.11	1081.70	15989.94	17308.45	654.18	26.46	0.88	15.98	0.53	40.79	1.36
Agroforestry2 (Food crops, Rubber, Coconut, and wetlands)	5	121.27	103.70	252.74	4117.43	4595.14	604.54	7.60	1.52	6.90	1.38	8.17	1.63
	10	121.27	103.70	470.76	8832.72	9528.45	604.54	15.76	1.58	13.07	1.31	18.20	1.82
	20	121.27	103.70	821.05	16408.79	17454.81	604.54	28.87	1.44	20.48	1.02	38.25	1.91
	30	121.27	103.70	1081.70	22046.10	23352.77	604.54	38.63	1.29	24.16	0.81	58.31	1.94
Agroforestry3 with 5 years Fallow (Food crops, Cocoa, Rubber, Coconut, Fallow and wetlands)	5	118.05	120.03	252.74	1914.25	2405.07	631.24	3.81	0.76	3.43	0.69	4.12	0.82
	10	118.05	120.03	470.76	5616.20	6325.04	631.24	10.02	1.00	8.13	0.81	11.75	1.18
	20	118.05	120.03	821.05	9799.98	10859.11	631.24	17.20	0.86	12.04	0.60	23.03	1.15
	30	118.05	120.03	1081.70	12843.08	14162.86	631.24	22.44	0.75	14.07	0.47	33.55	1.12

5. Scaling up results

Scaling up the per hectare level estimated economic values of the selected ecosystem services and the direct on-site REDD+ opportunity costs to the total conservation area in this study enables us to visualize the benefits and opportunity costs of conserving the Ankasa FCA. The per hectare level results were multiplied by the total area of the Ankasa FCA, which is reported to be 52,300 hectares with 34,900 hectares covering the Ankasa Forest Reserve in the south and the remaining 17,400 hectares is the Nini-Suhien National Park in the north.
Table 5.1describes the aggregate values of the selected ecosystem services for the Ankasa FCA. The aggregate value of the selected provisioning services for the conservation area was estimated to be about \$ 21.9 million in value with 87.18% accounted by the stumpage value of an estimated 32.8 million m3 of standing stock of commercial and non-commercial timber trees. The total value of the selected regulating services, which is value of an estimated 64.3 million tCO2e of carbon stock in biomass and soil, for total conservation area was estimated at about \$ 380million of which 78.37% was the value of carbon

stock in biomass. When compared with the value of the selected provisioning services, the value of biomass carbon stock as a regulating service was 15.6 times the aggregate stumpage value of the standing stock of trees in the whole conservation area.

The aggregate value of the selected supporting service, which is measured in terms of the replacement cost of soil fertility loss for the three important soil nutrients, is negative. A negative replacement cost implies a benefit. For the nitrogen nutrient, the available nitrogen in the soils of the whole conservation area was larger than the threshold level by estimated 17 thousand tons of nitrogen which was equivalent to same quantity of commercial nitrogen fertilizer worth of $ 1.28 million in value. However, in the case of phosphorous and potassium nutrients, we estimated deficiencies of 0.78 and 9.9 thousand tons respectively for the whole conservation area. This implies that in order to increase the soil phosphorous and potassium contents to the required threshold levels, an estimated $ 0.65 million worth of phosphorus and potassium fertilizers are needed for the whole conservation area.

The other ecosystem service considered in this study was biodiversity in tree species and plant species of non-timber forest product sources. Although spatial scale extrapolation the results of tree species diversity is not possible for technical and practical reasons, one can infer the level of tree species biodiversity reported in this study is the minimum level for the whole conservation area.

In terms of the cultural services, although the conservation area has biological diversity in plants and animal species as well as other features for tourism development, it was underutilized and the level of tourist arrivals was very insignificant.

Table 5 1: Aggregate values of selected ecosystem services of the Ankasa FCA

Ecosystem service	Unit	Total quantity of ecosystem service in million units			Total value of ecosystem service in million $		
		Ankasa Forest Reserve	Nini-Suhien National Park	Total	Ankasa Forest Reserve	Nini-Suhien National Park	Total
Provisioning services					14.58	7.27	21.85
Timber (stock)	m3	21.89	10.92	32.81	12.71	6.34	19.05
Commercial timber	m3	6.29	3.14	9.43	5.85	2.92	8.76
Non-commercial timber	m3	15.60	7.78	23.38	6.87	3.42	10.29
Non timber forest products (flow)		0.00	0.00	0.00	1.87	0.93	2.80
Fuel wood	kg	5.43	2.71	8.13	1.24	0.62	1.87
Wood for local construction	kg	0.50	0.25	0.74	0.38	0.19	0.56
Food	pieces	0.85	0.42	1.27	0.21	0.10	0.31
Medicinal plants	pieces	0.06	0.03	0.09	0.04	0.02	0.06
Regulating services					253.25	126.26	379.52
Carbon (stock)	ton	42.92	21.40	64.33	253.25	126.26	379.52
Biomass carbon	ton	33.64	16.77	50.41	198.48	98.96	297.43
Soil carbon	ton	9.28	4.63	13.91	54.78	27.31	82.09
Supporting services					-0.43	-0.21	-0.64
Replacement costs* of soil fertility loss (stock)	kg	-4.26	-2.12	-6.38	-0.43	-0.21	-0.64
Nitrogen	kg	-11.40	-5.68	-17.08	-0.85	-0.43	-1.28
Prosperous	kg	0.52	0.26	0.78	0.02	0.01	0.03
Potassium	kg	6.62	3.30	9.92	0.41	0.21	0.62
					268.26	133.75	402.01

*negative value of replacement cost implies benefits.

Table 5.2 describes the aggregate NPV of direct on-site opportunity costs of conserving the whole conservation area. Based on the three discount rates considered, the aggregate NPV of the direct on-site opportunity cost of conserving the whole conservation area for the next 30 years ranges between $ 284 million to $ 1.84 billion with corresponding emission reduction levels of 42 million tCO2e and 31.6 million tCO2e respectively as a global public good. This opportunity costs imply that the country will lose $ 9.45 million to 61.45 million per year as direct on-site net benefits forgone due to conserving the whole conservation area. This annual opportunity cost is equivalent to a minimum of 0.02% and maximum of 0.15% of Ghanas Gross Domestic Product (GDP) for the year 2012, which was about $40.71 billion (World Bank, 2012).

Table 5 2: Aggregate NPV of Direct on-site REDD+ Opportunity Cost of Conserving the Ankasa FCA

Land use changes	Total emission reductions in million tCO2e			Discount rate in %	NPV of Opportunity cost in million $ for a period of 30 years		
	Ankasa Forest Reserve	Nini-Suhien National Park	Total		Ankasa Forest Reserve	Nini-Suhien National Park	Total
Cocoa farm	28.03	13.97	42.00	0.00	538.99	268.72	807.71
				3.00	337.18	168.11	505.29
				7.26	189.19	94.33	283.52
Agroforestry1	22.83	11.38	34.21	0.00	931.27	464.30	1395.57

3.00 604.11 301.19 905.29

7.26 364.84 181.90 546.73

Agroforestry2 21.10 10.52 31.62 0.00 1230.25 613.36 1843.61

3.00 815.03 406.35 1221.38

7.26 509.74 254.14 763.88

Agroforestry3 22.03 10.98 33.01 0.00 739.12 368.50 1107.61

3.00 494.36 246.47 740.83

7.26 309.97 154.54 464.50

Conclusions

6. Conclusions and policy implications

This study estimates the economic values of selected ecosystem services of the Ankasa FCA and alternative land uses practices around the conservation areas. Moreover, it gives estimates for the direct on-site REDD+ opportunity costs of conserving the Conservation Area from conversion to four alternative land uses (namely, cocoa farm, Agroforestry1, Agroforestry2, and Agroforestry3), which are representative of existing land use practices by rural communities living around the conservation area. Although our valuation was carried out for selected ecosystem services and the REDD+ opportunity cost analysis is limited to the direct on-site costs, the results of the study are very crucial for designing policies that will reinforce the sustainability of the conservation of the Ankasa FCA and other conservation sites in Ghana. The results of this study could be used as an important input for designing REDD+ projects and programs for the conservation area as well as other potential forest reserves in Ghana. Moreover, sustainability of tropical forest conservation areas require understanding of the level of direct on-site opportunity costs to different stakeholders affected due to assigning a forest as a conservation site. Accordingly, this study has identified the direct opportunity costs to local authorities as well as local communities living around the Ankasa FCA.

According to information from the management plan of the conservation area, the forest was selectively logged until 1976. The conversion of the forest to a conservation area has entailed loss of stumpage revenue to the government. Stumpage revenue from timber harvesting in Ghana is an important source of revenue for local authorities to add on funds from the central government for financing development activities (Damnyag et al., 2011). Therefore, forgoing these revenues due to the conversion of the forest to its present state as a conservation area would imply limited capacity to finance other social and economic development activities which are important for increasing the welfare of the local communities. This study indicated that for continuing the conservation of the Ankasa FCA for the coming 30 years and hence protecting it from conversion to other land uses, the local communities incur a total opportunity cost of as low as 234.94 $/ha and as high as to 273.34 $/ha (Table 4.7) in net present value from forgone stumpage revenues of commercial and non-commercial timber harvesting. This forgone revenue accounts the lowest share, which is about 0.96 to 2.82%, to the total direct on-site opportunity costs of conserving the forest. This is partly due to the fact that stumpage fees in Ghana are administratively set very low (Hansen et al., 2009, Damnyag et al., 2011).

Recommendations

Non timber forest products in tropical countries play an important role in rural livelihood. They serve as source of food and income for subsistence and as a means of income diversification to reduce risks associated with crop failure in the main agricultural activities (Cavendish, 2000; Angelsen and Wunder, 2003; Belcher and Kusters, 2004; Vedeld et al., 2007).This study indicated that conserving the Ankasa FCA for the next 30 years and protecting it from conversion to other land uses imply opportunity costs as low as 144.75 $/ha and as high as 1081.70 $/ha (Table 4.7) in net present value from non-timber forest product use restriction to local communities. These values account 1.5 to 4.63% of the total direct on-site opportunity cost of conserving the conservation area.

Conversion of tropical forests to other land uses is mainly to derive provisioning services like food from crop and livestock production on the converted land. This study indicated that conserving the Ankasa FCA for the next 30 years from conversion to other land uses (cocoa farm, Agroforestry1, Agrofrestry2, and Agroforestry3 (Table 4.7)) imply an opportunity cost of as low as 9245.60 $/ha and as high as 22046.10 $/ha (Table 4.7) in net present values of forgone crop production by local communities. These values account the largest share (about 94.40 to 95.68%) to total direct on-site REDD+ opportunity cost of conserving the conservation area. Thus, in total up to 97% of the opportunity cost of conserving the Ankasa FCA from conversion to any of the alternative land use is incurred by rural communities in terms of the foregone net benefits from crop production and non-timber forest product use restrictions. During the field works for data collection, we have observed that rural communities were residing close to the conservation area and undertake agroforestry practices, mainly cocoa production. From our field observation of the southern part of the conservation area, we did not see a buffer zone that separates the conservation area from the land use practices by rural communities. Establishing a buffer zone is very important for the sustainable management of the conservation area and such an effort, however, should take in to account the opportunity costs that would be lost by the rural communities that have to be displaced for establishing the buffer zone.

Conservation of tropical forests provides global public goods like carbon dioxide emission reduction as a climate regulating ecosystem service and biodiversity as a supporting ecosystem service. This study indicated that the conservation of the Ankasa FCA from conversion to any of the four alternative land uses (namely, cocoa farm, Agroforestry1, Agrofrestry2, and Agroforestry3 (Table 4.7)) could result in emission reductions as low as 604.54 tCO2e/ha to as high as 803.11 tCO2e/ha from carbon stocks in biomass and soils. These levels of emission reductions are the lower bound estimates for the fact that our study did not take into account the carbon sequestration services that the forest is providing. Thus, the direct on-site REDD+ opportunity cost estimated in this study, which are as low as 12.03 $/tCO2e and as high as 38.63 $/tCO2e in net present value at a discount rate of 3% and period of 30 years, could also be lower if we consider the net difference in carbon sequestration services of the conservation area and that of each alternative land use.These REDD+ direct on-site opportunity cost estimates are lower than the 2008 price for carbon market of the EU Emission Trading Scheme, which were running about 35 to 40 $ per tCO2 and a little higher than the PointCarbon (2011) estimate of global carbon price of $ 35 per tCO2 for 2020. However, the REDD+ direct on-site opportunity cost estimates for this study are much higher than the REDD+ opportunity cost estimates in the literature. For example, from a review of 29 regional empirical studies, Boucher (2008) found an average REDD+ opportunity cost of 2.51/tCO2. A conversion of the area based Grieg-Grans estimate for the Stern (2006) and Eliasch (2008) Reviews to per-ton costs provides a range of $2.67 to $8.28 per tCO2 (Boucher, 2008). Estimates based on global economic models range from $6.77 to $17.86 with an average of $11.26 per tCO2 (Kindermann et al., 2008).

The study also indicated that the conservation area is home to more than 108 tree species with a minimum of 5cm and above in diameter and rich in plant species which are important sources of non-timber forest products. Moreover, the soils of the Ankasa FCA contain about an extra 327 kg available nitrogen nutrient per ha than the threshold level reported as indicator of forest soil health. However, both potassium and phosphorous nutrient levels available in the soils of the Ankasa Forest were found to be below the minimum threshold levels.

To sum up, conserving the Ankasa Forest Conservation area until 2042could provide a global public good of emission reduction level of 316 million tCO2e to the minimum at a direct on-site maximum opportunity cost of $ 1.84 billion to rural communities and local authorities in Ghana. The total opportunity cost would be either higher or lower than this for the fact that our estimate did not take into account two main important factors that would affect the value. These are: 1) net difference in carbon sequestration service between the forest conservation area and each of the alternative land use, which is likely to be positive and hence increase emission reduction level above our estimate, and 2) the indirect opportunity costs associated with not converting the conservation area to other land uses were not taken into account in this study, which include for example the value added forgone by all actors in the supply chain of firms using timber as major input in their production process, due to complete restriction of timber logging from the conservation area. Further studies should take the carbon sequestration services and indirect costs associated with conserving the forest as well as the implementation and transaction costs in order to have a complete estimate on the REDD+ costs for sustainable management of forest conservation areas.

Implications for practice

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Summary

Executive Summary

High rates of deforestation and forest degradation are among the serious environmental problems in Africa that are dwindling the level and quality of forest ecosystem services.Forest protected area management plays an important role in the global and nation level efforts of nature conservation. The Ankasa Forest Conservation Area is one of the most important protected areas in tropical forests of Western Africa. However, there is lackof information on the quantity and value of ecosystem services provided by the forest conservation area.The main objectives of this study were, therefore, to estimate the economic values of selected ecosystem services (timber, non-timber forest products, carbon, and soil nutrients) of the Ankasa Forest Conservation Area and the direct on-site REDD+ (Reducing Emissions from Deforestation and Degradation) opportunity costs of maintaining the conservation area from possible changes to other land uses commonly practiced by rural communities around the conservation area. Biophysical data from experimental sample plots and social-economic data from household survey were used to estimate the economic value of selected provisioning, regulating, and supporting ecosystem services of the conservation area. A number of ecological modeling techniques were used to estimate the quantities of selected ecosystem services. The concepts of ecosystem services and total economic value were applied as a conceptual framework whereas the revealed preference method of valuation was used for valuing the ecosystem services. The direct on-site REDD+ opportunity costs were estimated using the method of Net Present Value and using the microeconomic concept of opportunity cost. The Key findings of the study are presented below.

Provisioning services (Timber and Non-timber forest Products)

The standing volume of trees with diameter at breast height greater than or equal to 5 cm in the conservation area was about 627 m3/ha with stumpage value of about 364 $/ha, of which about 29% in volume and 46% in value was accounted by commercial timber species. The aggregate volume of trees for the whole conservation area was estimated at about 32.8 million m3 with a total stumpage value of about $ 19.1 million.

Summary

Rural households around the Ankasa Forest Conservation area extract non-timber forest products (fuel wood, wood for local construction, food (wild fruits, bush meat, snail, and mushrooms), and medicinal plants) from the land uses outside the conservation area. The total farm gate value of these ecosystem services was estimated at about 451 $/household/year, with fuel wood accounting about 67% of the value. If we divide this value by the average land size per household, we get a per hectare value that would be used for estimating the value of such ecosystem services that would be derived by rural communities from the Ankasa Conservation area, had there not been use restriction.Accordingly, the conservation area could provide the above non-timber forest products worth of about $ 2.8 million per year.

Regulating services (Carbon stock in biomass and soil)

The Ankasa Forest Conservation area stores carbon that amounts about 1230 tCO2e/ha and worth about 7257 $ at the weighted average price of 5.90 $/tCO2e of the international voluntary carbon market for the year 2012. The carbon in biomass, which is the sum of above ground tree biomass, root biomass, non-tree vegetation and litter, accounted about 78 % whereas the remaining was the stock of carbon in soils up to a depth of 60 cm. The carbon stock in biomass and soils of the whole conservation area was estimated at about 64.3 million tCO2e and worth of about $ 380million.

This value is equivalent to 15.6 times the aggregate stumpage value of the standing volume of trees in the conservation area. This study did not take into account the carbon sequestration services of the forest, which is an important component of the climate regulating service provided by the conservation area as a global public good.

Supporting services (Soil Nutrients and Biodiversity)

Nitrogen, phosphorous, and potassium nutrient contents in soils are important for plant growth and development. The nitrogen nutrient content in the Ankasa Forest conservation area was more than the minimum threshold level recommended for a healthy plant growth and development. The available nitrogen in the soil up to a depth of 60 cm was about 327 kg/ha in excess of the threshold level. This extra stock valued using the replacement cost method was estimated to worth about $ 25. The extra available nitrogen stock in the conservation area was estimated at about 17 thousand tons of nitrogen which worth about $ 1.3 million valued at a market price of commercial fertilizer in Ghana.

However, it was found that phosphorous and potassium nutrient contents in the soils of Ankasa were below the threshold levels required for plant growth. The available phosphorous and nitrogen nutrients in the soils up to a depth of 60cm were less by about 15 kg and 190 kg per hectare than the corresponding threshold levels respectively. This implies that supplementing these deficiencies with commercial fertilizer would require about $ 0.5 for phosphorous and about $12 for potassium on per hectare level. For the whole conservation area this would mean about $ 0.63 million worth of commercial fertilizer would be needed to increase the potassium nutrient content to the threshold level and about $ 26 thousand worth of additional commercial fertilizer to increase the soil phosphorous contents to the threshold level.

The conservation area is rich in biodiversity of tree species and plant species of non-timber forest products sources. A total of 108 tree species with diameter greater than or equal to 5 cm and 32 plant species of non-timber forest product sources were identified growing in inventoried plots with a total area of about 1 ha and 0.09 hectare respectively.

Cultural services (Tourism, research and education)

Although the Ankasa Forest Conservation area is rich in both plant and animal biodiversity and has great potential for eco-tourism, the development and benefits from eco-tourism from the forest so far are very insignificant. Over the period from 2002-2012, there was almost constant trend in the number of tourist arrivals to the conservation area. An average of 1326 tourist arrivals and revenue of $ 4121 per annum from the entrance fees was recorded for the same period. There were only 24 researchers and 18 student researches that were visiting the conservation area for research and educational purposes over a period of 11 years (2003-2013). In relative terms, the conservation area was able to derive an annual revenue of only 0.09 $/ha from tourist and foreign researchers arrivals.

REDD+ Opportunity Cost (PV of net income from cocoa farming and agroforestry)

Conserving the Ankasa Forest conservation area form possible conversions to other land uses, which are commonly practiced by rural communities around the conservation area, could result in emission reductions units in the range of about 605-803 tCO2e/ha. This emission reduction level refers only to the difference in stock of carbon in biomass and soils between the conservation area and each alternative land use on per hectare basis. The emission reduction level would be higher if we consider the difference in carbon sequestration service of the conservation area and each alternative land use, which is likely to be a positive value.

However, these levels of emission reduction units entail opportunity cost. The direct on-site opportunity cost of conserving the Ankasa Forest Conservation area for the next 30 years (until 2042) from conversion to the other land uses were estimated to range from between 9663-23353 $/ha in net present value depending on the type of the alternative land uses change. The lowest opportunity cost was estimated for pure cocoa farming as an alternative land uses and the highest opportunity cost was for an agroforestry land use that integrates local food crop production, rubber and coconut plantations on wet and non-wetlands. More than 90% of the opportunity cost was accounted by forgone net income from food crop production by rural communities.

The direct on-site REDD+ opportunity cost was, thus, estimated at in the range of about 12-39 $/CO2e in net present value for conserving the Forest Conservation Area for the next 30 years, which is equivalent to 0.4 -1.29 $/tCO2e per year. This result was based on a 3% discount rate and would be less if we consider a 7.26% discount rate which represents the real discount rate for Ghana. At this discount rate the direct on site opportunity cost was in the range of about 7-24 $/tCO2e.

The aggregate NPV (at 3% discount rate) of the direct on-site opportunity cost of conserving the whole conservation area for the next 30 years was estimated in the range of $ 505 million $ 1.22 billion, which is equivalent to 16.8 40.7 million $/year, with corresponding emission reduction levels of 42 million tCO2e and 31.6 million tCO2e respectively as a global public good. The range of annual opportunity cost is equivalent to 0.04- 0.10% of Ghanas 2012 Gross Domestic Product.

1. Introduction

According to the Millennium Ecosystem Assessment, ecosystem services are classified into four broad categories, namely, provisioning, regulating, supporting, and cultural services (MEA, 2005). Forest ecosystems as natural capital and the ecosystem services they provide make significant direct and indirect contributions to the global economy and human welfare. Forests in Africa play a significant role in biodiversity conservation and providing a number of ecosystem services and in climate change adaptation and mitigation; the sustained provision of ecosystem services can help people to adapt to the effects of changing climate while the carbon stored in the forests can contribute to climate change mitigation. However, the growing human population and the associated increasing demand of land for crop and livestock production (for both subsistence and commercial activities), human settlement, and production of biomass energy are among the major drivers for the degradation of forest resources.

Despite international and national environmental movements for conserving forest landscapes, the area of old-growth tropical forests continues to decline as the demand for rent from tropical forest land and resources increase (Ghauzoul and Sheil, 2010). In 2005 about half of the tropical humid forest contained about 50% or less tree cover, and that at least 20% of this biome was subject to timber extraction over the period 2000 to 2005 (Asner et al., 2009). Much of the global and national conservation efforts rely on protected area management. At the global scale there are over 100, 000 terrestrial protected areas accounting 12% of the land area (Chape et al. 2003), with the greatest coverage in the tropics. In the tropical moist forest zones a total area of about2.5 million km2 (2003 value), which accounts 23.3% of the land surface in this zones, was under some sort of national conservation designation (Chape et al. 2003, Ghauzoul and Sheil, 2010). Protected areas in tropical moist forests of Western and Central Africa constitute about 8.7% of the land area. The Ankasa Forest Conservation Area (FCA)that covers 523 km2in Western Ghana is one of these protected areas in tropical moist forests of Western Africa.

With the growing global interest on tropical forests for climate change mitigation and adaptation, the coverage of protected areasis expected to grow. The Global Climate Change Mitigation and adaptation financing mechanisms like, the Clean Development Mechanism (CDM), Payment for Ecosystem Service (PES) and Voluntary Carbon Market Mechanisms, and REDD+ are manifestations for the growing demand for the climate change mitigation role of forests. However, generating revenues from such financing mechanism through selling ecosystem services of existing or future protected areas requires data on the quantity and value of the forest ecosystem services. Moreover, based on the common sense that you cant manage what you dont measure, valuation of forest ecosystem services is important for sustainable forest management and conservation. In this regard, there has been a growing number of studies on valuation of ecosystem services at different special scales as a decision making tool for moving towards sustainable management and conservation of natural resources (European Communities, 2008; Braat, et al., 2008; Barbier, 2007; CBD, 2007; OECD, 2006; Berry, Olson & Campbell, 2003;Costanza, et al., 1997). Specifically, valuation of forest ecosystem services has been recognized as an important tool that can aid decision makers to evaluate trade-offs between alternative land uses and forest management regimes as well as caurses of social actions that change the use of forest ecosystems and the services they provide (MEA, 2005).

Thus, this study aimed at quantifying and valuing the ecosystems services of the Ankasa FCA and at estimating the direct on-site REDD+ opportunity costs of maintaining the conservation area from conversion to competing land uses.

Applied Methodology

1. Materials and Methods

1.1. Theoretical framework

1.1.1. Typology of forest ecosystem services

With the growing need for understanding and communicating the ecological, economic, social, and cultural values of forest ecosystem services, a number of conceptual frameworks for guiding valuation of these services have been realized over nearly the last two decades since the 1990s. The four categories of ecosystem services, namely provisioning, regulating, cultural, and supporting services, introduced by the Millennium Ecosystem Assessment are the results of one of such efforts and are widely accepted as a frame work of analysis in the contemporary valuation of ecosystem services (Figure 1). This framework provides a standard and internationally accepted conceptual structure through which all aspects of the utility of natural resources to sustainable livelihood and development can be understood (Noel and Soussan, 2010).

Figure 3 1: Typology of forest ecosystem services (Adapted from MEA, 2005).

1.1.2. Quantifying the forest ecosystem services

In the economic literature about valuation of environmental services and the application of cost benefit analysis of land use changes, it is important to identify the stakeholders affected by the project for which the valuation and/or cost benefit analysis is to be made. Discussion with stockholders is very important for determining the valuation objectives, selecting the most important ecosystem services to be valued, and determining the best competing land use against which cost benefit analysis will be carried out.

Valuation of forest ecosystem services then requires quantifying the identified ecosystem services at spatial and temporal scales. Generating such data requires the expertise of different scientific disciplines. It is possible to make a sound valuation exercise if only the physical quantities of the ecosystem services are derived from scientific studies of respective disciplines. Such an interdisciplinary approach entails a greater level of accuracy in the estimated values since it allows minimizing the use of generalized assumptions and hence reduces the associated uncertainties and errors in the valuation exercise.

Both primary and secondary data sources can be used for quantifying the ecosystem services of forest resources. The primary data sources could be field experiments by different scientific disciplines (at different levels e.g. forest biome, forest stand, plot, tree, species, etc.. levels), household surveys, expert opinions from interviews, and ground based input data for mapping ecosystem services at a wider spatial scale using GIS and remote sensing methodologies. The other sources of data are secondary data which may include official statistics on ecosystem services and published works from the literature.

1.1.3. Valuation methodologies

Once the physical quantities of ecosystem services are determined, converting to monetary values using the appropriate valuation method is the next step. The question of how to value these ecosystem services has become a focal issue in a number of discussions and is of direct relevance for the study. Forest resource and the ecosystem services they provide have value both as a stock or natural capital as well as in terms of the flow of yields of economically important ecosystem services they provide. A conceptual framework of valuation that distinguishes between values of assets (forest as natural capital stock) and products (flow value of forest ecosystem services) is essential to integrate such data into the national account (green GDP) of a country. A stock is a quantity existing at a point in time and a flow is a quantity per period. Stocks, flows, and their relationship are crucial to the operation of both the natural and economic systems (Common and Stagl, 2007).

Valuation of forest ecosystem services has been a challenging task for the fact that forests provide a number of non-traded ecosystem services for which market prices do not exist. For some traded goods and services of forest ecosystem services, market prices may not reflect the true scarcity of the services because of market imperfections. In the effort of addressing such critical valuation problem, the concept of Total Economic Value (TEV) has emerged over the last two decades following the work of Pearce (1993) (Table 1). According to the concept of TEV, the values of forest ecosystem services can be classified into two main categories: use values and non-use values. The use values further include direct use values (DUV), indirect use values (IUV), and option values (OV).

Table 3 1: Description of components of the Total Economic Value of Forest ecosystem Services

Value	Sub-value	Description	Examples
Use	Direct	Goods and services that directly accrue to the consumers either from direct use or interaction with the environmental resources and services.	Timber, fuel wood, recreation etc
	Indirect	Functions of forest ecosystems that accrue indirectly support and protection to economic activity and property.	Carbon sequestration, fixing and cycling of nutrients, soil erosion protection, water purification etc
	Option	Future uses of the forest or its biodiversity resources and other functions.	Genetic resources, old growth forests
Non-Use	Existence	The intrinsic values that non-users are willing to pay purely for the existence of the resource without the intention of directly or indirectly using the resource in future.	The demand of non-users for conservation of tropical rainforests, endangered wild animals like tiger etc...
	Bequest	Peoples willingness to pay for ensuring that forests will be preserved for the welfare of future generations.	Biodiversity; areas of scenic beauty

Source: Adapted from Pearce, 1993; CBD, 2007.

Direct and indirect use values of forest ecosystem services are relatively more easily quantified than option and non-use values. In the valuation literature, the common methods to value forest ecosystem services can be classified into revealed preference and non-revealed preference approaches (Table 2).

Table 3 2: Description of methods for valuing forest ecosystem services

Methods Sub-methods Description Examples

Revealed preference Market price Market prices Valuation of an ecosystem service using its market price. Timber, fuel wood, park entrance fees for tourists.

Production function Effect on production Determining the value of an ecosystem service by considering its role in production of other marketed goods and services. Upper water shade catchment protection services of forest to agricultural production, hydropower production, and irrigation at the bottom of the catchment.

Surrogate market approach Travel cost The method involves estimating the recreational value of forest ecosystem services by measuring the money and time that people spend to reach and visit the specific ecosystem. Value of an ecosystems scenic beauty, presence of wildlife, opportunities for sporting activities.

Hedonic pricing The method involves deriving the difference in the market price of a non-ecosystem good due to the existence of a specific environmental attribute. Effect of proximity to forested areas on property prices, wage rates etc

Cost based approach Opportunity cost This technique values the benefits of environmental protection (conserving a forest) in terms of what is being forgone as a net benefit from alternative land use. Conversion of forest to Shifting cultivation for subsistence or commercial agriculture.

Replacement cost This involves estimating the expenses of replacing an ecosystem services with a man-made product, infrastructure, or technology. Cost of commercial fertilizer to counteract nutrient loss due to soil erosion.

Averted expenditure The value of an ecosystem service can be inferred from the expenditure on technologies required to reduce the negative impacts of the missing or degraded service. A forest near urban areas providing air purification service through absorbing dust particles and pollutants. Such services can be inferred from what people spend on preventive technologies used to avoid the health impacts of the pollutants.

Damage cost The method involves valuing an ecosystem services role in protecting other assets. Catchment protection services of controlling downstream siltation and avoided productivity loss in agriculture.

Stated preference Contingent valuation Involves deriving the value of non-marketed ecosystem services by asking consumers directly about their willingness to pay (WTP) for a specific service or their willingness to accept compensation (WTA) for the loss of a service. Value of biodiversity, value of conserving a forest for the welfare of future generation. The method involves collecting survey data and complex econometric modeling.

Conjoint analysis The method asks respondents to consider the status quo and a specific hypothetical scenario, with participants choosing between various environmental services at different prices or costs. Used for all services that cannot be valued using stated and cost-based approaches. The method involves collecting survey data and complex econometric modeling.

Choice experiment The characteristics of the ecosystem service are explicitly defined; vary over choice cards along with a monetary metric. Then, individuals have to choose different combinations of characteristics of the ecosystem service over other combinations at various prices. Used for all services that cannot be valued using stated and cost-based approaches. The method involves collecting survey data and complex statistical and econometric modeling.
Adapted from Garrod and Willis, 1999; CBD, 2007; Noel and Soussan, 2010.

Valuation of forest ecosystem services has been a challenging task for the fact that forests provide a number of non-traded ecosystem services for which there are no market prices. For example, in the 2008 interim report of The Economics of Ecosystems and Biodiversity (TEEB) (European Communities, 2008), it is argued that:

It will be possible to make a quantitative assessment in biophysical terms only for part of the ecosystem services those for which the ecological production functions are relatively well understood and for which sufficient data are available. Due to the limitation of our economic tools, a still smaller share of these services can be valued in monetary terms. It is therefore important not to limit assessments to monetary values, but to include qualitative analysis and physical indicators as well.

Therefore, valuation is part of the multiple approaches that should be used for assessing the contribution of forest ecosystem services to human welfare. The following figure indicates the multiple approaches that can be used for assessing the contribution of forest ecosystems to human welfare.

Figure 3 2: Multiple approaches for assessing the contribution of Forest Ecosystem Services (Source: P. ten Brikn, Workshop on the Economics of Global Loss of Biological Diversity, 5-6 March 2008, Brussels. Cited in European Communities, 2008).

1.1.4. Opportunity costs of land use change

As part of the global effort for mitigating the increase in concentration of GHGs in the atmosphere and the associated impact on the global climate, there has been developments in the Science and Policy of Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+), with the plus indicating related objectives like biodiversity conservation, enhancement of forest carbon, and poverty reduction, (Angelsen et al., 2009; Hansen et al., 2009). The UNFCCC and several national and state governments have been working on the development of REDD+ crediting mechanism that would reward REDD+ efforts in tropical countries with issuance of emission/sequestration credits that could be traded in carbon markets (IETA, 2012). REDD+ entails costs which can be classified as opportunity, implementation, and transaction costs(Figure 3). REDD+ Opportunity costs refermainly to the forgone economic benefits of alternative land use and to some extent social and cultural costs which are not easily measured in economic terms (White et al., 2011).

Figure 3 3: Classification of REDD+ Costs (Source: White et al., 2011).

According to White et al. (2011) data on REDD+ opportunity cost estimates are important for five basic reasons. First, except for remote locations which may entail large implementation and transaction costs, opportunity costs of REDD+ are assumed to account for the largest share of the total cost of avoiding deforestation and forest degradation (Boucher, 2008a; Pagiola and Bosquet, 2009; Olsen and Bishop, 2009; White et al., 2011). Secondly, opportunity costs of REDD+ provide insights on the major drivers of deforestation and forest degradation, impacts REDD+ programs on the different social group and hence derive policies mechanism that can take into account the interests of marginalized groups (Pagiola and Bosquet, 2009, White et al., 2011). Third, the opportunity cost information can be used as a basis for designing fair compensation for the affected groups from changes in land use practices as part of REDD+ program. In areas where natural forest protected areas are efficiently managed opportunity cost estimate, which refers to the loss of income to nearby communities arising from use restrictions, is important for policy makers to understand the impacts of a REDD+ conservation policy (White et al., 2011).

1.2. Study area

The study was conducted in the Ankasa FCA (Figure 4) in of the Jomoro and Ellembelle Districts of the Western Region of Ghana. The conservation area is located at about 330 Km west of Accra and very close to the border with Côte DIvoire. According to information from the management plan of the forest the conservation area covers a total area of 523 km2 and includes the 349-km2 Ankasa Forest Reserve in the south and the 174-km2 Nini-Suhien National Park in the north. The conservation area is the only wildlife protected area in Ghana that is located in the wet evergreen tropical high rainforest belt. Apart from the forest reserve, which was selectively logged until 1976, the Ankasa FCA is in an almost intact state. The conservation area is rich in biodiversity and contains over 800 vascular plants species, 639

butterfly species, and more than 190 species of birds. It is also hometo a number of charismatic, rare and endangered species, including forest elephant, bongo, leopard, chimpanzees and possibly up to eight species of forest primates.

1.3. Data collection

The economic values of timber, non-timber forest products, carbon stocks in biomass and soils, soil nutrient losses, and crop production were estimated on per hectare basis of two forest land use types, namely the Ankasa FCAs and other land uses surrounding the conservation area. The major land uses around the conservation area include cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland. Moreover, the extent of tree biodiversity and the diversity of plant species used as non-timber forest products (for medicinal, food, local construction and other use) for both land uses categories were assessed. These ecosystem services were selected based on their importance in climate change mitigation and adaptation as well as the ease of empirical measurement.

1.3.1. Reconnaissance survey

In order to achieve the objectives of the study, first a reconnaissance survey was conducted for three days in May, 2013. The aim of the reconnaissance survey was to generate basic information on:

- the major land uses/covers outside of the forest reserve,
- the types of crops cultivated by rural households living around the conservation area, and

accessible routes in the conservation site that can be used for lying sample plots of the main survey.

The survey was held through physical observation and discussion with the Manager and staffs of the Ankasa FCAHead Quarter, and community leaders of rural households residing around the conservation area. Accordingly:

Five major land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) were identified as land uses outside of the conservation area).

A list of crops cultivated by rural households

Five routes to the conservation area, each close to one rural community living around the conservation area, were identified. These routes and/or the close by rural communities are locally called Old Ankasa, Odoyefe, Domeabra, Navrongo, and Kusasi.

Based on the physical observation of the study site and the above information, we refined the biophysical and household survey designs proposed for the collection of selected ecosystem services of the conservation area and the neighboring land uses.

We applied both plot level biophysical data collection survey design and household survey to collect data on the physical quantities of selected ecosystem services of the conservation area as well as each of the five land uses outside of the conservation area. The following sections describe the plot level and household survey designs and the corresponding data of ecosystem services collected using the survey designs.

1.3.2. Plot level survey

A total of 21 nested circular plots (Figure 5) were set in the Ankasa FCA using a stratified systematic random sampling method. First, the southern part of the conservation area which is called the Ankasa Forest Reserve was stratified into five (old-Ankasa route, Odoyefe route, Domeabra route, Navrongo route, and Kusasi route) based on accessibility. For each stratum, we selected a random point at a location about 200 to 500 meters from the boundary to inside of the reserve and set the first nested circular plot. From the first plot onwards, 2 plots were lied systematically at distance of 1-2 km to the North direction along the routes of Odoyefe, Navrongo, and Kusasi whereas to the East direction along the route of Domeabra. In the case of the Old-Ankasa route, which is the main gate to the park and has a forest road, we were able to set a total of 9 plots. In addition, a total of 25 sample plots (five plots per each of the major land uses) were set outside of the forest reserve using the same sampling procedure. Figure 3-5 shows the design of the nested circular plot and the measurements that were undertaken in the small, medium, and large radii of the plot.

Figure 3 5: Design of nested circular plot and measurements of ecosystem services

The inventory of Non-timber forest product species was undertaken in 18 of the 21 sample plots of the Ankasa FCA and 10 of the 25 sample plots of the other land uses outside of the conservation area.
The non-tree vegetation includes all the ground vegetation plus trees with less than 5cm diameter. The measurement for this biomass class was undertaken in a 1mX1m random quadrant in the small circular plot. The non-tree vegetation in the quadrant was harvested destructively and the fresh weigh was measured in the field. A sub sample was taken and measured in the field as well and the oven dry weight of the sub sample was determined at the FORIG lab. The samples were put in the oven at a temperature 105 0C and measured after every 24 hours until we observe a constant weight. The dry to wet ratio of the each sub-sample was calculated and used to determine the dry weight from of the non-tree vegetation per quadrant by multiplying the ratio with the total wet weight of the sample from each quadrant. We applied the same procedure for determining the dry weight of litter biomass per quadrant. In the case of both non-tree vegetation and litter biomass samples, we took measurements in 6 of the 21 plots in the conservation site and 7 of the 25 plots in the other land uses.

Soil samples were taken from a random point at about 1m from the center of the nested plot. For each plot, a total of 3 soil samples were taken using soil augur from three soil depth classes (0-20 cm, 20-40cm, and 40-60cm) by taking one sample from each soil depth class. We took soil core samples of each soil depth class for a total of 8 plots out of the 21 plots in the conservation site and for another 8 plots out of the 25 plots of the other land uses. A total of 138 (21X3 + 25X3) soil samples were analyzed at the Soil Research Institute of Ghana for determining the soil carbon and organic matter content, and contents of soil nutrients, specifically total nitrogen, available phosphorous and potassium. The core samples were dried in oven up to a constant weight and the fine soil are separated from the non-soil parts (stones and gravels). The dry weight of the fine soil was used to determine the soil bulk density.

1.3.3. Household survey

Based on the information from the reconnaissance survey, a structured household survey questionnaire was designed to collect data household demographic characteristics, land size, plot area and cultivated crops on each of the plots by the household, gross annual income from the crop production, input costs of the crop production, consumption and sale of non-timber forest products, and farm gate prices for crops, non-timber forest products, and market prices of agricultural inputs. The aim of the household survey was to generate data on net income from agroforestry food crop production per hectare and income from NTFP uses per household for estimating the REDD+ opportunity cost of the conservation area. Accordingly, stratified random samples of 63 rural households (12 to 13 household heads per rural community) were selected from the five rural communities living around the conservation area. A team of 3 enumerators were trained on the survey questionnaire and the survey was administered in June 2013. The data entered and analyzed using SPSS 16.00 software.

Data analysis

Based on data from the experimental plots, the household survey, and secondary data sources, the economic values of the following ecosystem services of the Ankasa Forest Conservation area and the surrounding land uses were estimated on per hectare basis. These ecosystem services are:

Provisioning services: Timber and Non-timber forest products

Regulating services: Carbon stock in biomass and carbon stock in soils both converted to carbon dioxide equivalent.

Supporting services: Soil nutrient cycling (Nitrogen, Phosphorous, Potassium); biodiversity (tree species diversity, non-timber forest product species diversity)

Cultural services: tourism, research and educational services of the Ankasa forest reserve.

The following sections provide details on the methods used to estimate the economic values of each of the above ecosystem services.

Estimates of the economic value of the provisioning ecosystem services

Stumpage value of timber species

Based on the plot level inventory data, on the species, name of sample trees and information from the Forestry commission of Ghana on the major tropical timber species, the sample trees of each plot were classified into timber and non-timber species. For the timber species, the volume of the timber for each sample tree was calculated using Wongs (1989) volume equation, which is a power model that uses DBH as a single predictor variable and widely used in tropical inventory. We specifically used Wongs (1989) volume model developed for Tropical Forests and given by Volume (m3/tree) = 0.004634DBH2.201, where DBH is tree diameter in cm.After determining the volume of each sample commercial tree species the total volume in the small, medium, and large radii of the nested plot were calculated as the summation of the trees in each radius class. The corresponding results were multiplied by the expansion factors of 198.94, 49.74, and 19.99 respectively and summed to convert in to hectare level values for each commercial timber species. Finally, the mean values for the Conservation Area and the other land uses were determined.

To estimate the economic value of each commercial timber species, the per hectare volume estimates for each species were multiplied by the average stumpage prices of the species. The stumpage prices for the different commercial timber species were obtained from the Forestry Commission of Ghana (Damnyag et al., 2011) and the prices were converted to $ at the official exchange rate of 1 $ = 2.0095GHc as of June 2013.

Estimates of Non-timber forest products

The estimation of the economic value of non-timber forest products was based on data from both the plot level and household surveys. The plot level survey was held to identify plant species that are used as non-timber forest product sources. Therefore, for both the conservation area and other land uses, the abundance and names of plant species used for medicinal, food, food and medicinal, local construction and ornamental purposes, fodder and other local uses were identified.

The household survey was used to assess the level of consumption and farm gate value of major non-timber forest products by rural households living around the Ankasa FCA. Accordingly, the average annual consumption levels per household and the corresponding farm gate values for the following major non-timber forest products were estimated based on the household survey data.

Fuel wood (for home consumption and for sale)

Wood for local construction (wood for house and other local construction, wood for making beds for drying crops, Canes, Rattan)

Food (Wild fruits like mango and avocado, bush meat, snail, mushrooms)

Medicinal plants

Estimating the economic value of the regulating service

Carbon storage in Biomass

In order to estimate the economic value of avoided emission of carbon that is currently stored in forest biomass we considered the carbon stock in standing trees greater than 5cm DBH, root of these standing trees, understory non-tree vegetation which includes ground floor vegetation and trees with less than 5cm DBH, and litter. The study did not take into account the biomass dead trees.

To determine the above ground dry biomass for trees greater than 5cm DBH, the Brown et al. (1989) allometric model developed for Wet Tropical forest zone was used. Among the three models developed by Brown et al. (1989) for the wet forest zone, we selected the model that uses DBH and tree height (H) as predictor variables and given by Y (Kg/tree) = exp(-3.3012 + 0.9439ln(DBH2H). In the case of coconut trees, we applied the model of Frangi and Lugo (1985) that uses only tree height as a predictor variable and given by Y = 4.5 + 7.7H. By using these models the aboveground dry biomass of each sample tree was estimated and the results for all the trees within each radius class of each nested sample plot was summed to convert the values to a per hectare level using the corresponding expansion factors. Finally, the mean dry biomass in kilo gram per hectare was calculated for the conservation area and the other land uses. The root biomass per hectare was estimated by multiplying the dry aboveground biomass with conversion factors (root to shoot ratios for tropical wet forests) of 0.205 for trees with dry above ground biomass less than 125 tons per hectare and 0.235 for dry aboveground biomass exceeding 125 tons per hectare (Monkay et al., 2006). To determine the dry weightsof the non-tree vegetation as well as the litter biomass the dry weights per quadrant as described in section 3.2.2 were converted to per hectare values after adjusting for the basal area ofstanding trees.

The dry biomasses factors of 0.46 for trees less than 10cm DBH, non-tree vegetation and litter biomasses and 0.49 for trees above 10cm DBH (Hughes et al., 2000) were used to convert the dry biomass into carbon. The resulting carbon content in tons per hectare for each of biomass component was multiplied by the conversion factor of 3.67 (i.e. the ration of the molecular weights of carbon dioxide molecule to carbon atom) to obtain the tons of carbon dioxide equivalent (tCO2e) per hectare (Olschewski and Benitez, 2005).

The weighted average price of $5.90/tCO2e in the voluntary carbon market for the year 2012, which is reported by Forest Trends Ecosystem Marketplace on the State of the Voluntary Carbon Markets 2013, was used to convert the estimated tCO2e per ha for each biomass component to their corresponding monetary values.

Carbon storage in Forest Soils

Based on the results of the laboratory analysis of the 138 soil samples analyzed for their organic carbon content at the Soil Research Institute of Ghana, the data on the soil bulk density, and following Mekuria et al. (2011) the soil organic carbon stock per hectare for each soil depth class was estimated using the following equation:

SOC (t/ha) = (% C X 10-2) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

Where, SOC is the soil organic carbon stock, C is the soil organic carbon content, Bd is soil bulk density respectively. The stock of soil carbon was multiplied by the conversion factor of 3.67 to obtain into tCO2e per hectare.

Estimating and describing the supporting ecosystem service

Estimating the value of soil fertility

The replacement cost method was applied to estimate the value of soil fertility loss. The method allows the estimation of the value of an ecosystem service by estimating the cost of replacing with an alternative or substitute good or service (Bishop, 1999). The method is widely used because it is relatively simple to use provided that data on nutrient loss is available (Bojö, 1996; Damnyag, 2011). In order to estimate the replacement cost of soil fertility loss we applied the following procedures.

First the available nutrient in the soil was determined on per hectare level based on the results of the laboratory analysis of the 138 soil samples analyzed for their nitrogen, phosphorous, and potassium contents at the Soil Research Institute of Ghana, the data on the soil bulk density, and following Mekuria et al. (2011) the available stocks of total nitrogen (TN), phosphorous (P), and potassium (K) for each soil depth class were estimated using the following equations:

TN (t/ha) = (% TN X 10-2) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

P (t/ha) = (Pppm X 10-6) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

K (t/ha) = (Kppm X 10-6) X (Bd in t/m3) X (Soil depth (0.2m))X (10000m2/ha)

Second, we estimated the corresponding threshold stock levels using the minimum soil property threshold levels (0.1% TN, 10 ppm of P, and 100 ppm of K) considered as moderate for plant growth and reported for assessing forest soil health (Amacher et al., 2007).Then, the nutrient loss for each soil nutrient was estimated by subtracting the available stock from the calculated threshold level. The results were then multiplied by the corresponding nutrient-to-fertilizer conversion ratios derived from a 50 Kg commercial fertilizer of NPK 15-15-15 to obtain the equivalent commercial fertilizer required to replace the nutrient loss (Niskanen, 1998; Nahuelhual et al., 2006; Damnyag et al., 2011). Finally, we estimated the replacement cost for each nutrient loss by multiplying the equivalent commercial fertilizer required to replace the nutrient loss by the annual average market price of the fertilizer in Ghana market.We obtained the monthly average prices of NPK 15-15-15 fertilizer in Ghana for the year 2012 from www.AfricaFertilizer.org and accordingly the annual average market price was 499.49 $ per ton for the year and this value was used in the calculation.

Describing biodiversity of trees and non-timber forest product source plants

In order to obtain a quantitative and qualitative description of the level of tree biodiversity as well as the diversity of plant based sources of non-timber forest products, tree species biodiversity and species diversity of plants and of non-timber forest product source were determined for the conservation area as well as the land uses outside the conservation area. Using the sample plot level inventory on the tree species and the non-timber forest product plant species, we calculated species diversity. Out of a wide range biodiversity indices available in the literature (Magurran, 1988), we applied the Shannon index (H), which has been proposed to estimate biodiversity in carbon sequestration projects (Ponce-Hernandez, 2004; Henry et al., 2009). Shannon index was calculated by multiplying the abundance of a species (pi) by the logarithm of this number:

$H_j = -\sum_{(i=1)}^{m} p_{ij} \ln(p_{ij})$

Where H is the Shannon index for the trees in small, medium and large diameter classes or for non-timber forest product use type or for land use type j depending on the scale of analysis.

$p_{ij} = n_{ij}/N_j$

Where ni is the number of subjects from the species I and N is the total number of subjects within plot j.

Estimating REDD+ Opportunity Cost of the Conservation Area

In order to estimate the opportunity cost of keeping the Ankasa FCA sustainably and hence avoid and/or reduce emissions from the likely deforestation from conversion to other competing land uses, we estimated the opportunity costs in terms of income loses to rural communities living around the conservation area arising from use restriction. Based on the date from the reconnaissance survey and the main plot level and household surveys, and the results of the valuation of ecosystem service of the conservation area and land uses around, we estimated the REDD+ opportunity cost of reducing emissions (in terms of $/tCO2; $/tCO2/ha; and $/tCO2/ha/yr) from potential conversions of the conservation area to four land use change options using the following procedures.

First, we identified four major land uses that represent the major livelihood basis of rural communities living around the conservation area. These land uses are:

Cocoa farming: refers to cocoa farms mixed with agro forestry food crops and some timber trees.

Agroforestry_1: refers to land use that integrates local food crop production, cocoa farming, rubber plantation, and coconut plantation on both wetlands and non-wetlands.

Agroforestry_2: refersto land use that integrates local food crop production, rubber plantation, and coconut plantation on both wetlands and non-wetlands.

Agroforestry_3: refers to land use that integrates local food crop production, cocoa farming, rubber plantation, coconut plantation and fallow lands on both wetlands and non-wetlands.

Figure 3 6: Ankasa Forest Conservation area (at the center) and land uses close to the conservation area (from left to right on top are wetland, cassava farm, cocoa farm. whereas from left to right in the bottom are rubber plantation, fallow land, and coconut plantation).

Second, four major types of ecosystem services were identified as source of income that can represent the direct on -site opportunity cost of not converting the Conservation area to either of the above four land use change options. This ecosystem services are commercial timber, timber for local uses, non-timber forest products, and crops (cocoa, Cassava, other crops (plantain, banana, yam, maize, coconut, palm, garden egg, okro, and pepper)). The flows of benefits and costs of producing each of these ecosystem services and hence the net benefits from each of the four land use options as well as the corresponding potential values from the forest reserve were estimated as follows.

Timber:the volume and stumpage values ($/ha) of commercial and non-commercial timber species were estimated based on the methods described in section 3.3.3.1 above and we took these values as net benefits from timber with the fact thatstumpage price is the price of the standing timber and does not include harvesting costs. For the Ankasa FCAand Cocoa farming, we took directly the estimated results. However, in the case of the land use options Agroforestry_1 to Agroforestry_3, the values were calculated by taking the weighted averages of the results of the different land uses included under each Agro forestry category. For example, the in the case of Agroforestry_1 the volume of timber refers to the weighted average of the volumes of timber per ha for the cocoa farm, coconut plantation, rubber plantation, and wetlands which are estimated based on the plot level inventory data in the study area.

NTFP: household level of annual consumption and farm gate values of NTFPs (Fuel wood for home consumption and for sale, wood for local construction, food, and medicinal plants) were estimated based on the data from the household survey as described in section 3.3.1.2 and the values were taken as net benefits from NTFP extraction with the assumption of zero labor cost of extraction. In order to convert these values to per hectare values we divided the values by the average land size per household with the assumption that households derive most of these products from the land that belongs to them. This assumption is based on our observation in the study area, the results of the household survey, as well as the ease of practicality in collecting data on NTFP harvesting through household survey than area based inventory. Furthermore, we did the following assumption in accounting the flows of NTFP to the four land use options and the conservation area. For the conservation area we assumed no income from NTFPs to nearby rural communities based on the fact that extraction of NTFP from the conservation area is illegal and completely prohibited. For the cocoa farming we considered income from food and medicinal plant NTFPs whereas for the three agroforestry types of land uses we considered incomes from all types of the NTFPs.

Crops: In order to account for net farm income of rural households, the questionnaire was designed to collect the following farm income accounting information. Each respondent was asked about the name and size of each plot of land he/she has been cultivating over the past 12 months in two production seasons. For each plot respondents were further asked to provide information on crop types cultivated in each season and identify them into major (dominant) cropand minor crops, the total harvest of the major crop and each of the other minor crops from the plot per season, and the inputs (hired labor, fertilizer, pesticides, and insecticides) used for each plot per season. The data was analyzed using SPSS 16.00 and the mean production per plot was estimated for each crop type for each season, the result was then multiplied by the average annual farm gate price of the specific crop to get the gross value of output per crop per plot. The results of gross outputs for the crops cultivated in a plot were summed to get the total value of crops per plot. The net income per plot was calculated by subtracting the total input costs, which was calculated by the quantity of input used by the price of inputs, from the total value of crop output from that plot. We classified the results of all plots (143 plots which in total cover an area of 499 hectares) by the major crop types (cocoa, Cassava, other crops (plantain, banana, yam, maize, coconut, palm, garden egg, okro, pepper) and estimated the mean output quantity and value, input costs, and net income per ha/year for each of these classes and their aggregate. In the assignment of the flows of costs and benefits of cocoa production over the time, we considered only costs of cocoa production and land preparation for the first four years of the discounting period with the assumption that if the conservation forest is to be converted to cocoa farm it will require at least 4 years for the cocoa trees to provide crops.

Third, for each land use type we estimated the total carbon stock per ha as a sum of carbon in biomass and soil and converted the result to tCO_2 equivalent as described in section 3.3.2. Finally, based on the results of the above procedures we estimated the present value of the direct opportunity cost of conserving the Ankasa FCA using the following equation:

NPV_JA=_(t=0)^T[({timNB_Jt-timNB_At }+{ntfpNB_Jt-ntfpNB_At }+{cropNB_Jt-cropNB_At }) (1-r)^(-1)]

NPV_JA=(_(t=0)^T[({timNB_Jt-timNB_At }+{ntfpNB_Jt-ntfpNB_At }+{cropNB_Jt-cropNB_At }) (1-r)^(-1)])/[tCO_(2_A)-tCO_(2_J)]

NPV_AJt=_(t=0)^T[(B_jt-C_jt) (1+r)^(-t)]

Where:

NPVAJ is the opportunity cost in $/tCO2 emission reduction from not converting A, which refers the Ankassa Forest Conservation area, to land use J (where J = 1 4, representing the above four land use options).

timNB is net benefit (benefit minus cost) from timber

ntfpNB is the net benefit from non-timber forest product extraction

cropNB is the net benefit from crop production

tCO2A is the stock of carbon in Ankassa forest in terms of tons of carbon dioxide equivalent

tCO2J is the stock of carbon in the alternative land use J in terms of tons of carbon dioxide equivalent

r is discount rate

t is time in years (t = 0, 1, 2, T and T = 5, 10, 20 and 30)

We applied two real discount rates (3% and 7.26%). The 3% is the discount rate for Annex I countries, which are the main buyers of carbon credits, whereas the 7.26% real discount rate was calculated for Ghana using national average nominal interest rate, i , of 15.5% (www.tradingeconomics.com; Bank of Ghana, 2012) and the expected inflation rate following (Fisher, 1930) as: r= (i-)/(1+).

Current consumer price and/or general price indices are often used as an estimate of future inflation. However, these indices reflect the general development of all prices, which might either over estimate or underestimate the future price development of the specific project outputs. Therefore we used data for five years (2014-2018) inflation forecasts for Ghana available online from www.economywhach.comand calculate an expected inflation rate of 7.69% and hence the real discount rate of 7.26%.

The project duration over which the economic analysis has to be carried out is another important parameter that has to be chosen. This is related to the issue of permanence, which refers to the question of How long do payments to families and other incentive measures need to be maintained to ensure that emissions reductions are permanent? Based on international experience in forestation projects for Clean development mechanism and official carbon accounting rules (UNFCCC, 2003) and related studies (Olschewski and Benitez, 2005; Mekuria et al., 2010), and with the objective of providing portfolio of accounting periods for possible decisions by potential buyers of carbon credits we selected four accounting periods, which are 5 years, 10 years, 20 years, and 30 years.

4. Results

4.1. Economic values of selected ecosystem services

4.1.1. Provisioning services: timber and non-timber forest products

Timber: Table 4.1 describes the total volume and stumpage values per hectare for the commercial and non-commercial timber in the study area. The Ankassa Forest Reserve contains 627.35 m3of standing volume of timber per hectare with a mean stumpage value of 364.26 $/ha. Commercial timber species (Annex A1) account 28.73% in volume and 45.99% in value of total standing timber per hectare. Among the commercial timber species, low value species accounted the largest proportion (76.52%) in volume per hectare whereas the high value timber species accounted the largest share (54.68%) in value per hectare. In the case of off-reserve land uses, the total standing volume and stumpage value of timber was 279.59 m3/ha and 131.22 $/ha respectively. This indicates that the Ankasa Forest Reserve has 247.76 m3/ha more standing timber volume than the average standing volume of timber in off- reserve land uses. In terms of value this corresponds to a difference of 233.04 $/ha.

Table 4 1: Volume and Stumpage value of commercial and non-commercial timber species by land cover

Species category	Forest reserve		Off-reserve land uses*	
	Volume in m3/ha Mean (SE)	Value in $/ha Mean(SE)	Volume in m3/ha Mean(SE)	Value in $/ha Mean(SE)
	Mean (SE)	Mean (SE)	Mean (SE)	
High value commercial timber	28.59 (13.97)	91.6 (44.57)	0.70 (0.70)	3.49 (3.49)
Medium value commercial timber	13.73 (10.53)	9.87 (7.23)	5.80 (4.66)	6.45 (4.60)
Low value timber species	137.92 (21.25)	66.06 (12.03)	98.78 (39.81)	44.59 (17.78)
Total timber species	180.24	167.53	105.28	54.52
Other tree species for local uses	447.11 (60.55)	196.73 (26.64)	174.307 (41.88)	76.696 (18.43)
Total timber	627.35	364.26	279.59	131.22

*refer Annex A2 for details on the corresponding data for the land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) whose values are aggregated as off-reserve land use.

N

on timber forest products:non timber forest product extraction from the Ankasa Forest Reserve is illegal and prohibited. The results of the level of annual consumption and farm gate values of NTFP extraction per household are described in Table 4.2 below therefore refer to the extractions from the off-reserve land uses. Households in study area reported that they were extracting non timber forest products (for fuel wood, wood for local construction, for food, and medicinal uses) with an average gross farm gate value of 451.27 $/household over 12 months from May 2012 to June 2013 from the off-reserve land uses .The farm gate value of fuel wood accounted the largest share (66.54%) of the gross farm gate value of all the NTFPs extracted whereas medicinal plant extraction accounted the least (only 2.19%). If we divide the values of the NTFP per household by the average land holding size of sample households in the study area (8.42 ha per household) to get a proxy at per hectare level, it implies that households extracted NTFP of with an average value of 53.59 $/ha/yr from the off-reserve land uses.

Table 4 2: Household consumption levels and farm gate values of major NTFPs from the Off-reserve land uses in rural areas around the Ankasa FCA.

NTFP % of HHs using the NTFP (N=63) Unit Consumption in Unit/HH/Yr Farm Gate Value in $/HH/Yr Farm Gate Value in $/ha/Yr *

Mean SE Mean SE

Fuel Wood: 300.29 51.20 35.66

Fuel wood for home consumption 100.00 Kilo gram 1193.10 123.63 243.04 39.48 28.86

Fuel wood for sale 11.10 Kilo gram 116.42 64.21 57.25 37.19 6.80

Wood for local construction: 90.54 22.68 10.75

Wood for local construction 66.70 Pieces 87.86 16.49 40.61 8.35 4.82

Wood for making beds for drying crops 44.40 Pieces 71.96 39.46 28.73 18.35 3.41

Canes 14.3 Pieces 21.00 12.60 6.91 4.10 0.82

Rattan 22.20 Pieces 26.65 9.51 14.291 5.48 1.70

Food: 50.45 13.82 5.99

Wild fruits (mango, avocado, ...) 23.80 Pieces 63.22 20.73 16.26 5.87 1.93

Bush meat (antelope and other animals) 11.10 Number 1.48 0.81 11.57 6.27 1.37

Bush meat (Rodents) 22.20 Number 7.13 2.53 19.43 8.14 2.31

Snails 14.30 Number 52.17 47.61 2.62 1.43 0.31

Mushrooms 6.30 Pieces 80.51 79.35 0.57 0.57 0.07

Medicine: 9.90 5.18 1.18

Medicinal plants 19.00 Pieces 13.95 6.03 9.90 5.18 1.18

Total 451.27 63.76 53.59

*the per hectare values were calculated by dividing the per household values by 8.42 hectares which is the average land size per household.

4.1.2. Regulating services: Carbon stock in biomass and soils

C

arbon stock: Forests store carbon in biomass and soil through the processes of photosynthesis and decomposition of organic matter respectively. Table 4.3 describes the total carbon pool in terms of CO2 equivalent and the corresponding market value for the Ankassa Forest Conservation and the off-reserve land uses. TheAnkasa forest stores 1229.93 tCO2e/ha and has a value of 7256.78 $/ha. Biomass carbon accounts the bigger share (78.37%) of the total carbon pool of the forest as well as its value whereas the carbon in the forests soils up to a depth of 0.6 meters accounts the remaining 21.63% both in quantity and value. In the case of biomass carbon, above ground tree biomass stores59.55% of the total carbon pool of the forest and tree root biomass accounts 12.72% of the total carbon pool of the forest. Non-tree vegetation and litter biomass together account the remaining 6.09% of the total carbon pool. The top soil (0-0.2 m depth) stores more carbon than the soils at higher depth classes. The carbon in the top soil accounts 11.82% of the total carbon pool of the forest reserve whereas the soils in the last two depth classes accounted only 6.81% and 3% of the total carbon pool respectively.

Table 4 3: Stocks and values of carbon in biomass and soils of Ankassa Forest Conservation Area and Off-reserve land uses

Ecosystem service Land Uses

Forest Reserve Off reserve

Cocoa Coconut Rubber Fallow Wetland Total

No. Plots 21 5 5 5 5 5 25

Biomass carbon in tCO2e/ha

AGB 732.46

(97.54) 94.16

(14.74) 45.96

(8.62) 387.38

(252.18) 209.42

(28.03) 516.82

(155.76) 250.75

(65.41)

Root biomass 156.47

(22.57) 19.30

(3.02) 9.42

(1.77) 79.41

(51.70) 42.93

(5.75) 105.95

(31.93) 51.40

(13.41)

Non tree vegetation biomass 56.98

(20.96) 0.00 17.39 9.89

(2.59) 43.08 21.02

(3.16) 20.37

(5.10)

Litter Biomass 18.00

(6.36) 8.41 2.20 6.35

(0.56) 10.06 7.00

(1.25) 6.77

(0.96)

Total 963.91 121.87 74.97 483.01 305.49 650.79 329.29

Value of tCO2e biomass carbon in $/ha 5687.07 719.06 442.97 2849.77 1802.37 3839.65 1942.84

Soil carbon in tCO2e/ha

Top 0-20 cm depth 145.37 (20.62) 153.90

(29.84) 105.67

(27.06) 134.94

(17.46) 208.80

(90.26) 93.30

(24.82) 139.32

(20.63)

20-40 cm depth 83.76

(10.07) 82.48

(20.39) 80.67

(28.33) 98.04

(18.92) 116.95

(35.09) 46.54

(18.32) 84.94

(11.28)

40-60 cm depth 36.89

(7.60) 68.56

(25.78) 45.40

(12.90) 50.43

(22.12) 59.20

(15.55) 12.40

(4.34) 47.20

(8.24)

Top 0-60 cm depth 266.02 304.95 231.75 283.42 384.93 152.24 271.46

Value of tCO2e of soil carbon in $/ha 1569.51 1799.15 1367.28 1672.15 2271.95 898.21 1601.58

Total carbon pool in tCO2e/ha 1229.93 426.82 306.72 766.43 690.43 803.03 600.75

Value of total carbon pool in $/ha 7256.58 2518.21 1809.62 4521.92 4073.55 4737.86 3544.42

For the land uses outside of the forest reserve, the study found a total carbon pool of 600.75 tCO2/ha with a value of 3544.42 $/ha as a weighted averages of the corresponding values for the five major land uses of the off-reserve. Among the five land uses off-the reserve, wetlands store the highest carbon on per hectare basis followed by rubber plantations and fallow lands whereas coconut plantations store the least. In terms of biomass carbon, the same trend was observed whereas in terms of soil carbon pool we observed a different ranking of the five land uses. Fallow lands store the highest carbon in soil on a per hectare basis followed by cocoa farms and rubber plantations whereas wetlands store the least carbon in soil.

Comparing the Ankasa forest reserve with the off-reserve land uses indicates that the total carbon pool and its value for the Ankasa forest reserve are more than twice the carbon pool and value for the off-reserve land uses on a per hectare level. The difference is totally accounted by the difference in biomass carbon pool between the two land uses. In the case of soil carbon, however, we found the opposite. The off-reserve land uses on average store a little more carbon than the soils in Ankasa

Forest Reserve on per hectare basis. But the differences in soil carbon pool at each of the soil depth classes between the Ankasa forest reserve and the Off-reserve sites were not statistically significant at 1% level (top soil: df =44, t=0.206, p=0.84; soil depth 20-40cm: df=44, t=-0.077, p=0.94; soil depth 40-60cm: df=44, t=-0.906, p=0.37).

4.1.3. Supporting services: Soil Nutrients and Biodiversity

4.1.3.1. Replacement cost of soil nutrient loss

N

itrogen is an important nutrient for plant growth. A minimum threshold level of 0.1% of nitrogen nutrient is considered as moderate for plant growth and reported for assessing forest soil health (Amacher et al., 2007). Table 4.4 below describes the replacement costs of soil nitrogen, phosphorus, and potassium nutrient losses for the Anakasa Conservation area and the off reserve land uses. The available nitrogen nutrient in the Off-reserve land uses was larger by 137.37 Kg/ha than the nitrogen nutrient in the soils of the Ankasa Forest reserve. However, in both the Ankasa forest reserve and the off-reserve land uses, the available nitrogen in soils was much greater than the threshold level implying no replacement cost for this particular nutrient at a threshold level of 0.1% nitrogen content in soil. The negative replacement costs of 22.47 $/ha for the Ankasa Forest reserve and 33.73 $/ha for the off reserve land uses imply the value of the extra stocks of available nitrogen in soil which can be considered as benefits. But if we consider a threshold level of 0.2% of nitrogen content, which Damnyag et al. (2011) used in their study as a threshold level required for the growth of Agroforetry crops in Ghana, the available soil nitrogen will be less than the threshold in both land uses. At this threshold level, the replacement cost of nitrogen nutrient loss was estimated at 139.49 $/ha for the Ankasa Forest Reserve whereas the replacement cost for the off reserve land uses was 131.18 $/ha (Annex A3).

P

hosphorous nutrient content available in soils of both the Ankasa FCA and the off-reserve land uses were below the threshold level of 10 milligram per kilogram of soil. The available phosphorous nutrient in the soils up to a depth of 0.6 meters were nearly equal in both site with about only 0.11 kg/ha higher in the soils of the off-reserve land uses than the Ankasa FCA.Thus, a replacement cost of 0.49 $/ha is required to increase the soil phosphorous content to the threshold level of 10 mg/kg for each of the two land uses. In the case of the five off-reserve land uses, cocoa farm exhibited the highest available phosphorous in kg/ha and lowest replacement cost in $/ha followed by rubber plantation and coconut plantations whereas fallow lands had the lowest available phosphorus in kg/ha and highest replacement cost in $/ha (Annex A3).

Table 4 4: Replacement costs of soil nutrient loss in Ankasa Forest Conservation and Off-reserve land uses

Nutrient Type by land use (n=sample size) Available nutrient in soil by soil depth in cm (N in %; P in mg/kg; K in mg/kg) (SE) Available nutrient in Kg/ha Nutrient loss * in kg/ha Nutrient-fertilizer conversion ratio Price per nutrient ($/kg) at 0.499 $/kg of fertilizer Replacement cost ($/ha)

0-20 20-40 40-60 Average

Forest Reserve (n=21)

Nitrogen(N) 0.19

(0.02) 0.10

(0.01) 0.05

(0.01) 0.11 2513.92 -326.58 0.150 0.075 -24.47

Phosphorous (P) 3.99

(0.72) 3.15

(0.61) 2.23

(0.49) 3.12 6.89 14.98 0.066 0.033 0.49

Potassium (K) 17.71

(1.67) 11.85

(0.98) 10.14

(1.18) 13.24 29.11 189.62 0.125 0.062 11.79

Off-Reserve **(n=25)

Nitrogen(N) 0.20

(0.02) 0.11

(0.01) 0.05

(0.01) 0.12 2651.29 -450.22 0.150 0.075 -33.73

Phosphorous (P) 4.20

(0.50) 2.98

(0.41) 2.37

(1.46) 3.19 7.00 15.01 0.066 0.033 0.49

Potassium (K) 25.93

(5.30) 19.26

(4.19) 10.90

(1.23) 18.70 41.07 179.03 0.125 0.062 11.13

*nutrient loss was calculated as the available nutrient minus the threshold level nutrient, which is calculated for the sites at threshold soil properties of (N= 0.1%, P=10 mg/kg; and K = 100 mg/kg), as described in section 3.3.3.1.

** refer Annex A3 for details on the corresponding data for the land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) whose values are aggregated as off-reserve land use.

P

otasium nutrient content available in soils of both the Ankasa FCA and the off-reserve land uses were also below the threshold level of 100 milligram per kilogram of soil. The available potassium nutrient in the off reserve land use soils up to a depth of 0.6 meters was 11.96 kg/ha higher than the available potassium nutrient in soils of the Ankasa Forest reserve. Thus, the replacement cost was higher for the Ankasa Forest Reserve by 0.70 $/ha than what is required to increase the soil potassium content of the off-reserve land use to the threshold level of 100 mg/kg. In the case of the five off-reserve land uses, fallow lands contain the highest available potassium in kg/ha and require the lowest replacement cost in $/ha followed by cocoa farm and coconut plantation whereas wetlands had the lowest available potassium in kg/ha and highest replacement cost in $/ha (Annex A3).

4.1.3.2. Biodiversity: Tree species diversity and NTFP source plant species diversity

B

iodiversity conservation in forests and other land uses is important for sustainable supply of all of the other ecosystem services. Table 4.5 describes tree species diversity in the Ankasa FCA and the Off-reserve land uses of the study area. A total 108 tree species with DBH 5cm of which 60 tree species were with DBH  30 cm were identified growing in 21 plots, which sum up an to area of 1.051 hectare, in the Ankasa FCA. Out of the total 406 individual trees greater than 5 cm diameter identified in the 21 plots (Annex A4.1), Diospyros sanza-minika is the main species accounting 4.4% of the total number of individual trees. In the case of trees of small and medium size classes, a total of 62 tree species with small diameter (5 cm  DBH < 15 cm)and 54 tree species with medium size class (15 cm  DBH < 30 cm) were identified growing in 21 plots within the4m and 8m radius nested plots respectively. The total area of all of the small radius nested plots was of 0.106 hectare whereas it was 0.422 hectare for the medium radius nested plots.

In the case of off-reserve land uses, a total only 39 tree species with DBH 5cm of which 12 tree species were with DBH  30 cm were identified growing in 25 plots, which sum up to an area of 1.251 hectare. Out of a total 346 individual trees greater than 5 cm diameter identified in the 25 plots, Theobroma cacao and Hevea brasiliensisare the two dominant species that account 22.30% and 21.10% respectively. In the case of trees of small and medium size classes, a total of 24 tree species with small diameter (5 cm  DBH < 15 cm) and 23 tree species with medium size class (15 cm  DBH < 30 cm) were identified growing in 25 plots within the 4m and 8m radius nested plots respectively. The total area of all of the small radius nested plots was of 0.126 hectare whereas it was 0.503 hectare for the medium radius nested plots.

The Shannon indices of each of the diameter classes for the Ankasa forest reserve are higher than the corresponding figures for the off-reserve land uses. This indicates that the Ankasa forest reserve is much richer in tree biodiversity than the off-reserve land uses. Moreover, the abundance of trees in the former land use is much higher than the off-reserve land uses. In the case of the five land uses of the off-reserve, fallow land is the richest in tree biodiversity followed by wetland whereas the other three land uses were almost mono-species.

Table 4 5: Biodiversity of tree species by diameter class in the Ankasa FCA and Off-reserve land uses.

Land use	Tree size	n(plot)	Number of Species	Shannon index	Main species
Forest Reserve					
	DBH  5 cm	21	108	2.40(0.08)	Diospyros sanza-minika
	5 cm  DBH < 15 cm	21	62	1.49(0.11)	Picralima nitida
	15 cm DBH < 30 cm	21	54	1.32(0.13)	Drypetes principum
	DBH  30 cm	21	60	1.60(0.11)	Heritiera utilis; Scytopetalum tieghemii
Other land uses					
	DBH  5 cm	25	39	0.54(0.14)	Theobroma cacao
	5 cm  DBH < 15 cm	25	24	0.38(0.11)	Hevea brasiliensis
	15 cm DBH < 30 cm	25	23	0.30(0.10)	Hevea brasiliensis
	DBH  30 cm	25	12	0.14(0.08)	Hevea brasiliensisHevea brasiliensis

Cocoa Farm DBH  5 cm 5 2 0.08(0.08) Theobroma cacao
5 cm  DBH < 15 cm 5 2 0.08(0.08) Theobroma cacao
15 cm DBH < 30 cm 5 1 0.00 Theobroma cacao
DBH  30 cm 5 0
Coconut Plantation DBH  5 cm 5 0
5 cm  DBH < 15 cm 5 1 0.00 Cocos nucifera
15 cm DBH < 30 cm 5 1 0.00 Cocos nucifera
DBH  30 cm 5 1 0.00 Cocos nucifera
Rubber Plantation DBH  5 cm 5 1 0.00 Hevea brasiliensis
5 cm  DBH < 15 cm 5 1 0.00 Hevea brasiliensis
15 cm DBH < 30 cm 5 1 0.00 Hevea brasiliensis
DBH  30 cm 5 1 0.00 Hevea brasiliensis
Fallow Land DBH  5 cm 5 20 1.37(0.16) Macaranga barteri; Musanga cercropioides
5 cm  DBH < 15 cm 5 12 0.82(0.26) Ficus sur
15 cm DBH < 30 cm 5 11 0.94(0.16) Macaranga barteri
DBH  30 cm 5 1 0.00 Musanga cercropioides
Wetland DBH  5 cm 5 18 1.26(0.23) Raphia hookeri
5 cm  DBH < 15 cm 5 11 0.99(0.15) Anthocleista vogelli
15 cm DBH < 30 cm 5 10 0.56(0.28) Raphia hookeri
DBH  30 cm 5 10 0.70(0.29) Raphia hookeri

Table 4.6 describes the biodiversity in non-timber forest product plant sources in the Ankasa FCA and off-reserve land uses. In the Ankasa forest reserve a total of 32 plant species (Annex A5.1) that are source of non-timber forest products were identified growing in 18 plots which sum up an area of 0.09 hectare. In the case of the off-reserve land uses there were 29 plant species (Annex A5.2) of non-timber forest product sources growing in 10 plots that sum up and area of 0.05 hectare. The Shannon index for the diversity of the non-timber forest product source plant species of the Ankasa Forest reserve was higher than the off-reserve land uses indicating a richer biodiversity in the former land use.

Table 4 6: Biodiversity of non-timber forest product source plants in Ankasa Forest Reserve and Off-reserve land uses

Land use Use as a NTFP n (plot) Number of species Shannon
index Main species
Forest Reserve Medicinal 13 6 0.28(0.04) Sphenocentrum jollyanum
Food 13 9 0.24(0.06) Chrysophyllum albidum
Food and Medicinal 13 4 0.32(0.03) Piper guineense
Construction and ornamental 4 10 0.12(0.02) Eremospatha hookeri; Strombosia glaucescens
Other uses (resin, fodder, ...) 5 6 0.08(0.01) Napoleonaea vogelii
Total 18 32 1.03(0.22) Sphenocentrum jollyanum
Other land uses Medicinal 7 19 0.65(0.15) Aframomum stanfieldii
Food 7 5 0.14(0.04) Elaeis guineensis
Food and Medicinal 4 3 0.05(0.02) Psidium guajava
Construction and ornamental 1 3 0.04 Raphia hookeri

Other uses (resin, fodder, ...) 3 1 0.02(0.01) Baphia nitida
Total 10 29 0.89(0.20) Aframomum stanfieldii

4.1.4. Cultural services: Tourism, research and educational services

T
ourism, recreation, research and educational services are most important cultural services that forests in general and conservation area forests in particular could provide.Despite the rich biodiversity in both plant and animal species found in the conservation area and the high potential for tourism development, the conservation area has not been used to tap such a potential that can contribute to the development of the country. Both the number of tourist arrivals the revenue from the sector that the conservation area was getting over the period from 2002-2012 indicate that the conservation area on average generated revenue of $4121 from 1326 tourist arrival per year. As figure 2 below shows, both the number of tourist arrivals and revenue from the sector was not showing a sign of increasing trend over the period from 2004 to 2009 but for the last three years there were improvements mainly on the revenue from tourist arrivals. In terms of the research and educational services that the conservation area could provide, over a period of 11 years from 2003-2013 there were only 24 researchers (21 foreign and 3 domestic researchers) and 18 student researchers (4 foreign and 14 domestic student researchers) who visited the conservation area for a short to medium term research works of 1 to 6 months duration. The conservation area was able to generate only 590.91 $/year from the foreign researchers and foreign student researchers with the former accounting 94% of the generated revenue.
Considering the total size of the conservation area which is estimated to be 523 km2, the revenues that the conservation area was generating from tourist and researchersvisitsare insignificant. For example the sum of the average revenues per year imply that the conservation area was generating only 9.01$/km2 or 0.09 $/ha from the tourist and foreign researchers arrivals.

Figure 4 1: Number of tourist arrivals at Ankasa FCA and revenue generated over the period 2002-2012. (Source: Ankasa FCA Management Headquarter).

4.2. REDD+ opportunity cost of the Ankassa Forest Reserve

R
educing Emissions from Deforestation and forest Degradation (REDD) entails opportunity costs, implementation and transaction costs. Opportunity costs include direct on-site costs, indirect off-site costs, and socio-cultural costs (White et al., 2011). Table 4.7 below describes the direct on-site opportunity costs of conserving the Ankasa FCA for the next 5 to 30 years. The difference in NPVs between converting and not converting the Ankasa forest to other land uses, which measures the direct on-site opportunity cost of conserving the forest, was highest for Agroforestry2 followed by Agroforestry1 but lowest for cocoa farm. The direct on-site opportunity cost of conserving the forest for the next 30 years ranges from 9662.69 $/ha to 23352.80 $/ha in net present values. Net income from crop production accounts more than 90% of this opportunity cost of conserving the Ankasa forest from conversion to any of the four alternative land uses. The details on net income from crop production in the off-reserve land uses can be seen in Annex A6. The remaining less than 10% of the opportunity cost is in terms of forgone net benefits from commercial and non-commercial timber and

non-timber forest products.

The difference in total stock of carbon measured in carbon dioxide equivalent between the Ankasa forest and each of the four alternative land use measures the emission reduction units that can be realized from conserving the forest. As Table 4.7 shows, the emission reduction in tCO2/ha is the highest in the case of conserving the Ankasa FCA from conversion to cocoa farm whereas the lowest is in the case of conserving the forest from conversion to Agroforestry2.

The net present value of the direct on-site opportunity of conserving the Ankasa FCA for a period of 30 years at a discount rate of 3% ranges from 12.03 -38.63 $/tCO2e , which implies that the forest can be conserved at a direct on-site opportunity cost of 0.40-1.29 $/tCO2e/yr. If we take a higher discount rate, say 7.26% which is the real discount rate for Ghana calculated based on interest rate of 15.5% and average expected inflation rate of 7.69% (www.economywatch.org), the maximum direct on-site opportunity cost of conserving the forest for a period of 30 years was estimated at 0.81$/tCO2e/yr in net present value, which is the forgone net benefit form not converting the forest to Agroforestry2. On the contrary if we assume a zero real discount rate which would imply a relatively stronger intergenerational equity, the maximum direct on-site opportunity cost would be only 1.94$/tCO2e/yr in net present value terms.

Table 4 7: Direct on-site REDD+ Opportunity cost estimates for the Ankasa FCA.

Land use change options Years Difference in NPV of Forest Conservation Area and NPV of each land use change options by ecosystem service type in $/ha Emission Reduction in tCO2/ha NPV of Opportunity costs at 3% real discount rate

NPV of Opportunity costs at 7.26% real discount rate

NPV of Opportunity costs at 0.00% real discount rate

Commercial timber Non-Commercial timber NTFP Crops Total $/tCO2e $/tCO2e/yr $/tCO2e $/tCO2e/yr $/tCO2e $/tCO2e/yr

Conserving Forest Reserve from Converting to:

Cocoa farm 5 169.35 102.99 33.82 -75.12 231.04 803.11 0.29 0.06 0.22 0.04 0.35 0.07

10 169.35 102.99 63.00 2376.25 2711.59 803.11 3.38 0.34 2.56 0.26 4.14 0.41

20 169.35 102.99 109.87 6314.88 6697.09 803.11 8.34 0.42 5.36 0.27 11.73 0.59

30 169.35 102.99 144.75 9245.60 9662.69 803.11 12.03 0.40 6.75 0.23 19.23 0.64

Agroforestry1 (Food crops, Cocoa, Rubber, Coconut, and wetlands) 5 116.70 120.11 252.74 1914.25 2403.80 654.18 3.67 0.73 3.31 0.66 3.97 0.79

10 116.70 120.11 470.76 5616.19 6323.76 654.18 9.67 0.97 7.84 0.78 11.34 1.13

20 116.70 120.11 821.05 11564.12 12621.98 654.18 19.29 0.96 13.28 0.66 26.06 1.30

30 116.70 120.11 1081.70 15989.94 17308.45 654.18 26.46 0.88 15.98 0.53 40.79 1.36

Agroforestry2 (Food crops, Rubber, Coconut, and wetlands) 5 121.27 103.70 252.74 4117.43 4595.14 604.54 7.60 1.52 6.90 1.38 8.17 1.63

10 121.27 103.70 470.76 8832.72 9528.45 604.54 15.76 1.58 13.07 1.31 18.20 1.82
20 121.27 103.70 821.05 16408.79 17454.81 604.54 28.87 1.44 20.48 1.02 38.25 1.91
30 121.27 103.70 1081.70 22046.10 23352.77 604.54 38.63 1.29 24.16 0.81 58.31 1.94
Agroforestry3 with 5 years Fallow (Food crops, Cocoa, Rubber, Coconut, Fallow and wetlands) 5 118.05 120.03 252.74 1914.25 2405.07 631.24 3.81 0.76 3.43 0.69 4.12 0.82
10 118.05 120.03 470.76 5616.20 6325.04 631.24 10.02 1.00 8.13 0.81 11.75 1.18
20 118.05 120.03 821.05 9799.98 10859.11 631.24 17.20 0.86 12.04 0.60 23.03 1.15
30 118.05 120.03 1081.70 12843.08 14162.86 631.24 22.44 0.75 14.07 0.47 33.55 1.12

5. Scaling up results

Scaling up the per hectare level estimated economic values of the selected ecosystem services and the direct on-site REDD+ opportunity costs to the total conservation area in this study enables us to visualize the benefits and opportunity costs of conserving the Ankasa FCA. The per hectare level results were multiplied by the total area of the Ankasa FCA, which is reported to be 52,300 hectares with 34,900 hectares covering the Ankasa Forest Reserve in the south and the remaining 17,400 hectares is the Nini-Suhien National Park in the north.

Table 5.1describes the aggregate values of the selected ecosystem services for the Ankasa FCA. The aggregate value of the selected provisioning services for the conservation area was estimated to be about $ 21.9 million in value with 87.18% accounted by the stumpage value of an estimated 32.8 million m3 of standing stock of commercial and non-commercial timber trees. The total value of the selected regulating services, which is value of an estimated 64.3 million tCO2e of carbon stock in biomass and soil, for total conservation area was estimated at about $ 380million of which 78.37% was the value of carbon stock in biomass. When compared with the value of the selected provisioning services, the value of biomass carbon stock as a regulating service was 15.6 times the aggregate stumpage value of the standing stock of trees in the whole conservation area.

The aggregate value of the selected supporting service, which is measured in terms of the replacement cost of soil fertility loss for the three important soil nutrients, is negative. A negative replacement cost implies a benefit. For the nitrogen nutrient, the available nitrogen in the soils of the whole conservation area was larger than the threshold level by estimated 17 thousand tons of nitrogen which was equivalent to same quantity of commercial nitrogen fertilizer worth of $ 1.28 million in value. However, in the case of phosphorous and potassium nutrients, we estimated deficiencies of 0.78 and 9.9 thousand tons respectively for the whole conservation area. This implies that in order to increase the soil phosphorous and potassium contents to the required threshold levels, an estimated $ 0.65 million worth of phosphorus and potassium fertilizers are needed for the whole conservation area.

The other ecosystem service considered in this study was biodiversity in tree species and plant species of non-timber forest product sources. Although spatial scale extrapolation the results of tree species diversity is not possible for technical and practical reasons, one can infer the level of tree species biodiversity reported in this study is the minimum level for the whole conservation area.

In terms of the cultural services, although the conservation area has biological diversity in plants and animal species as well as other features for tourism development, it was underutilized and the level of tourist arrivals was very insignificant.

Table 5 1: Aggregate values of selected ecosystem services of the Ankasa FCA

Ecosystem service Unit Total quantity of ecosystem service in million units Total value of ecosystem service in million $

Ankasa Forest Reserve Nini-Suhien National Park Total Ankasa Forest Reserve Nini-Suhien National Park Total

Provisioning services 14.58 7.27 21.85

Timber (stock) m3 21.89 10.92 32.81 12.71 6.34 19.05

Commercial timber m3 6.29 3.14 9.43 5.85 2.92 8.76

Non-commercial timber m3 15.60 7.78 23.38 6.87 3.42 10.29

Non timber forest products (flow) 0.00 0.00 0.00 1.87 0.93 2.80

Fuel wood kg 5.43 2.71 8.13 1.24 0.62 1.87

Wood for local construction kg 0.50 0.25 0.74 0.38 0.19 0.56

Food pieces 0.85 0.42 1.27 0.21 0.10 0.31

Medicinal plants pieces 0.06 0.03 0.09 0.04 0.02 0.06

Regulating services 253.25 126.26 379.52

Carbon (stock) ton 42.92 21.40 64.33 253.25 126.26 379.52

Biomass carbon ton 33.64 16.77 50.41 198.48 98.96 297.43

Soil carbon ton 9.28 4.63 13.91 54.78 27.31 82.09

Supporting services -0.43 -0.21 -0.64

Replacement costs* of soil fertility loss (stock) kg -4.26 -2.12 -6.38 -0.43 -0.21 -0.64

Nitrogen kg -11.40 -5.68 -17.08 -0.85 -0.43 -1.28

Prosperous kg 0.52 0.26 0.78 0.02 0.01 0.03

Potassium kg 6.62 3.30 9.92 0.41 0.21 0.62

268.26 133.75 402.01

*negative value of replacement cost implies benefits.

Table 5.2 describes the aggregate NPV of direct on-site opportunity costs of conserving the whole conservation area. Based on the three discount rates considered, the aggregate NPV of the direct on-site opportunity cost of conserving the whole conservation area for the next 30 years ranges between $ 284 million to $ 1.84 billion with corresponding emission reduction levels of 42 million tCO2e and 31.6 million tCO2e respectively as a global public good. This opportunity costs imply that the country will lose $ 9.45 million to 61.45 million per year as direct on-site net benefits forgone due to conserving the whole conservation area. This annual opportunity cost is equivalent to a minimum of 0.02% and maximum of 0.15% of Ghanas Gross Domestic Product (GDP) for the year 2012, which was about $40.71 billion (World Bank, 2012).

Table 5 2: Aggregate NPV of Direct on-site REDD+ Opportunity Cost of Conserving the Ankasa FCA

Land use changes Total emission reductions in million tCO2e Discount rate in % NPV of Opportunity cost in million $ for a period of 30 years

Ankasa Forest Reserve Nini-Suhien National Park Total Ankasa Forest Reserve Nini-Suhien National Park Total

Cocoa farm 28.03 13.97 42.00 0.00 538.99 268.72 807.71

3.00 337.18 168.11 505.29

7.26 189.19 94.33 283.52

Agroforestry1 22.83 11.38 34.21 0.00 931.27 464.30 1395.57

3.00 604.11 301.19 905.29

7.26 364.84 181.90 546.73

Analysis and interpretation of the data and results

Agroforestry2 21.10 10.52 31.62 0.00 1230.25 613.36 1843.61
3.00 815.03 406.35 1221.38
7.26 509.74 254.14 763.88
Agroforestry3 22.03 10.98 33.01 0.00 739.12 368.50 1107.61
3.00 494.36 246.47 740.83
7.26 309.97 154.54 464.50

Conclusions

6. Conclusions and policy implications

This study estimates the economic values of selected ecosystem services of the Ankasa FCA and alternative land uses practices around the conservation areas. Moreover, it gives estimates for the direct on-site REDD+ opportunity costs of conserving the Conservation Area from conversion to four alternative land uses (namely, cocoa farm, Agroforestry1, Agroforestry2, and Agroforestry3), which are representative of existing land use practices by rural communities living around the conservation area. Although our valuation was carried out for selected ecosystem services and the REDD+ opportunity cost analysis is limited to the direct on-site costs, the results of the study are very crucial for designing policies that will reinforce the sustainability of the conservation of the Ankasa FCA and other conservation sites in Ghana. The results of this study could be used as an important input for designing REDD+ projects and programs for the conservation area as well as other potential forest reserves in Ghana. Moreover, sustainability of tropical forest conservation areas require understanding of the level of direct on-site opportunity costs to different stakeholders affected due to assigning a forest as a conservation site. Accordingly, this study has identified the direct opportunity costs to local authorities as well as local communities living around the Ankasa FCA.

According to information from the management plan of the conservation area, the forest was selectively logged until 1976. The conversion of the forest to a conservation area has entailed loss of stumpage revenue to the government. Stumpage revenue from timber harvesting in Ghana is an important source of revenue for local authorities to add on funds from the central government for financing development activities (Damnyag et al., 2011). Therefore, forgoing these revenues due to the conversion of the forest to its present state as a conservation area would imply limited capacity to finance other social and economic development activities which are important for increasing the welfare of the local communities. This study indicated that for continuing the conservation of the Ankasa FCA for the coming 30 years and hence protecting it from conversion to other land uses, the local communities incur a total opportunity cost of as low as 234.94 $/ha and as high as to 273.34 $/ha (Table 4.7) in net present value from forgone stumpage revenues of commercial and non-commercial timber harvesting. This forgone revenue accounts the lowest share, which is about 0.96 to 2.82%, to the total direct on-site opportunity costs of conserving the forest. This is partly due to the fact that stumpage fees in Ghana are administratively set very low (Hansen et al., 2009, Damnyag et al., 2011).

Recommendations

Non timber forest products in tropical countries play an important role in rural livelihood. They serve as source of food and income for subsistence and as a means of income diversification to reduce risks associated with crop failure in the main agricultural activities (Cavendish, 2000; Angelsen and Wunder, 2003; Belcher and Kusters, 2004; Vedeld et al., 2007).This study indicated that conserving the Ankasa FCA for the next 30 years and protecting it from conversion to other land uses imply opportunity costs as low as 144.75 $/ha and as high as 1081.70 $/ha (Table 4.7) in net present value from non-timber forest product use restriction to local communities. These values account 1.5 to 4.63% of the total direct on-site opportunity cost of conserving the conservation area.

Conversion of tropical forests to other land uses is mainly to derive provisioning services like food from crop and livestock production on the converted land. This study indicated that conserving the Ankasa FCA for the next 30 years from conversion to other land uses (cocoa farm, Agroforestry1, Agrofrestry2, and Agroforestry3 (Table 4.7)) imply an opportunity cost of as low as 9245.60 $/ha and as high as 22046.10 $/ha (Table 4.7) in net present values of forgone crop production by local communities. These values account the largest share (about 94.40 to 95.68%) to total direct on-site REDD+ opportunity cost of conserving the conservation area. Thus, in total up to 97% of the opportunity cost of conserving the Ankasa FCA from conversion to any of the alternative land use is incurred by rural communities in terms of the foregone net benefits from crop production and non-timber forest product use restrictions. During the field works for data collection, we have observed that rural communities were residing close to the conservation area and undertake agroforestry practices, mainly cocoa production. From our field observation of the southern part of the conservation area, we did not see a buffer zone that separates the conservation area from the land use practices by rural communities. Establishing a buffer zone is very important for the sustainable management of the conservation area and such an effort, however, should take in to account the opportunity costs that would be lost by the rural communities that have to be displaced for establishing the buffer zone.

Conservation of tropical forests provides global public goods like carbon dioxide emission reduction as a climate regulating ecosystem service and biodiversity as a supporting ecosystem service. This study indicated that the conservation of the Ankasa FCA from conversion to any of the four alternative land uses (namely, cocoa farm, Agroforestry1, Agrofrestry2, and Agroforestry3 (Table 4.7)) could result in emission reductions as low as 604.54 tCO2e/ha to as high as 803.11 tCO2e/ha from carbon stocks in biomass and soils. These levels of emission reductions are the lower bound estimates for the fact that our study did not take into account the carbon sequestration services that the forest is providing. Thus, the direct on-site REDD+ opportunity cost estimated in this study, which are as low as 12.03 $/tCO2e and as high as 38.63 $/tCO2e in net present value at a discount rate of 3% and period of 30 years, could also be lower if we consider the net difference in carbon sequestration services of the conservation area and that of each alternative land use.These REDD+ direct on-site opportunity cost estimates are lower than the 2008 price for carbon market of the EU Emission Trading Scheme, which were running about 35 to 40 $ per tCO2 and a little higher than the PointCarbon (2011) estimate of global carbon price of $ 35 per tCO2 for 2020. However, the REDD+ direct on-site opportunity cost estimates for this study are much higher than the REDD+ opportunity cost estimates in the literature. For example, from a review of 29 regional empirical studies, Boucher (2008) found an average REDD+ opportunity cost of 2.51/tCO2. A conversion of the area based Grieg-

Recommendations

Grans estimate for the Stern (2006) and Eliasch (2008) Reviews to per-ton costs provides a range of $2.67 to $8.28 per tCO2 (Boucher, 2008). Estimates based on global economic models range from $6.77 to $17.86 with an average of $11.26 per tCO2 (Kindermann et al., 2008).

The study also indicated that the conservation area is home to more than 108 tree species with a minimum of 5cm and above in diameter and rich in plant species which are important sources of non-timber forest products. Moreover, the soils of the Ankasa FCA contain about an extra 327 kg available nitrogen nutrient per ha than the threshold level reported as indicator of forest soil health. However, both potassium and phosphorous nutrient levels available in the soils of the Ankasa Forest were found to be below the minimum threshold levels.

To sum up, conserving the Ankasa Forest Conservation area until 2042could provide a global public good of emission reduction level of 316 million tCO2e to the minimum at a direct on-site maximum opportunity cost of $ 1.84 billion to rural communities and local authorities in Ghana. The total opportunity cost would be either higher or lower than this for the fact that our estimate did not take into account two main important factors that would affect the value. These are: 1) net difference in carbon sequestration service between the forest conservation area and each of the alternative land use, which is likely to be positive and hence increase emission reduction level above our estimate, and 2) the indirect opportunity costs associated with not converting the conservation area to other land uses were not taken into account in this study, which include for example the value added forgone by all actors in the supply chain of firms using timber as major input in their production process, due to complete restriction of timber logging from the conservation area. Further studies should take the carbon sequestration services and indirect costs associated with conserving the forest as well as the implementation and transaction costs in order to have a complete estimate on the REDD+ costs for sustainable management of forest conservation areas.

Implications for practice

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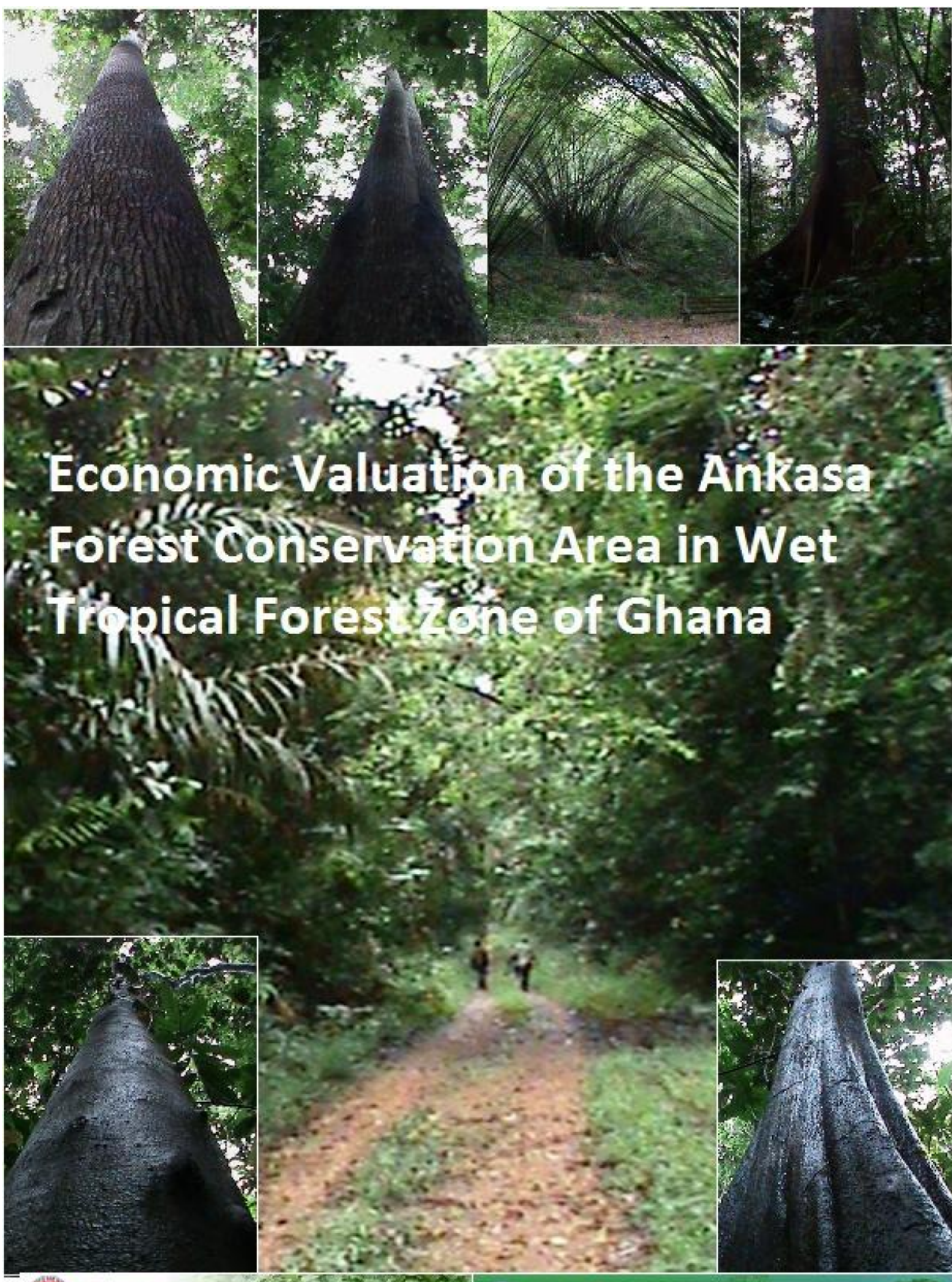
Economic Valuation of the Ankasa Forest Conservation Area in Wet Tropical Forest Zone of Ghana



Forestry Research Institute of Ghana

ITTO International Tropical Timber Organization

Sustaining Tropical Forests

REDUCING EMISSIONS FROM DEFORESTATION AND FOREST DEGRADATION THROUGH COLLABORATIVE MANAGEMENT WITH LOCAL COMMUNITIES (ITTO PROJECT RED-PD/ 026/09)

Technical report on

Economic Valuation of Ecosystem Services of the Ankasa Forest Conservation Area in Wet Tropical Forest Zone of Ghana

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This study was conducted to estimate the economic value of selected ecosystem service of the Ankasa FCA and assess the on-site direct opportunity costs of maintaining it from possible conversion to other land uses through deforestation and degradation. The study was based on experimental plot level and household surveys in the study site. The authors would like to thank all who have taken part in conducting the surveys.

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Executive Summary

High rates of deforestation and forest degradation are among the serious environmental problems in Africa that are dwindling the level and quality of forest ecosystem services.Forest protected area management plays an important role in the global and nation level efforts of nature conservation. The Ankasa Forest Conservation Area is one of the most important protected areas in tropical forests of Western Africa. However, there is lackof information on the quantity and value of ecosystem services provided by the forest conservation area.The main objectives of this study were, therefore, to estimate the economic values of selected ecosystem services (timber, non-timber forest products, carbon, and soil nutrients) of the Ankasa Forest Conservation Area and the direct on-site REDD+ (Reducing Emissions from Deforestation and Degradation) opportunity costs of maintaining the conservation area from possible changes to other land uses commonly practiced by rural communities around the conservation area. Biophysical data from experimental sample plots and social-economic data from household survey were used to estimate the economic value of selected provisioning, regulating, and supporting ecosystem services of the conservation area. A number of ecological modeling techniques were used to estimate the quantities of selected ecosystem services. The concepts of ecosystem services and total economic value were applied as a conceptual framework whereas the revealed preference method of valuation was used for valuing the ecosystem services. The direct on-site REDD+ opportunity costs were estimated using the method of Net Present Value and using the microeconomic concept of opportunity cost. The Key findings of the study are presented below.

Provisioning services (Timber and Non-timber forest Products)

- The standing volume of trees with diameter at breast height greater than or equal to 5 cm in the conservation area was about 627 m^3/ha with stumpage value of about 364 $/ha, of which about 29% in volume and 46% in value was accounted by commercial timber species. The aggregate volume of trees for the whole conservation area was estimated at about 32.8 million m^3 with a total stumpage value of about $ 19.1 million.

- Rural households around the Ankasa Forest Conservation area extract non-timber forest products (fuel wood, wood for local construction, food (wild fruits, bush meat, snail, and mushrooms), and medicinal plants) from the land uses outside the conservation area. The total farm gate value of these ecosystem services was estimated at about 451 $/household/year, with fuel wood accounting about 67% of the value. If we divide this value by the average land size per household, we get a per hectare value that would be used for estimating the value of such ecosystem services that would be derived by rural communities from the Ankasa Conservation area, had there not been use restriction.Accordingly, the conservation area could provide the above non-timber forest products worth of about $ 2.8 million per year.

Regulating services (Carbon stock in biomass and soil)

- The Ankasa Forest Conservation area stores carbon that amounts about 1230 tCO_2e/ha and worth about 7257 $ at the weighted average price of 5.90 $/$tCO_2e$ of the international voluntary carbon market for the year 2012. The carbon in biomass, which is the sum of above ground tree biomass, root biomass, non-tree vegetation and litter, accounted about 78 % whereas the remaining was the stock of carbon in soils up to a depth of 60 cm. The carbon stock in biomass and soils of the whole conservation area was estimated at about 64.3 million tCO_2e and worth of about $ 380million.

- This value is equivalent to 15.6 times the aggregate stumpage value of the standing volume of trees in the conservation area. This study did not take into account the carbon sequestration services of the forest, which is an important component of the climate regulating service provided by the conservation area as a global public good.

Supporting services (Soil Nutrients and Biodiversity)

- Nitrogen, phosphorous, and potassium nutrient contents in soils are important for plant growth and development. The nitrogen nutrient content in the Ankasa Forest conservation area was more than the minimum threshold level recommended for a healthy plant growth and development. The available nitrogen in the soil up to a depth of 60 cm was about 327 kg/ha in excess of the threshold level. This extra stock valued using the replacement cost method was estimated to worth about $ 25. The extra available nitrogen stock in the conservation area was estimated at about 17 thousand tons of nitrogen which worth about $ 1.3 million valued at a market price of commercial fertilizer in Ghana.

- However, it was found that phosphorous and potassium nutrient contents in the soils of Ankasa were below the threshold levels required for plant growth. The available phosphorous and nitrogen nutrients in the soils up to a depth of 60cm were less by about 15 kg and 190 kg per hectare than the corresponding threshold levels respectively. This implies that supplementing these deficiencies with commercial fertilizer would require about $ 0.5 for phosphorous and about $12 for potassium on per hectare level. For the whole conservation area this would mean about $ 0.63 million worth of commercial fertilizer would be needed to increase the potassium nutrient content to the threshold level and about $ 26 thousand worth of additional commercial fertilizer to increase the soil phosphorous contents to the threshold level.

- The conservation area is rich in biodiversity of tree species and plant species of non-timber forest products sources. A total of 108 tree species with diameter greater than or equal to 5 cm and 32 plant species of non-timber forest product sources were identified growing in inventoried plots with a total area of about 1 ha and 0.09 hectare respectively.

Cultural services (Tourism, research and education)

- Although the Ankasa Forest Conservation area is rich in both plant and animal biodiversity and has great potential for eco-tourism, the development and benefits from eco-tourism from the forest so far are very insignificant. Over the period from 2002-2012, there was almost constant trend in the number of tourist arrivals to the conservation area. An average of 1326 tourist arrivals and revenue of $ 4121 per annum from the entrance fees was recorded for the same period. There were only 24 researchers and 18 student researches that were visiting the conservation area for research and educational purposes over a period of 11 years (2003-2013). In relative terms, the conservation area was able to derive an annual revenue of only 0.09 $/ha from tourist and foreign researchers arrivals.

REDD+ Opportunity Cost (PV of net income from cocoa farming and agroforestry)

- Conserving the Ankasa Forest conservation area form possible conversions to other land uses, which are commonly practiced by rural communities around the conservation area, could result in emission reductions units in the range of about 605-803 tCO_2e/ha. This emission reduction level refers only to the difference in stock of carbon in biomass and soils between the conservation area and each alternative land use on per hectare basis. The emission reduction level would be higher if we consider the difference in carbon sequestration service of the conservation area and each alternative land use, which is likely to be a positive value.

- However, these levels of emission reduction units entail opportunity cost. The direct on-site opportunity cost of conserving the Ankasa Forest Conservation area for the next 30 years (until 2042) from conversion to the other land uses were estimated to range from between 9663-23353 $/ha in net present value depending on the type of the alternative land uses change. The lowest opportunity cost was estimated for pure cocoa farming as an alternative land uses and the highest opportunity cost was for an agroforestry land use that integrates local food crop production, rubber and coconut plantations on wet and non-wetlands. More than 90% of the opportunity cost was accounted by forgone net income from food crop production by rural communities.

- The direct on-site REDD+ opportunity cost was, thus, estimated at in the range of about 12-39 $/$CO_2$e in net present value for conserving the Forest Conservation Area for the next 30 years, which is equivalent to 0.4 -1.29 $/tCO2e per year. This result was based on a 3% discount rate and would be less if we consider a 7.26% discount rate which represents the real discount rate for Ghana. At this discount rate the direct on site opportunity cost was in the range of about 7-24 $/$tCO_2$e.

- The aggregate NPV (at 3% discount rate) of the direct on-site opportunity cost of conserving the whole conservation area for the next 30 years was estimated in the range of $ 505 million – $ 1.22 billion, which is equivalent to 16.8 – 40.7 million $/year, with corresponding emission reduction levels of 42 million tCO_2e and 31.6 million tCO_2e respectively as a global public good. The range of annual opportunity cost is equivalent to 0.04- 0.10% of Ghana's 2012 Gross Domestic Product.

Table of Contents

List of Figures

List of Tables

Acronyms

Bd	Bulk Density
CDM	Clean Development Mechanism
cm	Centimeter
DBH	Diameter at breast height (diameter at 1.3 m height of the tree)
DUV	Direct Use Value
FCA	Forest Conservation Area
FORIG	Forestry Research Institute of Ghana
GDP	Gross Domestic Product
Ha	Hectare
IETA	International Emissions Trading Association
IUV	Indirect Use Value
K	Potassium
Km	Kilo meter
M	Meter
MEA	Millennium Ecosystem Assessment
NB	Net Benefit
NPV	Net Present Value
NTPF	Non Timber Forest Product
OV	Option Value
P	Phosphorous
PES	Payment for Ecosystem Services
REDD	Reducing Emissions from Deforestation and Degradation
SOC	Soil Organic carbon
tCO2e	Tons of carbon dioxide equivalent
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
TN	Total Nitrogen
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

According to the Millennium Ecosystem Assessment, ecosystem services are classified into four broad categories, namely, provisioning, regulating, supporting, and cultural services (MEA, 2005). Forest ecosystems as natural capital and the ecosystem services they provide make significant direct and indirect contributions to the global economy and human welfare. Forests in Africa play a significant role in biodiversity conservation and providing a number of ecosystem services and in climate change adaptation and mitigation; the sustained provision of ecosystem services can help people to adapt to the effects of changing climate while the carbon stored in the forests can contribute to climate change mitigation. However, the growing human population and the associated increasing demand of land for crop and livestock production (for both subsistence and commercial activities), human settlement, and production of biomass energy are among the major drivers for the degradation of forest resources.

Despite international and national environmental movements for conserving forest landscapes, the area of old-growth tropical forests continues to decline as the demand for rent from tropical forest land and resources increase (Ghauzoul and Sheil, 2010). In 2005 about half of the tropical humid forest contained about 50% or less tree cover, and that at least 20% of this biome was subject to timber extraction over the period 2000 to 2005 (Asner et al., 2009). Much of the global and national conservation efforts rely on protected area management. At the global scale there are over 100, 000 terrestrial protected areas accounting 12% of the land area (Chape et al. 2003), with the greatest coverage in the tropics. In the tropical moist forest zones a total area of about2.5 million km^2 (2003 value), which accounts 23.3% of the land surface in this zones, was under some sort of national conservation designation (Chape et al. 2003, Ghauzoul and Sheil, 2010). Protected areas in tropical moist forests of Western and Central Africa constitute about 8.7% of the land area. The Ankasa Forest Conservation Area (FCA)that covers 523 km^{2}in Western Ghana is one of these protected areas in tropical moist forests of Western Africa.

With the growing global interest on tropical forests for climate change mitigation and adaptation, the coverage of protected areasis expected to grow. The Global Climate Change Mitigation and adaptation financing mechanisms like, the Clean Development Mechanism (CDM), Payment for Ecosystem Service (PES) and Voluntary Carbon Market Mechanisms, and REDD+ are manifestations for the growing demand for the climate change mitigation role of forests. However, generating revenues from such financing mechanism through selling ecosystem services of existing or future protected areas requires data on the quantity and value of the forest ecosystem services. Moreover, based on the common sense that “you can’t manage what you don’t measure”, valuation of forest ecosystem services is important for sustainable forest management and conservation. In this regard, there has been a growing number of studies on valuation of ecosystem services at different special scales as a decision making tool for moving towards sustainable management and conservation of natural resources (European Communities, 2008; Braat, *et al.*, 2008; Barbier, 2007; CBD, 2007; OECD, 2006; Berry, Olson & Campbell, 2003;Costanza, *et al.*, 1997). Specifically, valuation of forest ecosystem services has been recognized as an important tool that can aid decision makers to evaluate trade-offs between alternative land uses and forest management regimes as well as caurses of social actions that change the use of forest ecosystems and the services they provide (MEA, 2005).

Thus, this study aimed at quantifying and valuing the ecosystems services of the Ankasa FCA and at estimating the direct on-site REDD+ opportunity costs of maintaining the conservation area from conversion to competing land uses.

2. Objectives of the study

The main objective of the study was to estimate the economic values of the major forest ecosystem services in the core protected areas and buffer zones of the Ankasa FCA and estimate the direct on-site opportunity costs of conserving the protected area from conversion to alternative land uses. Thus, the study had the following specific objectives:

- ✓ Identifying the major land uses practiced by rural communities around the conservation area.
- ✓ Estimate the economic values of selected major ecosystem services representing provisioning, regulating, cultural, and supporting services of the conservation area.
- ✓ Estimate the economic values of selected major ecosystem services representing provisioning, regulating, and supporting services of the major land uses practiced by rural communities around the conservation area.
- ✓ Estimate the REDD+ opportunity cost (in $\$/tCO_2e$ emission reduction) of conserving the conservation area from possible conversion to alternative land uses practiced by rural communities around the Ankasa FCA.
- ✓ Assess the role and economic values of the forests to climate change adaptation (reducing vulnerability to climate change) and climate change mitigation (though the carbon storage services (additionality condition) from avoided possible deforestation and forest degradation (leakage value)).
- ✓ Identify potential Payment for Ecosystem Services for the sustainable management of carbon or other ecosystem services provided by the conservation area.

3. Materials and Methods

3.1. Theoretical framework

3.1.1. Typology of forest ecosystem services

With the growing need for understanding and communicating the ecological, economic, social, and cultural values of forest ecosystem services, a number of conceptual frameworks for guiding valuation of these services have been realized over nearly the last two decades since the 1990s. The four categories of ecosystem services, namely provisioning, regulating, cultural, and supporting services, introduced by the Millennium Ecosystem Assessment are the results of one of such efforts and are widely accepted as a frame work of analysis in the contemporary valuation of ecosystem services (Figure 1). This framework provides a standard and internationally accepted conceptual structure through which all aspects of the utility of natural resources to sustainable livelihood and development can be understood (Noel and Soussan, 2010).

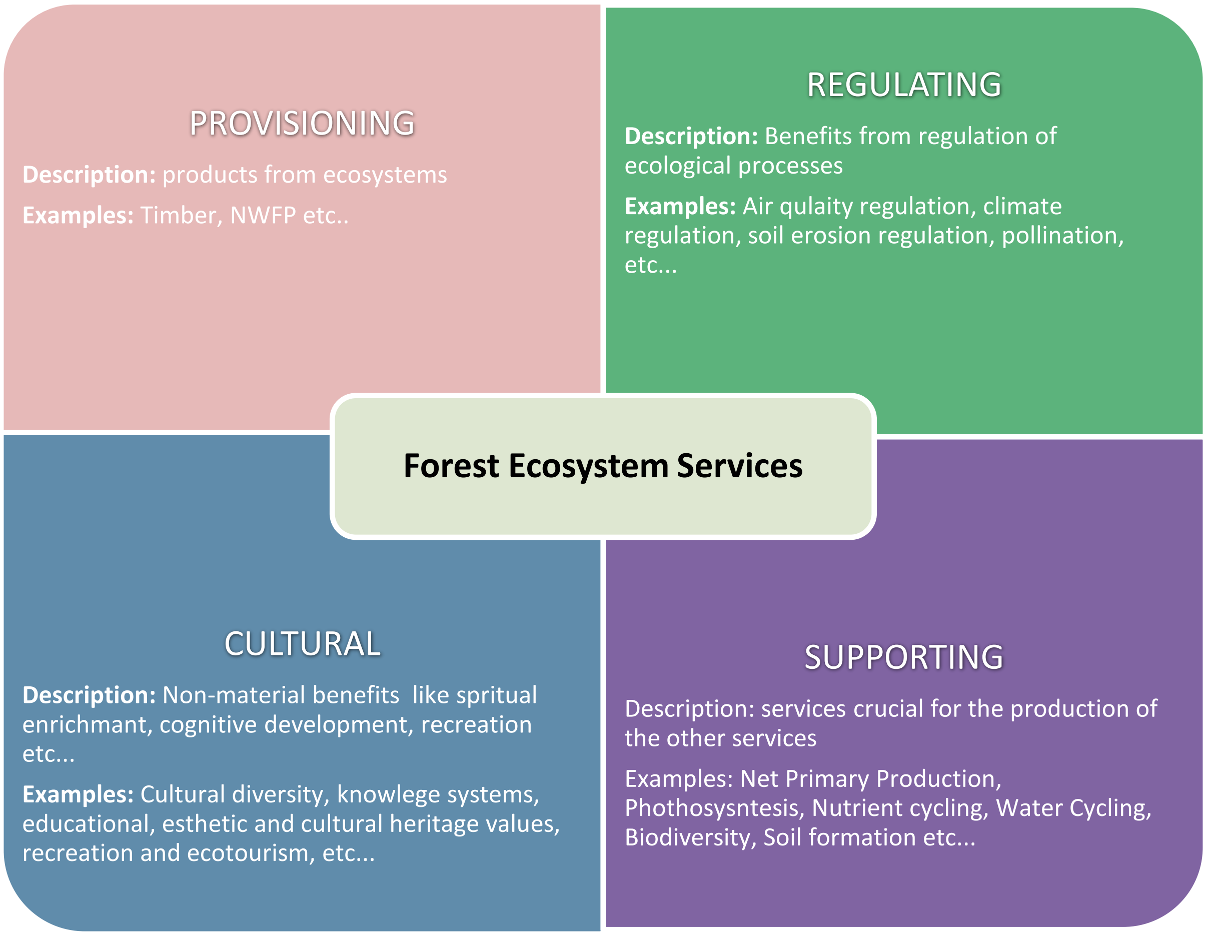

Figure 3-1: Typology of forest ecosystem services (Adapted from MEA, 2005).

3.1.2. Quantifying the forest ecosystem services

In the economic literature about valuation of environmental services and the application of cost benefit analysis of land use changes, it is important to identify the stakeholders affected by the project for which the valuation and/or cost benefit analysis is to be made. Discussion with stockholders is very important for determining the valuation objectives, selecting the most important ecosystem services to be valued, and determining the best competing land use against which cost benefit analysis will be carried out.

Valuation of forest ecosystem services then requires quantifying the identified ecosystem services at spatial and temporal scales. Generating such data requires the expertise of different scientific disciplines. It is possible to make a sound valuation exercise if only the physical quantities of the ecosystem services are derived from scientific studies of respective disciplines. Such an interdisciplinary approach entails a greater level of accuracy in the estimated values since it allows minimizing the use of generalized assumptions and hence reduces the associated uncertainties and errors in the valuation exercise.

Both primary and secondary data sources can be used for quantifying the ecosystem services of forest resources. The primary data sources could be field experiments by different scientific disciplines (at different levels e.g. forest biome, forest stand, plot, tree, species, etc.. levels), household surveys, expert opinions from interviews, and ground based input data for mapping ecosystem services at a wider spatial scale using GIS and remote sensing methodologies. The other sources of data are secondary data which may include official statistics on ecosystem services and published works from the literature.

3.1.3. Valuation methodologies

Once the physical quantities of ecosystem services are determined, converting to monetary values using the appropriate valuation method is the next step. The question of how to value these ecosystem services has become a focal issue in a number of discussions and is of direct relevance for the study. Forest resource and the ecosystem services they provide have value both as a stock or natural capital as well as in terms of the flow of yields of economically important ecosystem services they provide. A conceptual framework of valuation that distinguishes between values of assets (forest as natural capital stock) and products (flow value of forest ecosystem services) is essential to integrate such data into the national account (green GDP) of a country. A stock is a quantity existing at a point in time and a flow is a quantity per period. Stocks, flows, and their relationship are crucial to the operation of both the natural and economic systems (Common and Stagl, 2007).

Valuation of forest ecosystem services has been a challenging task for the fact that forests provide a number of non-traded ecosystem services for which market prices do not exist. For some traded goods and services of forest ecosystem services, market prices may not reflect the true scarcity of the services because of market imperfections. In the effort of addressing such critical valuation problem, the concept of Total Economic Value (TEV) has emerged over the last two decades following the work of Pearce (1993) (Table 1). According to the concept of TEV, the values of forest ecosystem services can be classified into two main categories: use values and non-use values. The use values further include direct use values (DUV), indirect use values (IUV), and option values (OV).

Table 3-1: Description of components of the Total Economic Value of Forest ecosystem Services

Value	Sub-value	Description	Examples
Use	Direct	Goods and services that directly accrue to the consumers either from direct use or interaction with the environmental resources and services.	Timber, fuel wood, recreation etc…
	Indirect	Functions of forest ecosystems that accrue indirectly support and protection to economic activity and property.	Carbon sequestration, fixing and cycling of nutrients, soil erosion protection, water purification etc…
	Option	Future uses of the forest or its biodiversity resources and other functions.	Genetic resources, old growth forests
Non-Use	Existence	The intrinsic values that non-users are willing to pay purely for the existence of the resource without the intention of directly or indirectly using the resource in future.	The demand of non-users for conservation of tropical rainforests, endangered wild animals like tiger etc...
	Bequest	People's willingness to pay for ensuring that forests will be preserved for the welfare of future generations.	Biodiversity; areas of scenic beauty

Source: Adapted from Pearce, 1993; CBD, 2007.

Direct and indirect use values of forest ecosystem services are relatively more easily quantified than option and non-use values. In the valuation literature, the common methods to value forest ecosystem services can be classified into revealed preference and non-revealed preference approaches (Table 2).

Table 3-2: Description of methods for valuing forest ecosystem services

Methods		Sub-methods	Description	Examples
Revealed preference	Market price	Market prices	Valuation of an ecosystem service using its market price.	Timber, fuel wood, park entrance fees for tourists.
	Production function	Effect on production	Determining the value of an ecosystem service by considering its role in production of other marketed goods and services.	Upper water shade catchment protection services of forest to agricultural production, hydropower production, and irrigation at the bottom of the catchment.
	Surrogate market approach	Travel cost	The method involves estimating the recreational value of forest ecosystem services by measuring the money and time that people spend to reach and visit the specific ecosystem.	Value of an ecosystem's scenic beauty, presence of wildlife, opportunities for sporting activities.
		Hedonic pricing	The method involves deriving the difference in the market price of a non-ecosystem good due to the existence of a specific environmental attribute.	Effect of proximity to forested areas on property prices, wage rates etc…
	Cost based approach	Opportunity cost	This technique values the benefits of environmental protection (conserving a forest) in terms of what is being forgone as a net benefit from alternative land use.	Conversion of forest to Shifting cultivation for subsistence or commercial agriculture.
		Replacement cost	This involves estimating the expenses of replacing an ecosystem services with a man-made product, infrastructure, or technology.	Cost of commercial fertilizer to counteract nutrient loss due to soil erosion.
		Averted expenditure	The value of an ecosystem service can be inferred from the expenditure on technologies required to reduce the negative impacts of the missing or degraded service.	A forest near urban areas providing air purification service through absorbing dust particles and pollutants. Such services can be inferred from what people spend on preventive technologies used to avoid the health impacts of the pollutants.
		Damage cost	The method involves valuing an ecosystem service's role in protecting other assets.	Catchment protection services of controlling downstream siltation and avoided productivity loss in agriculture.
Stated preference	Contingent valuation		Involves deriving the value of non-marketed ecosystem services by asking consumers directly about their willingness to pay (WTP) for a specific service or their willingness to accept compensation (WTA) for the loss of a service.	Value of biodiversity, value of conserving a forest for the welfare of future generation. The method involves collecting survey data and complex econometric modeling.
	Conjoint analysis		The method asks respondents to consider the status quo and a specific hypothetical scenario, with participants choosing between various environmental services at different prices or costs.	Used for all services that cannot be valued using stated and cost-based approaches. The method involves collecting survey data and complex econometric modeling.
	Choice experiment		The characteristics of the ecosystem service are explicitly defined; vary over choice cards along with a monetary metric. Then, individuals have to choose different combinations of characteristics of the ecosystem service over other combinations at various prices.	Used for all services that cannot be valued using stated and cost-based approaches. The method involves collecting survey data and complex statistical and econometric modeling.

Adapted from Garrod and Willis, 1999; CBD, 2007; Noel and Soussan, 2010.

Valuation of forest ecosystem services has been a challenging task for the fact that forests provide a number of non-traded ecosystem services for which there are no market prices. For example, in the 2008 interim report of The Economics of Ecosystems and Biodiversity (TEEB) (European Communities, 2008), it is argued that:

> *"It will be possible to make a quantitative assessment in biophysical terms only for part of the ecosystem services – those for which the ecological 'production functions' are relatively well understood and for which sufficient data are available. Due to the limitation of our economic tools, a still smaller share of these services can be **valued in monetary terms**. It is therefore important not to limit assessments to monetary values, but to include **qualitative analysis** and **physical indicators** as well."*

Therefore, valuation is part of the multiple approaches that should be used for assessing the contribution of forest ecosystem services to human welfare. The following figure indicates the multiple approaches that can be used for assessing the contribution of forest ecosystems to human welfare.

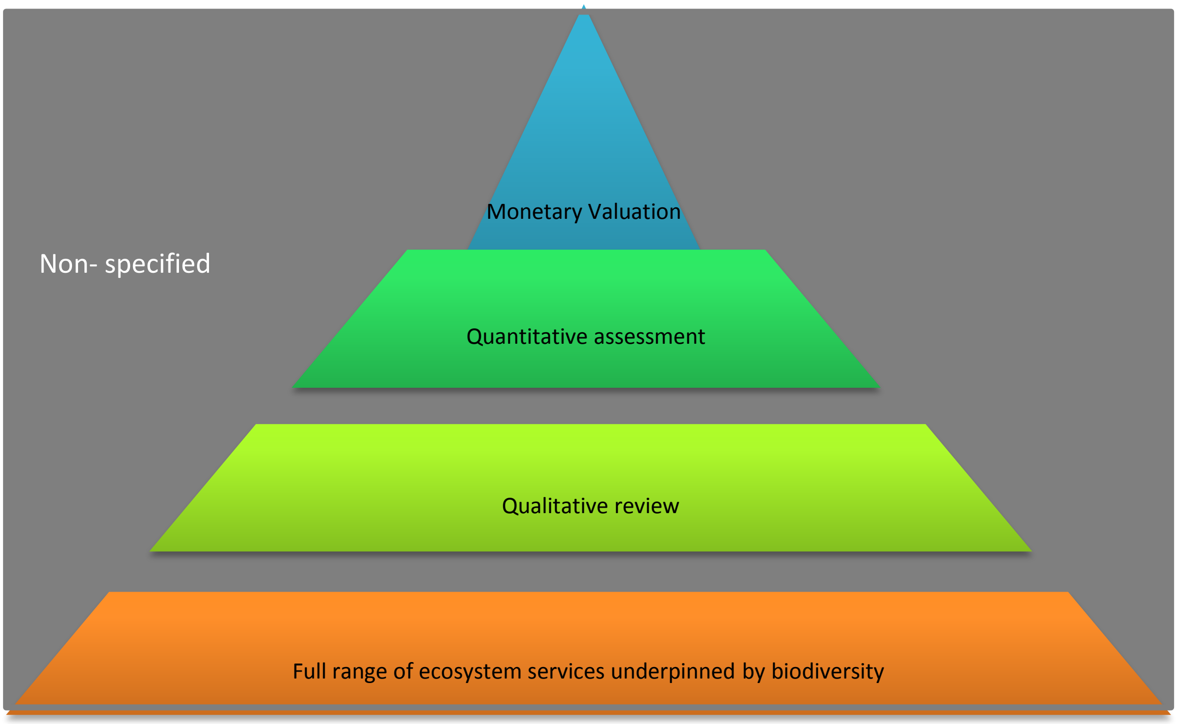

Figure 3-2: Multiple approaches for assessing the contribution of Forest Ecosystem Services (Source: P. ten Brikn, Workshop on the Economics of Global Loss of Biological Diversity, 5-6 March 2008, Brussels. Cited in European Communities, 2008).

3.1.4. Opportunity costs of land use change

As part of the global effort for mitigating the increase in concentration of GHGs in the atmosphere and the associated impact on the global climate, there has been developments in the Science and Policy of Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+), with the plus indicating related objectives like biodiversity conservation, enhancement of forest carbon, and poverty reduction, (Angelsen et al., 2009; Hansen et al., 2009). The UNFCCC and several national and state governments have been working on the development of REDD+ crediting mechanism that would reward REDD+ efforts in tropical countries with issuance of emission/sequestration credits that could be traded in carbon markets (IETA, 2012). REDD+ entails costs which can be classified as opportunity, implementation, and transaction costs(Figure 3). REDD+ Opportunity costs refermainly to the forgone economic benefits of alternative land use and to some extent social and cultural costs which are not easily measured in economic terms (White et al., 2011).

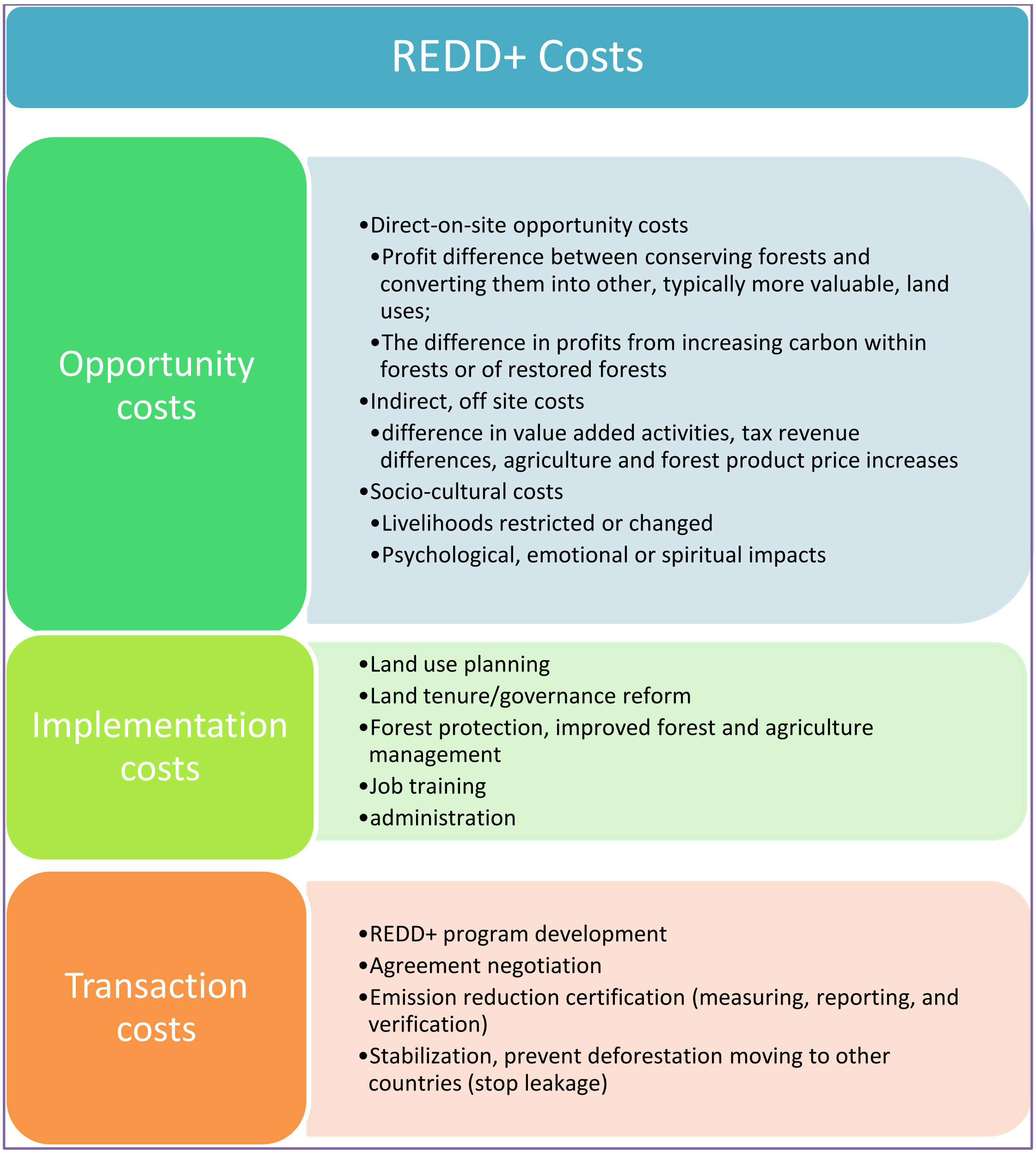

Figure 3-3: Classification of REDD+ Costs (Source: White et al., 2011).

According to White et al. (2011) data on REDD+ opportunity cost estimates are important for five basic reasons. First, except for remote locations which may entail large implementation and transaction costs, opportunity costs of REDD+ are assumed to account for the largest share of the total cost of avoiding deforestation and forest degradation (Boucher, 2008a; Pagiola and Bosquet, 2009; Olsen and Bishop, 2009; White et al., 2011). Secondly, opportunity costs of REDD+ provide insights on the major drivers of deforestation and forest degradation, impacts REDD+ programs on the different social group and hence derive policies mechanism that can take into account the interests of marginalized groups (Pagiola and Bosquet, 2009, White et al., 2011). Third, the opportunity cost information can be used as a basis for designing fair compensation for the affected groups from changes in land use practices as part of REDD+ program. In areas where natural forest protected areas are efficiently managed opportunity cost estimate, which refers to the loss of income to nearby communities arising from use restrictions, is important for policy makers to understand the impacts of a REDD+ conservation policy (White et al., 2011).

3.2. Study area

The study was conducted in the Ankasa FCA (Figure 4) in of the Jomoro and Ellembelle Districts of the Western Region of Ghana. The conservation area is located at about 330 Km west of Accra and very close to the border with Côte D'Ivoire. According to information from the management plan of the forest the conservation area covers a total area of 523 km^2 and includes the 349-km^2 Ankasa Forest Reserve in the south and the 174-km^2 Nini-Suhien National Park in the north. The conservation area is the only wildlife protected area in Ghana that is located in the wet evergreen tropical high rainforest belt. Apart from the forest reserve, which was selectively logged until 1976, the Ankasa FCA is in an almost intact state. The conservation area is rich in biodiversity and contains over 800 vascular plants species, 639 butterfly species, and more than 190 species of birds. It is also hometo a number of charismatic, rare and endangered species, including forest elephant, bongo, leopard, chimpanzees and possibly up to eight species of forest primates.

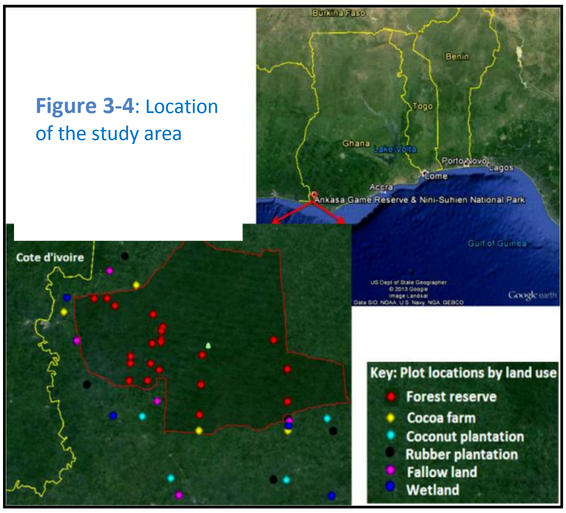

Figure 3-4: Location of the study area

3.3. Data collection

The economic values of timber, non-timber forest products, carbon stocks in biomass and soils, soil nutrient losses, and crop production were estimated on per hectare basis of two forest land use types, namely the Ankasa FCAs and other land uses surrounding the conservation area. The major land uses around the conservation area include cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland. Moreover, the extent of tree biodiversity and the diversity of plant species used as non-timber forest products (for medicinal, food, local construction and other use) for both land uses categories were assessed. These ecosystem services were selected based on their importance in climate change mitigation and adaptation as well as the ease of empirical measurement.

3.3.1. Reconnaissance survey

In order to achieve the objectives of the study, first a reconnaissance survey was conducted for three days in May, 2013. The aim of the reconnaissance survey was to generate basic information on:

- the major land uses/covers outside of the forest reserve,
- the types of crops cultivated by rural households living around the conservation area, and
- accessible routes in the conservation site that can be used for lying sample plots of the main survey.

The survey was held through physical observation and discussion with the Manager and staffs of the Ankasa FCAHead Quarter, and community leaders of rural households residing around the conservation area. Accordingly:

- Five major land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) were identified as land uses outside of the conservation area).
- A list of crops cultivated by rural households
- Five routes to the conservation area, each close to one rural community living around the conservation area, were identified. These routes and/or the close by rural communities are locally called Old Ankasa, Odoyefe, Domeabra, Navrongo, and Kusasi.

Based on the physical observation of the study site and the above information, we refined the biophysical and household survey designs proposed for the collection of selected ecosystem services of the conservation area and the neighboring land uses.

We applied both plot level biophysical data collection survey design and household survey to collect data on the physical quantities of selected ecosystem services of the conservation area as well as each of the five land uses outside of the conservation area. The following sections describe the plot level and household survey designs and the corresponding data of ecosystem services collected using the survey designs.

3.3.2. Plot level survey

A total of 21 nested circular plots (Figure 5) were set in the Ankasa FCA using a stratified systematic random sampling method. First, the southern part of the conservation area which is called the Ankasa Forest Reserve was stratified into five (old-Ankasa route, Odoyefe route, Domeabra route, Navrongo route, and Kusasi route) based on accessibility. For each stratum, we selected a random point at a location about 200 to 500 meters from the boundary to inside of the reserve and set the first nested circular plot. From the first plot onwards, 2 plots were lied systematically at distance of 1-2 km to the North direction along the routes of Odoyefe, Navrongo, and Kusasi whereas to the East direction along the route of Domeabra. In the case of the Old-Ankasa route, which is the main gate to the park and has a forest road, we were able to set a total of 9 plots. In addition, a total of 25 sample plots (five plots per each of the major land uses) were set outside of the forest reserve using the same sampling procedure. Figure 3-5 shows the design of the nested circular plot and the measurements that were undertaken in the small, medium, and large radii of the plot.

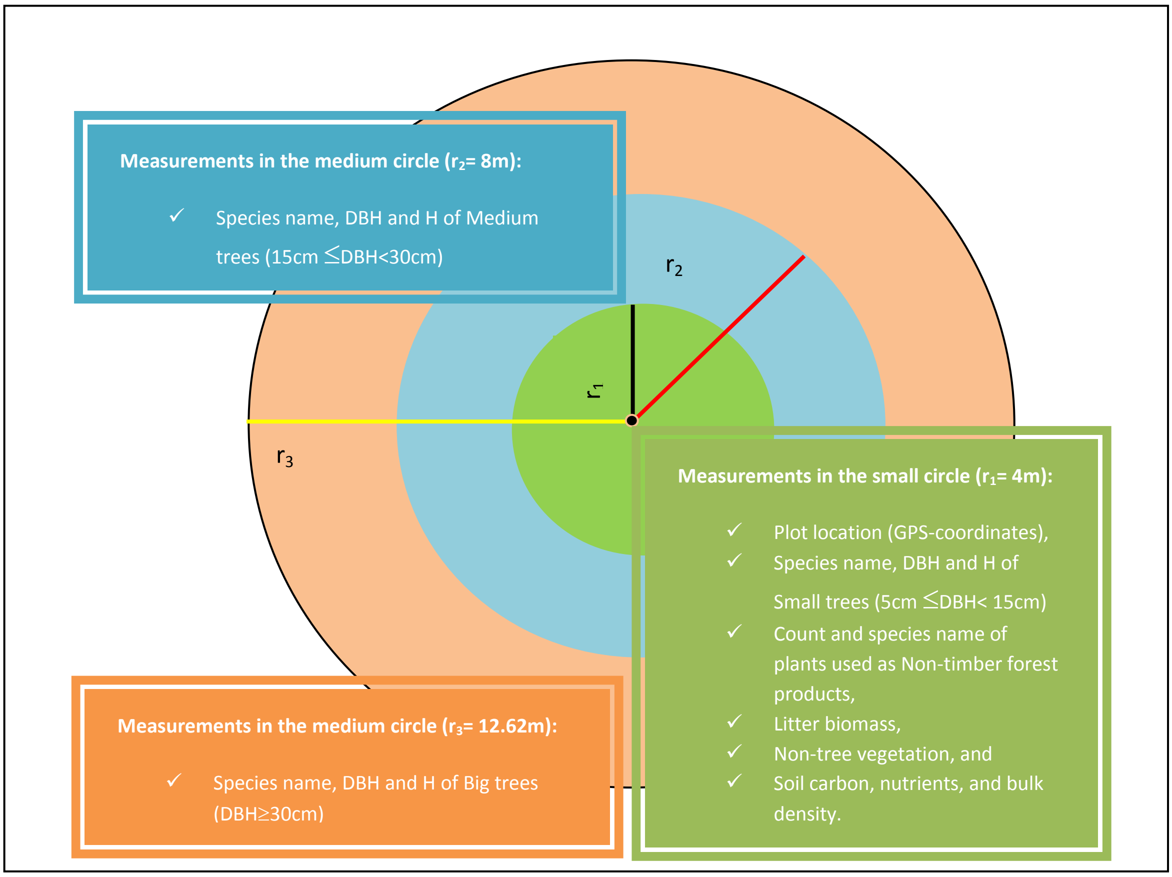

Figure 3-5: Design of nested circular plot and measurements of ecosystem services

The inventory of Non-timber forest product species was undertaken in 18 of the 21 sample plots of the Ankasa FCA and 10 of the 25 sample plots of the other land uses outside of the conservation area.

The non-tree vegetation includes all the ground vegetation plus trees with less than 5cm diameter. The measurement for this biomass class was undertaken in a 1mX1m random quadrant in the small circular plot. The non-tree vegetation in the quadrant was harvested destructively and the fresh weigh was measured in the field. A sub sample was taken and measured in the field as well and the oven dry weight of the sub sample was determined at the FORIG lab. The samples were put in the oven at a temperature 105 ^{0}C and measured after every 24 hours until we observe a constant weight. The dry to wet ratio of the each sub-sample was calculated and used to determine the dry weight from of the non-tree vegetation per quadrant by multiplying the ratio with the total wet weight of the sample from each quadrant. We applied the same procedure for determining the dry weight of litter biomass per quadrant. In the case of both non-tree vegetation and litter biomass samples, we took measurements in 6 of the 21 plots in the conservation site and 7 of the 25 plots in the other land uses.

Soil samples were taken from a random point at about 1m from the center of the nested plot. For each plot, a total of 3 soil samples were taken using soil augur from three soil depth classes (0-20 cm, 20-40cm, and 40-60cm) by taking one sample from each soil depth class. We took soil core samples of each soil depth class for a total of 8 plots out of the 21 plots in the conservation site and for another 8 plots out of the 25 plots of the other land uses. A total of 138 (21X3 + 25X3) soil samples were analyzed at the Soil Research Institute of Ghana for determining the soil carbon and organic matter content, and contents of soil nutrients, specifically total nitrogen, available phosphorous and potassium. The core samples were dried in oven up to a constant weight and the fine soil are separated from the non-soil parts (stones and gravels). The dry weight of the fine soil was used to determine the soil bulk density.

3.3.3. Household survey

Based on the information from the reconnaissance survey, a structured household survey questionnaire was designed to collect data household demographic characteristics, land size, plot area and cultivated crops on each of the plots by the household, gross annual income from the crop production, input costs of the crop production, consumption and sale of non-timber forest products, and farm gate prices for crops, non-timber forest products, and market prices of agricultural inputs. The aim of the household survey was to generate data on net income from agroforestry food crop production per hectare and income from NTFP uses per household for estimating the REDD+ opportunity cost of the conservation area. Accordingly, stratified random samples of 63 rural households (12 to 13 household heads per rural community) were selected from the five rural communities living around the conservation area. A team of 3 enumerators were trained on the survey questionnaire and the survey was administered in June 2013. The data entered and analyzed using SPSS 16.00 software.

3.4. Data analysis

Based on data from the experimental plots, the household survey, and secondary data sources, the economic values of the following ecosystem services of the Ankasa Forest Conservation area and the surrounding land uses were estimated on per hectare basis. These ecosystem services are:

- **Provisioning services**: Timber and Non-timber forest products
- **Regulating services**: Carbon stock in biomass and carbon stock in soils both converted to carbon dioxide equivalent.
- **Supporting services**: Soil nutrient cycling (Nitrogen, Phosphorous, Potassium); biodiversity (tree species diversity, non-timber forest product species diversity)
- **Cultural services**: tourism, research and educational services of the Ankasa forest reserve.

The following sections provide details on the methods used to estimate the economic values of each of the above ecosystem services.

3.4.1. Estimates of the economic value of the provisioning ecosystem services

3.4.1.1. Stumpage value of timber species

Based on the plot level inventory data, on the species, name of sample trees and information from the Forestry commission of Ghana on the major tropical timber species, the sample trees of each plot were classified into timber and non-timber species. For the timber species, the volume of the timber for each sample tree was calculated using Wong's (1989) volume equation, which is a power model that uses DBH as a single predictor variable and widely used in tropical inventory. We specifically used Wong's (1989) volume model developed for Tropical Forests and given by Volume (m^3/tree) = $0.004634DBH^{2.201}$, where DBH is tree diameter in cm.After determining the volume of each sample commercial tree species the total volume in the small, medium, and large radii of the nested plot were calculated as the summation of the trees in each radius class. The corresponding results were multiplied by the expansion factors of 198.94, 49.74, and 19.99 respectively and summed to convert in to hectare level values for each commercial timber species. Finally, the mean values for the Conservation Area and the other land uses were determined.

To estimate the economic value of each commercial timber species, the per hectare volume estimates for each species were multiplied by the average stumpage prices of the species. The stumpage prices for the different commercial timber species were obtained from the Forestry Commission of Ghana (Damnyag et al., 2011) and the prices were converted to $ at the official exchange rate of 1 $ = 2.0095GHc as of June 2013.

3.4.1.2. Estimates of Non-timber forest products

The estimation of the economic value of non-timber forest products was based on data from both the plot level and household surveys. The plot level survey was held to identify plant species that are used as non-timber forest product sources. Therefore, for both the conservation area and other land uses, the abundance and names of plant species used for medicinal, food, food and medicinal, local construction and ornamental purposes, fodder and other local uses were identified.

The household survey was used to assess the level of consumption and farm gate value of major non-timber forest products by rural households living around the Ankasa FCA. Accordingly, the average annual consumption levels per household and the corresponding farm gate values for the following major non-timber forest products were estimated based on the household survey data.

- Fuel wood (for home consumption and for sale)
- Wood for local construction (wood for house and other local construction, wood for making beds for drying crops, Canes, Rattan)
- Food (Wild fruits like mango and avocado, bush meat, snail, mushrooms)
- Medicinal plants

3.4.2. Estimating the economic value of the regulating service

3.4.2.1. Carbon storage in Biomass

In order to estimate the economic value of avoided emission of carbon that is currently stored in forest biomass we considered the carbon stock in standing trees greater than 5cm DBH, root of these standing trees, understory non-tree vegetation which includes ground floor vegetation and trees with less than 5cm DBH, and litter. The study did not take into account the biomass dead trees.

To determine the above ground dry biomass for trees greater than 5cm DBH, the Brown et al. (1989) allometric model developed for Wet Tropical forest zone was used. Among the three models developed by Brown et al. (1989) for the wet forest zone, we selected the model that uses DBH and tree height (H) as predictor variables and given by $Y \text{ (Kg/tree)} = \exp(-3.3012 + 0.9439\ln(DBH^2H))$. In the case of coconut trees, we applied the model of Frangi and Lugo (1985) that uses only tree height as a predictor variable and given by $Y = 4.5 + 7.7H$. By using these models the aboveground dry biomass of each sample tree was estimated and the results for all the trees within each radius class of each nested sample plot was summed to convert the values to a per hectare level using the corresponding expansion factors. Finally, the mean dry biomass in kilo gram per hectare was calculated for the conservation area and the other land uses. The root biomass per hectare was estimated by multiplying the dry aboveground biomass with conversion factors (root to shoot ratios for tropical wet forests) of 0.205 for trees with dry above ground biomass less than 125 tons per hectare and

0.235 for dry aboveground biomass exceeding 125 tons per hectare (Monkay et al., 2006). To determine the dry weightsof the non-tree vegetation as well as the litter biomass the dry weights per quadrant as described in section 3.2.2 were converted to per hectare values after adjusting for the basal area ofstanding trees.

The dry biomasses factors of 0.46 for trees less than 10cm DBH, non-tree vegetation and litter biomasses and 0.49 for trees above 10cm DBH (Hughes et al., 2000) were used to convert the dry biomass into carbon. The resulting carbon content in tons per hectare for each of biomass component was multiplied by the conversion factor of 3.67 (i.e. the ration of the molecular weights of carbon dioxide molecule to carbon atom) to obtain the tons of carbon dioxide equivalent (tCO_2e) per hectare (Olschewski and Benitez, 2005).

The weighted average price of $5.90/$tCO_2e$ in the voluntary carbon market for the year 2012, which is reported by Forest Trends' Ecosystem Marketplace on the *State of the Voluntary Carbon Markets 2013*, was used to convert the estimated tCO_2e per ha for each biomass component to their corresponding monetary values.

3.4.2.2. Carbon storage in Forest Soils

Based on the results of the laboratory analysis of the 138 soil samples analyzed for their organic carbon content at the Soil Research Institute of Ghana, the data on the soil bulk density, and following Mekuria et al. (2011) the soil organic carbon stock per hectare for each soil depth class was estimated using the following equation:

$$\text{SOC (t/ha)} = (\%\ C \times 10^{-2}) \times (\text{Bd in t/m}^3) \times (\text{Soil depth (0.2m)}) \times (10000\text{m}^2/\text{ha})$$

Where, SOC is the soil organic carbon stock, C is the soil organic carbon content, Bd is soil bulk density respectively. The stock of soil carbon was multiplied by the conversion factor of 3.67 to obtain into tCO_2e per hectare.

3.4.3. Estimating and describing the supporting ecosystem service

3.4.3.1. Estimating the value of soil fertility

The replacement cost method was applied to estimate the value of soil fertility loss. The method allows the estimation of the value of an ecosystem service by estimating the cost of replacing with an alternative or substitute good or service (Bishop, 1999). The method is widely used because it is relatively simple to use provided that data on nutrient loss is available (Bojö, 1996; Damnyag, 2011). In order to estimate the replacement cost of soil fertility loss we applied the following procedures.

First the available nutrient in the soil was determined on per hectare level based on the results of the laboratory analysis of the 138 soil samples analyzed for their nitrogen, phosphorous, and potassium contents at the Soil Research Institute of Ghana, the data on the soil bulk density, and following Mekuria et al. (2011) the available stocks of total nitrogen (TN), phosphorous (P), and potassium (K) for each soil depth class were estimated using the following equations:

$$TN\ (t/ha) = (\%\ TN \times 10^{-2}) \times (Bd\ in\ t/m^3) \times (Soil\ depth\ (0.2m)) \times (10000m^2/ha)$$

$$P\ (t/ha) = (P_{ppm} \times 10^{-6}) \times (Bd\ in\ t/m^3) \times (Soil\ depth\ (0.2m)) \times (10000m^2/ha)$$

$$K\ (t/ha) = (K_{ppm} \times 10^{-6}) \times (Bd\ in\ t/m^3) \times (Soil\ depth\ (0.2m)) \times (10000m^2/ha)$$

Second, we estimated the corresponding threshold stock levels using the minimum soil property threshold levels (0.1% TN, 10 ppm of P, and 100 ppm of K) considered as moderate for plant growth and reported for assessing forest soil health (Amacher et al., 2007).Then, the nutrient loss for each soil nutrient was estimated by subtracting the available stock from the calculated threshold level. The results were then multiplied by the corresponding nutrient-to-fertilizer conversion ratios derived from a 50 Kg commercial fertilizer of NPK 15-15-15 to obtain the equivalent commercial fertilizer required to replace the nutrient loss (Niskanen, 1998; Nahuelhual et al., 2006; Damnyag et al., 2011). Finally, we estimated the replacement cost for each nutrient loss by multiplying the equivalent commercial fertilizer required to replace the nutrient loss by the annual average market price of the fertilizer in Ghana market.We obtained the monthly average prices of NPK 15-15-15 fertilizer in Ghana for the year 2012 from www.AfricaFertilizer.org and accordingly the annual average market price was 499.49 $ per ton for the year and this value was used in the calculation.

3.4.3.2. Describing biodiversity of trees and non-timber forest product source plants

In order to obtain a quantitative and qualitative description of the level of tree biodiversity as well as the diversity of plant based sources of non-timber forest products, tree species biodiversity and species diversity of plants and of non-timber forest product source were determined for the conservation area as well as the land uses outside the conservation area. Using the sample plot level inventory on the tree species and the non-timber forest product plant species, we calculated species diversity. Out of a wide range biodiversity indices available in the literature (Magurran, 1988), we applied the Shannon index (H), which has been proposed to estimate biodiversity in carbon sequestration projects (Ponce-Hernandez, 2004; Henry et al., 2009). Shannon index was calculated by multiplying the abundance of a species (p_i) by the logarithm of this number:

$$H_j = -\sum_{i=1}^{m} p_{ij} \ln(p_{ij})$$

Where H is the Shannon index for the trees in small, medium and large diameter classes or for non-timber forest product use type or for land use type j depending on the scale of analysis.

$$p_{ij} = \frac{n_{ij}}{N_j}$$

Where n_i is the number of subjects from the species I and N is the total number of subjects within plot j.

3.4.4. Estimating REDD+ Opportunity Cost of the Conservation Area

In order to estimate the opportunity cost of keeping the Ankasa FCA sustainably and hence avoid and/or reduce emissions from the likely deforestation from conversion to other competing land uses, we estimated the opportunity costs in terms of income loses to rural communities living around the conservation area arising from use restriction. Based on the date from the reconnaissance survey and the main plot level and household surveys, and the results of the valuation of ecosystem service of the conservation area and land uses around, we estimated the REDD+ opportunity cost of reducing emissions (in terms of $/tCO2; $/tCO2/ha; and $/tCO2/ha/yr) from potential conversions of the conservation area to four land use change options using the following procedures.

First, we identified four major land uses that represent the major livelihood basis of rural communities living around the conservation area. These land uses are:

- Cocoa farming: refers to cocoa farms mixed with agro forestry food crops and some timber trees.
- Agroforestry_1: refers to land use that integrates local food crop production, cocoa farming, rubber plantation, and coconut plantation on both wetlands and non-wetlands.
- Agroforestry_2: refersto land use that integrates local food crop production, rubber plantation, and coconut plantation on both wetlands and non-wetlands.
- Agroforestry_3: refers to land use that integrates local food crop production, cocoa farming, rubber plantation, coconut plantation and fallow lands on both wetlands and non-wetlands.

Figure 3-6: Ankasa Forest Conservation area (at the center) and land uses close to the conservation area (from left to right on top are wetland, cassava farm, cocoa farm. whereas from left to right in the bottom are rubber plantation, fallow land, and coconut plantation).

Second, four major types of ecosystem services were identified as source of income that can represent the direct on-site opportunity cost of not converting the Conservation area to either of the above four land use change options. This ecosystem services are commercial timber, timber for local uses, non-timber forest products, and crops (cocoa, Cassava, other crops (plantain, banana, yam, maize, coconut, palm, garden egg, okro, and pepper)). The flows of benefits and costs of producing each of these ecosystem services and hence the net benefits from each of the four land use options as well as the corresponding potential values from the forest reserve were estimated as follows.

Timber:the volume and stumpage values ($/ha) of commercial and non-commercial timber species were estimated based on the methods described in section 3.3.3.1 above and we took these values as net benefits from timber with the fact thatstumpage price is the price of the standing timber and does not include harvesting costs. For the Ankasa FCAand Cocoa farming, we took directly the estimated results. However, in the case of the land use options Agroforestry_1 to Agroforestry_3, the values were calculated by taking the weighted averages of the results of the different land uses included under each Agro forestry category. For example, the in the case of Agroforestry_1 the volume of timber refers to the weighted average of the volumes of timber per ha for the cocoa farm, coconut plantation, rubber plantation, and wetlands which are estimated based on the plot level inventory data in the study area.

NTFP: household level of annual consumption and farm gate values of NTFPs (Fuel wood for home consumption and for sale, wood for local construction, food, and medicinal plants) were estimated based on the data from the household survey as described in section 3.3.1.2 and the values were taken as net benefits from NTFP extraction with the assumption of zero labor cost of extraction. In order to convert these values to per hectare values we divided the values by the average land size per household with the assumption that households derive most of these products from the land that belongs to them. This assumption is based on our observation in the study area, the results of the household survey, as well as the ease of practicality in collecting data on NTFP harvesting through household survey than area based inventory. Furthermore, we did the following assumption in accounting the flows of NTFP to the four land use options and the conservation area. For the conservation area we assumed no income from NTFPs to nearby rural communities based on the fact that extraction of NTFP from the conservation area is illegal and completely prohibited. For the cocoa farming we considered income from food and medicinal plant NTFPs whereas for the three agroforestry types of land uses we considered incomes from all types of the NTFPs.

Crops: In order to account for net farm income of rural households, the questionnaire was designed to collect the following farm income accounting information. Each respondent was asked about the name and size of each plot of land he/she has been cultivating over the past 12 months in two production seasons. For each plot respondents were further asked to provide information on crop types cultivated in each season and identify them into major (dominant) cropand minor crops, the total harvest of the major crop and each of the other minor crops from the plot per season, and the inputs (hired labor, fertilizer, pesticides, and insecticides) used for each plot per season. The data was analyzed using SPSS 16.00 and the mean production per plot was estimated for each crop type for each season, the result was then multiplied by the average annual farm gate price of the specific crop to get the gross value of output per crop per plot. The results of gross outputs for the crops cultivated in a plot were summed to get the total value of crops per plot. The net income per plot was calculated by subtracting the total input costs, which was calculated by the quantity of input used by the price of inputs, from the total value of crop output from that plot. We classified the results of all plots (143 plots which in total cover an area of 499 hectares) by the major crop types (cocoa, Cassava, other crops (plantain, banana, yam, maize, coconut, palm, garden egg, okro, pepper) and estimated the mean output quantity and value, input costs, and net income per ha/year for each of these classes and their aggregate. In the assignment of the flows of costs and benefits of cocoa production over the time, we considered only costs of cocoa production and land preparation for the first four years of the discounting period with the assumption that if the conservation forest is to be converted to cocoa farm it will require at least 4 years for the cocoa trees to provide crops.

Third, for each land use type we estimated the total carbon stock per ha as a sum of carbon in biomass and soil and converted the result to tCO2 equivalent as described in section 3.3.2. Finally, based on the results of the above procedures we estimated the present value of the direct opportunity cost of conserving the Ankasa FCA using the following equation:

$$NPV_{JA} = \sum_{t=0}^{T}\left[\left(\{timNB_{Jt} - timNB_{At}\} + \{ntfpNB_{Jt} - ntfpNB_{At}\} + \{cropNB_{Jt} - cropNB_{At}\}\right)(1-r)^{-1}\right]$$

$$NPV_{JA} = \frac{\sum_{t=0}^{T}\left[\left(\{timNB_{Jt} - timNB_{At}\} + \{ntfpNB_{Jt} - ntfpNB_{At}\} + \{cropNB_{Jt} - cropNB_{At}\}\right)(1-r)^{-1}\right]}{\left[tCO_{2_A} - tCO_{2_J}\right]}$$

$$NPV_{AJt} = \sum_{t=0}^{T}\left[\left(B_{jt} - C_{jt}\right)(1+r)^{-t}\right]$$

Where:

NPV_{AJ} is the opportunity cost in $/$tCO_2$ emission reduction from not converting A, which refers the Ankassa Forest Conservation area, to land use J (where J = 1 … 4, representing the above four land use options).

timNB is net benefit (benefit minus cost) from timber

ntfpNB is the net benefit from non-timber forest product extraction

cropNB is the net benefit from crop production

tCO_{2A} is the stock of carbon in Ankassa forest in terms of tons of carbon dioxide equivalent

tCO_{2J} is the stock of carbon in the alternative land use J in terms of tons of carbon dioxide equivalent

r is discount rate

t is time in years (t = 0, 1, 2, …T and T = 5, 10, 20 and 30)

We applied two real discount rates (3% and 7.26%). The 3% is the discount rate for Annex I countries, which are the main buyers of carbon credits, whereas the 7.26% real discount rate was calculated for Ghana using national average nominal interest rate, i , of 15.5% (www.tradingeconomics.com; Bank of Ghana, 2012) and the expected inflation rate π following (Fisher, 1930) as: $r = \frac{i-\pi}{1+\pi}$.

Current consumer price and/or general price indices are often used as an estimate of future inflation. However, these indices reflect the general development of all prices, which might either over estimate or underestimate the future price development of the specific project outputs. Therefore we used data for five years (2014-2018) inflation forecasts for Ghana available online from www.economywhach.comand calculate an expected inflation rate of 7.69% and hence the real discount rate of 7.26%.

The project duration over which the economic analysis has to be carried out is another important parameter that has to be chosen. This is related to the issue of permanence, which refers to the question of 'How long do payments to families and other incentive measures need to be maintained to ensure that emissions reductions are permanent?' Based on international experience in forestation projects for Clean development mechanism and official carbon accounting rules (UNFCCC, 2003) and related studies (Olschewski and Benitez, 2005; Mekuria et al., 2010), and with the objective of providing portfolio of accounting periods for possible decisions by potential buyers of carbon credits we selected four accounting periods, which are 5 years, 10 years, 20 years, and 30 years.

4. Results

4.1. Economic values of selected ecosystem services

4.1.1. Provisioning services: timber and non-timber forest products

Timber: Table 4.1 describes the total volume and stumpage values per hectare for the commercial and non-commercial timber in the study area. The Ankassa Forest Reserve contains 627.35 $m^3$of standing volume of timber per hectare with a mean stumpage value of 364.26 $/ha. Commercial timber species (Annex A1) account 28.73% in volume and 45.99% in value of total standing timber per hectare. Among the commercial timber species, low value species accounted the largest proportion (76.52%) in volume per hectare whereas the high value timber species accounted the largest share (54.68%) in value per hectare. In the case of off-reserve land uses, the total standing volume and stumpage value of timber was 279.59 m3/ha and 131.22 $/ha respectively. This indicates that the Ankasa Forest Reserve has 247.76 m^3/ha more standing timber volume than the average standing volume of timber in off- reserve land uses. In terms of value this corresponds to a difference of 233.04 $/ha.

Table 4-1: Volume and Stumpage value of commercial and non-commercial timber species by land cover

Species category	Forest reserve		Off-reserve land uses*	
	Volume in m^3/ha Mean (SE)	Value in $/ha Mean(SE)	Volume in m^3/ha Mean(SE)	Value in $/ha Mean(SE)
		Mean (SE)	Mean (SE)	Mean (SE)
High value commercial timber	28.59 (13.97)	91.6 (44.57)	0.70 (0.70)	3.49 (3.49)
Medium value commercial timber	13.73 (10.53)	9.87 (7.23)	5.80 (4.66)	6.45 (4.60)
Low value timber species	137.92 (21.25)	66.06 (12.03)	98.78 (39.81)	44.59 (17.78)
Total timber species	180.24	167.53	105.28	54.52
Other tree species for local uses	447.11 (60.55)	196.73 (26.64)	174.307 (41.88)	76.696 (18.43)
Total timber	627.35	364.26	279.59	131.22

*refer Annex A2 for details on the corresponding data for the land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) whose values are aggregated as off-reserve land use.

Non timber forest products:non timber forest product extraction from the Ankasa Forest Reserve is illegal and prohibited. The results of the level of annual consumption and farm gate values of NTFP extraction per household are described in Table 4.2 below therefore refer to the extractions from the off-reserve land uses. Households in study area reported that they were extracting non timber forest products (for fuel wood, wood for local construction, for food, and medicinal uses) with an average gross farm gate value of 451.27 $/household over 12 months from May 2012 to June 2013 from the off-reserve land uses .The farm gate value of fuel wood accounted the largest share (66.54%) of the gross farm gate value of all the NTFPs extracted whereas medicinal plant extraction accounted the least (only 2.19%). If we divide the values of the NTFP per household by the average land holding size of sample households in the study area (8.42 ha per household) to get a proxy at per hectare level, it implies that households extracted NTFP of with an average value of 53.59 $/ha/yr from the off-reserve land uses.

Table 4-2: Household consumption levels and farm gate values of major NTFPs from the Off-reserve land uses in rural areas around the Ankasa FCA.

NTFP	% of HHs using the NTFP (N=63)	Unit	Consumption in Unit/HH/Yr		Farm Gate Value in $/HH/Yr		Farm Gate Value in $/ha/Yr *
			Mean	SE	Mean	SE	
Fuel Wood:					300.29	51.20	35.66
Fuel wood for home consumption	100.00	Kilo gram	1193.10	123.63	243.04	39.48	28.86
Fuel wood for sale	11.10	Kilo gram	116.42	64.21	57.25	37.19	6.80
Wood for local construction:					90.54	22.68	10.75
Wood for local construction	66.70	Pieces	87.86	16.49	40.61	8.35	4.82
Wood for making beds for drying crops	44.40	Pieces	71.96	39.46	28.73	18.35	3.41
Canes	14.3	Pieces	21.00	12.60	6.91	4.10	0.82
Rattan	22.20	Pieces	26.65	9.51	14.291	5.48	1.70
Food:					50.45	13.82	5.99
Wild fruits (mango, avocado, ...)	23.80	Pieces	63.22	20.73	16.26	5.87	1.93
Bush meat (antelope and other animals)	11.10	Number	1.48	0.81	11.57	6.27	1.37
Bush meat (Rodents)	22.20	Number	7.13	2.53	19.43	8.14	2.31
Snails	14.30	Number	52.17	47.61	2.62	1.43	0.31
Mushrooms	6.30	Pieces	80.51	79.35	0.57	0.57	0.07
Medicine:					9.90	5.18	1.18
Medicinal plants	19.00	Pieces	13.95	6.03	9.90	5.18	1.18
Total					451.27	63.76	53.59

**the per hectare values were calculated by dividing the per household values by 8.42 hectares which is the average land size per household.*

4.1.2. Regulating services: Carbon stock in biomass and soils

Carbon stock: Forests store carbon in biomass and soil through the processes of photosynthesis and decomposition of organic matter respectively. Table 4.3 describes the total carbon pool in terms of CO2 equivalent and the corresponding market value for the Ankassa Forest Conservation and the off-reserve land uses. TheAnkasa forest stores 1229.93 tCO_2e/ha and has a value of 7256.78 $/ha. Biomass carbon accounts the bigger share (78.37%) of the total carbon pool of the forest as well as its value whereas the carbon in the forests soils up to a depth of 0.6 meters accounts the remaining 21.63% both in quantity and value. In the case of biomass carbon, above ground tree biomass stores59.55% of the total carbon pool of the forest and tree root biomass accounts 12.72% of the total carbon pool of the forest. Non-tree vegetation and litter biomass together account the remaining 6.09% of the total carbon pool. The top soil (0-0.2 m depth) stores more carbon than the soils at higher depth classes. The carbon in the top soil accounts 11.82% of the total carbon pool of the forest reserve whereas the soils in the last two depth classes accounted only 6.81% and 3% of the total carbon pool respectively.

Table 4-3: Stocks and values of carbon in biomass and soils of Ankassa Forest Conservation Area and Off-reserve land uses

Ecosystem service	Land Uses						
	Forest Reserve	Off reserve					
		Cocoa	Coconut	Rubber	Fallow	Wetland	Total
No. Plots	21	5	5	5	5	5	25
Biomass carbon in tCO_2e/ha							
AGB	732.46 (97.54)	94.16 (14.74)	45.96 (8.62)	387.38 (252.18)	209.42 (28.03)	516.82 (155.76)	250.75 (65.41)
Root biomass	156.47 (22.57)	19.30 (3.02)	9.42 (1.77)	79.41 (51.70)	42.93 (5.75)	105.95 (31.93)	51.40 (13.41)
Non tree vegetation biomass	56.98 (20.96)	0.00	17.39	9.89 (2.59)	43.08	21.02 (3.16)	20.37 (5.10)
Litter Biomass	18.00 (6.36)	8.41	2.20	6.35 (0.56)	10.06	7.00 (1.25)	6.77 (0.96)
Total	**963.91**	121.87	74.97	483.01	305.49	650.79	**329.29**
Value of tCO_2e biomass carbon in $/ha	**5687.07**	719.06	442.97	2849.77	1802.37	3839.65	**1942.84**
Soil carbon in tCO_2e/ha							
Top 0-20 cm depth	145.37 (20.62)	153.90 (29.84)	105.67 (27.06)	134.94 (17.46)	208.80 (90.26)	93.30 (24.82)	139.32 (20.63)
20-40 cm depth	83.76 (10.07)	82.48 (20.39)	80.67 (28.33)	98.04 (18.92)	116.95 (35.09)	46.54 (18.32)	84.94 (11.28)
40-60 cm depth	36.89 (7.60)	68.56 (25.78)	45.40 (12.90)	50.43 (22.12)	59.20 (15.55)	12.40 (4.34)	47.20 (8.24)
Top 0-60 cm depth	**266.02**	304.95	231.75	283.42	384.93	152.24	**271.46**
Value of tCO_2e of soil carbon in $/ha	**1569.51**	1799.15	1367.28	1672.15	2271.95	898.21	**1601.58**
Total carbon pool in tCO_2e/ha	**1229.93**	426.82	306.72	766.43	690.43	803.03	**600.75**
Value of total carbon pool in $/ha	**7256.58**	2518.21	1809.62	4521.92	4073.55	4737.86	**3544.42**

For the land uses outside of the forest reserve, the study found a total carbon pool of 600.75 $tCO2/ha$ with a value of 3544.42 $/ha as a weighted averages of the corresponding values for the five major land uses of the off-reserve. Among the five land uses off-the reserve, wetlands store the highest carbon on per hectare basis followed by rubber plantations and fallow lands whereas coconut plantations store the least. In terms of biomass carbon, the same trend was observed whereas in terms of soil carbon pool we observed a different ranking of the five land uses. Fallow lands store the highest carbon in soil on a per hectare basis followed by cocoa farms and rubber plantations whereas wetlands store the least carbon in soil.

Comparing the Ankasa forest reserve with the off-reserve land uses indicates that the total carbon pool and its value for the Ankasa forest reserve are more than twice the carbon pool and value for the off-reserve land uses on a per hectare level. The difference is totally accounted by the difference in biomass carbon pool between the two land uses. In the case of soil carbon, however, we found the opposite. The off-reserve land uses on average store a little more carbon than the soils in Ankasa Forest Reserve on per hectare basis. But the differences in soil carbon pool at each of the soil depth classes between the Ankasa forest reserve and the Off-reserve sites were not statistically significant at 1% level (top soil: df =44, t=0.206, p=0.84; soil depth 20-40cm: df=44, t=-0.077, p=0.94; soil depth 40-60cm: df=44, t=-0.906, p=0.37).

4.1.3. Supporting services: Soil Nutrients and Biodiversity

4.1.3.1. Replacement cost of soil nutrient loss

Nitrogen is an important nutrient for plant growth. A minimum threshold level of 0.1% of nitrogen nutrient is considered as moderate for plant growth and reported for assessing forest soil health (Amacher et al., 2007). Table 4.4 below describes the replacement costs of soil nitrogen, phosphorus, and potassium nutrient losses for the Anakasa Conservation area and the off reserve land uses. The available nitrogen nutrient in the Off-reserve land uses was larger by 137.37 Kg/ha than the nitrogen nutrient in the soils of the Ankasa Forest reserve. However, in both the Ankasa forest reserve and the off-reserve land uses, the available nitrogen in soils was much greater than the threshold level implying no replacement cost for this particular nutrient at a threshold level of 0.1% nitrogen content in soil. The negative replacement costs of 22.47 $/ha for the Ankasa Forest reserve and 33.73 $/ha for the off reserve land uses imply the value of the extra stocks of available nitrogen in soil which can be considered as benefits. But if we consider a threshold level of 0.2% of nitrogen content, which Damnyag et al. (2011) used in their study as a threshold level required for the growth of Agroforetry crops in Ghana, the available soil nitrogen will be less than the threshold in both land uses. At this threshold level, the replacement cost of nitrogen nutrient loss was estimated at 139.49 $/ha for the Ankasa Forest Reserve whereas the replacement cost for the off reserve land uses was 131.18 $/ha (Annex A3).

Phosphorous nutrient content available in soils of both the Ankasa FCA and the off-reserve land uses were below the threshold level of 10 milligram per kilogram of soil. The available phosphorous nutrient in the soils up to a depth of 0.6 meters were nearly equal in both site with about only 0.11 kg/ha higher in the soils of the off-reserve land uses than the Ankasa FCA.Thus, a replacement cost of 0.49 $/ha is required to increase the soil phosphorous content to the threshold level of 10 mg/kg for each of the two land uses. In the case of the five off-reserve land uses, cocoa farm exhibited the highest available phosphorous in kg/ha and lowest replacement cost in $/ha followed by rubber plantation and coconut plantations whereas fallow lands had the lowest available phosphorus in kg/ha and highest replacement cost in $/ha (Annex A3).

Table 4-4: Replacement costs of soil nutrient loss in Ankasa Forest Conservation and Off-reserve land uses

Nutrient Type by land use (n=sample size)	Available nutrient in soil by soil depth in cm (N in %; P in mg/kg; K in mg/kg) (SE)				Available nutrient in Kg/ha	Nutrient loss * in kg/ha	Nutrient-fertilizer conversion ratio	Price per nutrient ($/kg) at 0.499 $/kg of fertilizer	Replacement cost ($/ha)
	0-20	20-40	40-60	Average					
Forest Reserve (n=21)									
Nitrogen(N)	0.19 (0.02)	0.10 (0.01)	0.05 (0.01)	0.11	2513.92	-326.58	0.150	0.075	-24.47
Phosphorous (P)	3.99 (0.72)	3.15 (0.61)	2.23 (0.49)	3.12	6.89	14.98	0.066	0.033	0.49
Potassium (K)	17.71 (1.67)	11.85 (0.98)	10.14 (1.18)	13.24	29.11	189.62	0.125	0.062	11.79
Off-Reserve **(n=25)									
Nitrogen(N)	0.20 (0.02)	0.11 (0.01)	0.05 (0.01)	0.12	2651.29	-450.22	0.150	0.075	-33.73
Phosphorous (P)	4.20 (0.50)	2.98 (0.41)	2.37 (1.46)	3.19	7.00	15.01	0.066	0.033	0.49
Potassium (K)	25.93 (5.30)	19.26 (4.19)	10.90 (1.23)	18.70	41.07	179.03	0.125	0.062	11.13

**nutrient loss was calculated as the available nutrient minus the threshold level nutrient, which is calculated for the sites at threshold soil properties of (N= 0.1%, P=10 mg/kg; and K = 100 mg/kg), as described in section 3.3.3.1.*

*** refer Annex A3 for details on the corresponding data for the land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) whose values are aggregated as off-reserve land use.*

Potasium nutrient content available in soils of both the Ankasa FCA and the off-reserve land uses were also below the threshold level of 100 milligram per kilogram of soil. The available potassium nutrient in the off reserve land use soils up to a depth of 0.6 meters was 11.96 kg/ha higher than the available potassium nutrient in soils of the Ankasa Forest reserve. Thus, the replacement cost was higher for the Ankasa Forest Reserve by 0.70 $/ha than what is required to increase the soil potassium content of the off-reserve land use to the threshold level of 100 mg/kg. In the case of the five off-reserve land uses, fallow lands contain the highest available potassium in kg/ha and require the lowest replacement cost in $/ha followed by cocoa farm and coconut plantation whereas wetlands had the lowest available potassium in kg/ha and highest replacement cost in $/ha (Annex A3).

4.1.3.2. Biodiversity: Tree species diversity and NTFP source plant species diversity

Biodiversity conservation in forests and other land uses is important for sustainable supply of all of the other ecosystem services. Table 4.5 describes tree species diversity in the Ankasa FCA and the Off-reserve land uses of the study area. A total 108 tree species with DBH$\geq$ 5cm of which 60 tree species were with DBH $\geq$ 30 cm were identified growing in 21 plots, which sum up an to area of 1.051 hectare, in the Ankasa FCA. Out of the total 406 individual trees greater than 5 cm diameter identified in the 21 plots (Annex A4.1), *Diospyros sanza-minika* is the main species accounting 4.4% of the total number of individual trees. In the case of trees of small and medium size classes, a total of 62 tree species with small diameter (5 cm $\leq$ DBH < 15 cm)and 54 tree species with medium size class (15 cm $\leq$ DBH < 30 cm) were identified growing in 21 plots within the4m and 8m radius nested plots respectively. The total area of all of the small radius nested plots was of 0.106 hectare whereas it was 0.422 hectare for the medium radius nested plots.

In the case of off-reserve land uses, a total only 39 tree species with DBH$\geq$ 5cm of which 12 tree species were with DBH $\geq$ 30 cm were identified growing in 25 plots, which sum up to an area of 1.251 hectare. Out of a total 346 individual trees greater than 5 cm diameter identified in the 25 plots, *Theobroma cacao and Hevea brasiliensisare* the two dominant species that account 22.30% and 21.10% respectively. In the case of trees of small and medium size classes, a total of 24 tree species with small diameter (5 cm $\leq$ DBH < 15 cm) and 23 tree species with medium size class (15 cm $\leq$ DBH < 30 cm) were identified growing in 25 plots within the 4m and 8m radius nested plots respectively. The total area of all of the small radius nested plots was of 0.126 hectare whereas it was 0.503 hectare for the medium radius nested plots.

The Shannon indices of each of the diameter classes for the Ankasa forest reserve are higher than the corresponding figures for the off-reserve land uses. This indicates that the Ankasa forest reserve is much richer in tree biodiversity than the off-reserve land uses. Moreover, the abundance of trees in the former land use is much higher than the off-reserve land uses. In the case of the five land uses of the off-reserve, fallow land is the richest in tree biodiversity followed by wetland whereas the other three land uses were almost mono-species.

Table 4-5: Biodiversity of tree species by diameter class in the Ankasa FCA and Off-reserve land uses.

Land use	Tree size	n(plot)	Number of Species	Shannon index	Main species
Forest Reserve	DBH ≥ 5 cm	21	108	2.40(0.08)	*Diospyros sanza-minika*
	5 cm ≤ DBH < 15 cm	21	62	1.49(0.11)	*Picralima nitida*
	15 cm ≤DBH < 30 cm	21	54	1.32(0.13)	*Drypetes principum*
	DBH ≥ 30 cm	21	60	1.60(0.11)	*Heritiera utilis; Scytopetalum tieghemii*
Other land uses	DBH ≥ 5 cm	25	39	0.54(0.14)	*Theobroma cacao*
	5 cm ≤ DBH < 15 cm	25	24	0.38(0.11)	*Hevea brasiliensis*
	15 cm ≤DBH < 30 cm	25	23	0.30(0.10)	*Hevea brasiliensis*
	DBH ≥ 30 cm	25	12	0.14(0.08)	*Hevea brasiliensisHevea brasiliensis*
Cocoa Farm	DBH ≥ 5 cm	5	2	0.08(0.08)	*Theobroma cacao*
	5 cm ≤ DBH < 15 cm	5	2	0.08(0.08)	*Theobroma cacao*
	15 cm ≤DBH < 30 cm	5	1	0.00	*Theobroma cacao*
	DBH ≥ 30 cm	5	0		
Coconut Plantation	DBH ≥ 5 cm	5	0		
	5 cm ≤ DBH < 15 cm	5	1	0.00	*Cocos nucifera*
	15 cm ≤DBH < 30 cm	5	1	0.00	*Cocos nucifera*
	DBH ≥ 30 cm	5	1	0.00	*Cocos nucifera*
Rubber Plantation	DBH ≥ 5 cm	5	1	0.00	*Hevea brasiliensis*
	5 cm ≤ DBH < 15 cm	5	1	0.00	*Hevea brasiliensis*
	15 cm ≤DBH < 30 cm	5	1	0.00	*Hevea brasiliensis*
	DBH ≥ 30 cm	5	1	0.00	*Hevea brasiliensis*
Fallow Land	DBH ≥ 5 cm	5	20	1.37(0.16)	*Macaranga barteri; Musanga cercropioides*
	5 cm ≤ DBH < 15 cm	5	12	0.82(0.26)	*Ficus sur*
	15 cm ≤DBH < 30 cm	5	11	0.94(0.16)	*Macaranga barteri*
	DBH ≥ 30 cm	5	1	0.00	*Musanga cercropioides*
Wetland	DBH ≥ 5 cm	5	18	1.26(0.23)	*Raphia hookeri*
	5 cm ≤ DBH < 15 cm	5	11	0.99(0.15)	Anthocleista vogelli
	15 cm ≤DBH < 30 cm	5	10	0.56(0.28)	*Raphia hookeri*
	DBH ≥ 30 cm	5	10	0.70(0.29)	*Raphia hookeri*

Table 4.6 describes the biodiversity in non-timber forest product plant sources in the Ankasa FCA and off-reserve land uses. In the Ankasa forest reserve a total of 32 plant species (Annex A5.1) that are source of non-timber forest products were identified growing in 18 plots which sum up an area of 0.09 hectare. In the case of the off-reserve land uses there were 29 plant species (Annex A5.2) of non-timber forest product sources growing in 10 plots that sum up and area of 0.05 hectare. The Shannon index for the diversity of the non-timber forest product source plant species of the Ankasa Forest reserve was higher than the off-reserve land uses indicating a richer biodiversity in the former land use.

Table 4-6: Biodiversity of non-timber forest product source plants in Ankasa Forest Reserve and Off-reserve land uses

Land use	Use as a NTFP	n (plot)	Number of species	Shannon index	Main species
Forest Reserve	Medicinal	13	6	0.28(0.04)	*Sphenocentrum jollyanum*
	Food	13	9	0.24(0.06)	*Chrysophyllum albidum*
	Food and Medicinal	13	4	0.32(0.03)	*Piper guineense*
	Construction and ornamental	4	10	0.12(0.02)	*Eremospatha hookeri; Strombosia glaucescens*
	Other uses (resin, fodder, ...)	5	6	0.08(0.01)	*Napoleonaea vogelii*
	Total	18	32	1.03(0.22)	*Sphenocentrum jollyanum*
Other land uses	Medicinal	7	19	0.65(0.15)	*Aframomum stanfieldii*
	Food	7	5	0.14(0.04)	*Elaeis guineensis*
	Food and Medicinal	4	3	0.05(0.02)	*Psidium guajava*
	Construction and ornamental	1	3	0.04	*Raphia hookeri*
	Other uses (resin, fodder, ...)	3	1	0.02(0.01)	*Baphia nitida*
	Total	10	29	0.89(0.20)	*Aframomum stanfieldii*

4.1.4. Cultural services: Tourism, research and educational services

Tourism, recreation, research and educational services are most important cultural services that forests in general and conservation area forests in particular could provide.Despite the rich biodiversity in both plant and animal species found in the conservation area and the high potential for tourism development, the conservation area has not been used to tap such a potential that can contribute to the development of the country. Both the number of tourist arrivals the revenue from the sector that the conservation area was getting over the period from 2002-2012 indicate that the conservation area on average generated revenue of $4121 from 1326 tourist arrival per year. As figure 2 below shows, both the number of tourist arrivals and revenue from the sector was not showing a sign of increasing trend over the period from 2004 to 2009 but for the last three years there were improvements mainly on the revenue from tourist arrivals. In terms of the research and educational services that the conservation area could provide, over a period of 11 years from 2003-2013 there were only 24 researchers (21 foreign and 3 domestic researchers) and 18 student researchers (4 foreign and 14 domestic student researchers) who visited the conservation area for a short to medium term research works of 1 to 6 months duration. The conservation area was able to generate only 590.91 $/year from the foreign researchers and foreign student researchers with the former accounting 94% of the generated revenue.

Considering the total size of the conservation area which is estimated to be 523 km^2, the revenues that the conservation area was generating from tourist and researchers'visitsare insignificant. For example the sum of the average revenues per year imply that the conservation area was generating only 9.01$/km^2 or 0.09 $/ha from the tourist and foreign researchers arrivals.

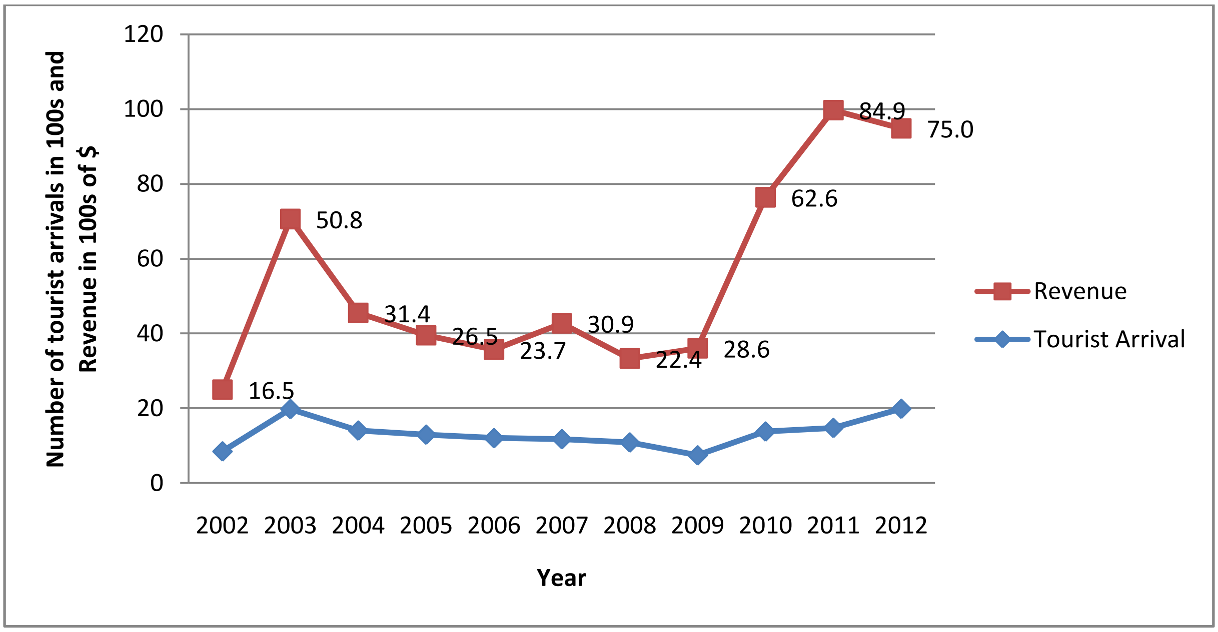

Figure 4-1: Number of tourist arrivals at Ankasa FCA and revenue generated over the period 2002-2012. (Source: Ankasa FCA Management Headquarter).

4.2. REDD+ opportunity cost of the Ankassa Forest Reserve

Reducing Emissions from Deforestation and forest Degradation (REDD) entails opportunity costs, implementation and transaction costs. Opportunity costs include direct on-site costs, indirect off-site costs, and socio-cultural costs (White et al., 2011). Table 4.7 ~~below~~ describes the direct on-site opportunity costs of conserving the Ankasa FCA for the next 5 to 30 years. The difference in NPVs between converting and not converting the Ankasa forest to other land uses, which measures the direct on-site opportunity cost of conserving the forest, was highest for Agroforestry2 followed by Agroforestry1 but lowest for cocoa farm. The direct on-site opportunity cost of conserving the forest for the next 30 years ranges from 9662.69 $/ha to 23352.80 $/ha in net present values. Net income from crop production accounts more than 90% of this opportunity cost of conserving the Ankasa forest from conversion to any of the four alternative land uses. The details on net income from crop production in the off-reserve land uses can be seen in Annex A6. The remaining less than 10% of the opportunity cost is in terms of forgone net benefits from commercial and non-commercial timber and non-timber forest products.

The difference in total stock of carbon measured in carbon dioxide equivalent between the Ankasa forest and each of the four alternative land use measures the emission reduction units that can be realized from conserving the forest. As Table 4.7 shows, the emission reduction in tCO_2/ha is the highest in the case of conserving the Ankasa FCA from conversion to cocoa farm whereas the lowest is in the case of conserving the forest from conversion to Agroforestry2.

The net present value of the direct on-site opportunity of conserving the Ankasa FCA for a period of 30 years at a discount rate of 3% ranges from 12.03 -38.63 $/tCO_2e$, which implies that the forest can be conserved at a direct on-site opportunity cost of 0.40-1.29 $/tCO_2e/yr$. If we take a higher discount rate, say 7.26% which is the real discount rate for Ghana calculated based on interest rate of 15.5% and average expected inflation rate of 7.69% (www.economywatch.org), the maximum direct on-site opportunity cost of conserving the forest for a period of 30 years was estimated at 0.81$/tCO_2e/yr$ in net present value, which is the forgone net benefit form not converting the forest to Agroforestry2. On the contrary if we assume a zero real discount rate which would imply a relatively stronger intergenerational equity, the maximum direct on-site opportunity cost would be only 1.94$/tCO_2e/yr$ in net present value terms.

Table 4-7: Direct on-site REDD+ Opportunity cost estimates for the Ankasa FCA.

Land use change options	Years	Difference in NPV of Forest Conservation Area and NPV of each land use change options by ecosystem service type in $/ha					Emission Reduction in tCO_2/ha	NPV of Opportunity costs at 3% real discount rate		NPV of Opportunity costs at 7.26% real discount rate		NPV of Opportunity costs at 0.00% real discount rate	
		Commercial timber	Non-Commercial timber	NTFP	Crops	Total		$/tCO_2e$	$/tCO_2e/yr$	$/tCO_2e$	$/tCO_2e/yr$	$/tCO_2e$	$/tCO_2e/yr$
Conserving Forest Reserve from Converting to:													
Cocoa farm	5	169.35	102.99	33.82	-75.12	231.04	803.11	0.29	0.06	0.22	0.04	0.35	0.07
	10	169.35	102.99	63.00	2376.25	2711.59	803.11	3.38	0.34	2.56	0.26	4.14	0.41
	20	169.35	102.99	109.87	6314.88	6697.09	803.11	8.34	0.42	5.36	0.27	11.73	0.59
	30	169.35	102.99	144.75	9245.60	9662.69	803.11	12.03	0.40	6.75	0.23	19.23	0.64
Agroforestry1 (Food crops, Cocoa, Rubber, Coconut, and wetlands)	5	116.70	120.11	252.74	1914.25	2403.80	654.18	3.67	0.73	3.31	0.66	3.97	0.79
	10	116.70	120.11	470.76	5616.19	6323.76	654.18	9.67	0.97	7.84	0.78	11.34	1.13
	20	116.70	120.11	821.05	11564.12	12621.98	654.18	19.29	0.96	13.28	0.66	26.06	1.30
	30	116.70	120.11	1081.70	15989.94	17308.45	654.18	26.46	0.88	15.98	0.53	40.79	1.36
Agroforestry2 (Food crops, Rubber, Coconut, and wetlands)	5	121.27	103.70	252.74	4117.43	4595.14	604.54	7.60	1.52	6.90	1.38	8.17	1.63
	10	121.27	103.70	470.76	8832.72	9528.45	604.54	15.76	1.58	13.07	1.31	18.20	1.82
	20	121.27	103.70	821.05	16408.79	17454.81	604.54	28.87	1.44	20.48	1.02	38.25	1.91
	30	121.27	103.70	1081.70	22046.10	23352.77	604.54	38.63	1.29	24.16	0.81	58.31	1.94
Agroforestry3 with 5 years Fallow (Food crops, Cocoa, Rubber, Coconut, Fallow and wetlands)	5	118.05	120.03	252.74	1914.25	2405.07	631.24	3.81	0.76	3.43	0.69	4.12	0.82
	10	118.05	120.03	470.76	5616.20	6325.04	631.24	10.02	1.00	8.13	0.81	11.75	1.18
	20	118.05	120.03	821.05	9799.98	10859.11	631.24	17.20	0.86	12.04	0.60	23.03	1.15
	30	118.05	120.03	1081.70	12843.08	14162.86	631.24	22.44	0.75	14.07	0.47	33.55	1.12

5. Scaling up results

Scaling up the per hectare level estimated economic values of the selected ecosystem services and the direct on-site REDD+ opportunity costs to the total conservation area in this study enables us to visualize the benefits and opportunity costs of conserving the Ankasa FCA. The per hectare level results were multiplied by the total area of the Ankasa FCA, which is reported to be 52,300 hectares with 34,900 hectares covering the Ankasa Forest Reserve in the south and the remaining 17,400 hectares is the Nini-Suhien National Park in the north.

Table 5.1describes the aggregate values of the selected ecosystem services for the Ankasa FCA. The aggregate value of the selected provisioning services for the conservation area was estimated to be about $ 21.9 million in value with 87.18% accounted by the stumpage value of an estimated 32.8 million m^3 of standing stock of commercial and non-commercial timber trees. The total value of the selected regulating services, which is value of an estimated 64.3 million tCO_2e of carbon stock in biomass and soil, for total conservation area was estimated at about $ 380million of which 78.37% was the value of carbon stock in biomass. When compared with the value of the selected provisioning services, the value of biomass carbon stock as a regulating service was 15.6 times the aggregate stumpage value of the standing stock of trees in the whole conservation area.

The aggregate value of the selected supporting service, which is measured in terms of the replacement cost of soil fertility loss for the three important soil nutrients, is negative. A negative replacement cost implies a benefit. For the nitrogen nutrient, the available nitrogen in the soils of the whole conservation area was larger than the threshold level by estimated 17 thousand tons of nitrogen which was equivalent to same quantity of commercial nitrogen fertilizer worth of $ 1.28 million in value. However, in the case of phosphorous and potassium nutrients, we estimated deficiencies of 0.78 and 9.9 thousand tons respectively for the whole conservation area. This implies that in order to increase the soil phosphorous and potassium contents to the required threshold levels, an estimated $ 0.65 million worth of phosphorus and potassium fertilizers are needed for the whole conservation area.

The other ecosystem service considered in this study was biodiversity in tree species and plant species of non-timber forest product sources. Although spatial scale extrapolation the results of tree species diversity is not possible for technical and practical reasons, one can infer the level of tree species biodiversity reported in this study is the minimum level for the whole conservation area.

In terms of the cultural services, although the conservation area has biological diversity in plants and animal species as well as other features for tourism development, it was underutilized and the level of tourist arrivals was very insignificant.

Table 5-1: Aggregate values of selected ecosystem services of the Ankasa FCA

Ecosystem service	Unit	Total quantity of ecosystem service in million units			Total value of ecosystem service in million $		
		Ankasa Forest Reserve	Nini-Suhien National Park	Total	Ankasa Forest Reserve	Nini-Suhien National Park	Total
Provisioning services					**14.58**	**7.27**	**21.85**
Timber (stock)	m^3	21.89	10.92	32.81	12.71	6.34	19.05
Commercial timber	m^3	6.29	3.14	9.43	5.85	2.92	8.76
Non-commercial timber	m^3	15.60	7.78	23.38	6.87	3.42	10.29
Non timber forest products (flow)		0.00	0.00	0.00	1.87	0.93	2.80
Fuel wood	kg	5.43	2.71	8.13	1.24	0.62	1.87
Wood for local construction	kg	0.50	0.25	0.74	0.38	0.19	0.56
Food	pieces	0.85	0.42	1.27	0.21	0.10	0.31
Medicinal plants	pieces	0.06	0.03	0.09	0.04	0.02	0.06
Regulating services					**253.25**	**126.26**	**379.52**
Carbon (stock)	ton	42.92	21.40	64.33	253.25	126.26	379.52
Biomass carbon	ton	33.64	16.77	50.41	198.48	98.96	297.43
Soil carbon	ton	9.28	4.63	13.91	54.78	27.31	82.09
Supporting services					**-0.43**	**-0.21**	**-0.64**
Replacement costs* of soil fertility loss (stock)	kg	-4.26	-2.12	-6.38	-0.43	-0.21	-0.64
Nitrogen	kg	-11.40	-5.68	-17.08	-0.85	-0.43	-1.28
Prosperous	kg	0.52	0.26	0.78	0.02	0.01	0.03
Potassium	kg	6.62	3.30	9.92	0.41	0.21	0.62
					268.26	**133.75**	**402.01**

*negative value of replacement cost implies benefits.

Table 5.2 describes the aggregate NPV of direct on-site opportunity costs of conserving the whole conservation area. Based on the three discount rates considered, the aggregate NPV of the direct on-site opportunity cost of conserving the whole conservation area for the next 30 years ranges between $ 284 million to $ 1.84 billion with corresponding emission reduction levels of 42 million tCO_2e and 31.6 million tCO_2e respectively as a global public good. This opportunity costs imply that the country will lose $ 9.45 million to 61.45 million per year as direct on-site net benefits forgone due to conserving the whole conservation area. This annual opportunity cost is equivalent to a minimum of 0.02% and maximum of 0.15% of Ghana's Gross Domestic Product (GDP) for the year 2012, which was about $40.71 billion (World Bank, 2012).

Table 5-2: Aggregate NPV of Direct on-site REDD+ Opportunity Cost of Conserving the Ankasa FCA

Land use changes	Total emission reductions in million tCO2e			Discount rate in %	NPV of Opportunity cost in million $ for a period of 30 years		
	Ankasa Forest Reserve	Nini-Suhien National Park	Total		Ankasa Forest Reserve	Nini-Suhien National Park	Total
Cocoa farm	28.03	13.97	42.00	0.00	538.99	268.72	807.71
				3.00	337.18	168.11	505.29
				7.26	189.19	94.33	283.52
Agroforestry1	22.83	11.38	34.21	0.00	931.27	464.30	1395.57
				3.00	604.11	301.19	905.29
				7.26	364.84	181.90	546.73
Agroforestry2	21.10	10.52	31.62	0.00	1230.25	613.36	1843.61
				3.00	815.03	406.35	1221.38
				7.26	509.74	254.14	763.88
Agroforestry3	22.03	10.98	33.01	0.00	739.12	368.50	1107.61
				3.00	494.36	246.47	740.83
				7.26	309.97	154.54	464.50

6. Conclusions and policy implications

This study estimates the economic values of selected ecosystem services of the Ankasa FCA and alternative land uses practices around the conservation areas. Moreover, it gives estimates for the direct on-site REDD+ opportunity costs of conserving the Conservation Area from conversion to four alternative land uses (namely, cocoa farm, Agroforestry1, Agroforestry2, and Agroforestry3), which are representative of existing land use practices by rural communities living around the conservation area. Although our valuation was carried out for selected ecosystem services and the REDD+ opportunity cost analysis is limited to the direct on-site costs, the results of the study are very crucial for designing policies that will reinforce the sustainability of the conservation of the Ankasa FCA and other conservation sites in Ghana. The results of this study could be used as an important input for designing REDD+ projects and programs for the conservation area as well as other potential forest reserves in Ghana. Moreover, sustainability of tropical forest conservation areas require understanding of the level of direct on-site opportunity costs to different stakeholders affected due to assigning a forest as a conservation site. Accordingly, this study has identified the direct opportunity costs to local authorities as well as local communities living around the Ankasa FCA.

According to information from the management plan of the conservation area, the forest was selectively logged until 1976. The conversion of the forest to a conservation area has entailed loss of stumpage revenue to the government. Stumpage revenue from timber harvesting in Ghana is an important source of revenue for local authorities to add on funds from the central government for financing development activities (Damnyag et al., 2011). Therefore, forgoing these revenues due to the conversion of the forest to its present state as a conservation area would imply limited capacity to finance other social and economic development activities which are important for increasing the welfare of the local communities. This study indicated that for continuing the conservation of the Ankasa FCA for the coming 30 years and hence protecting it from conversion to other land uses, the local communities incur a total opportunity cost of as low as 234.94 $/ha and as high as to 273.34 $/ha (Table 4.7) in net present value from forgone stumpage revenues of commercial and non-commercial timber harvesting. This forgone revenue accounts the lowest share, which is about 0.96 to 2.82%, to the total direct on-site opportunity costs of conserving the forest. This is partly due to the fact that stumpage fees in Ghana are administratively set very low (Hansen et al., 2009, Damnyag et al., 2011).

Non timber forest products in tropical countries play an important role in rural livelihood. They serve as source of food and income for subsistence and as a means of income diversification to reduce risks associated with crop failure in the main agricultural activities (Cavendish, 2000; Angelsen and Wunder, 2003; Belcher and Kusters, 2004; Vedeld et al., 2007).This study indicated that conserving the Ankasa FCA for the next 30 years and protecting it from conversion to other land uses imply opportunity costs as low as 144.75 $/ha and as high as 1081.70 $/ha (Table 4.7) in net present value from non-timber forest product use restriction to local communities. These values account 1.5 to 4.63% of the total direct on-site opportunity cost of conserving the conservation area.

Conversion of tropical forests to other land uses is mainly to derive provisioning services like food from crop and livestock production on the converted land. This study indicated that conserving the Ankasa FCA for the next 30 years from conversion to other land uses (cocoa farm, Agroforestry1, Agrofrestry2, and Agroforestry3 (Table 4.7)) imply an opportunity cost of as low as 9245.60 $/ha and as high as 22046.10 $/ha (Table 4.7) in net present values of forgone crop production by local communities. These values account the largest share (about 94.40 to 95.68%) to total direct on-site REDD+ opportunity cost of conserving the conservation area. Thus, in total up to 97% of the opportunity cost of conserving the Ankasa FCA from conversion to any of the alternative land use is incurred by rural communities in terms of the foregone net benefits from crop production and non-timber forest product use restrictions. During the field works for data collection, we have observed that rural communities were residing close to the conservation area and undertake agroforestry practices, mainly cocoa production. From our field observation of the southern part of the conservation area, we did not see a buffer zone that separates the conservation area from the land use practices by rural communities. Establishing a buffer zone is very important for the sustainable management of the conservation area and such an effort, however, should take in to account the opportunity costs that would be lost by the rural communities that have to be displaced for establishing the buffer zone.

Conservation of tropical forests provides global public goods like carbon dioxide emission reduction as a climate regulating ecosystem service and biodiversity as a supporting ecosystem service. This study indicated that the conservation of the Ankasa FCA from conversion to any of the four alternative land uses (namely, cocoa farm, Agroforestry1, Agrofrestry2, and Agroforestry3 (Table 4.7)) could result in emission reductions as low as 604.54 tCO2e/ha to as high as 803.11 tCO2e/ha from carbon stocks in biomass and soils. These levels of emission reductions are the lower bound estimates for the fact that our study did not take into account the carbon sequestration services that the forest is providing. Thus, the direct on-site REDD+ opportunity cost estimated in this study, which are as low as 12.03 $/tCO2e and as high as 38.63 $/tCO2e in net present value at a discount rate of 3% and period of 30 years, could also be lower if we consider the net difference in carbon sequestration services of the conservation area and that of each alternative land use.These REDD+ direct on-site opportunity cost estimates are lower than the 2008 price for carbon market of the EU Emission Trading Scheme, which were running about 35 to 40 $ per tCO_2 and a little higher than the PointCarbon (2011) estimate of global carbon price of $ 35 per tCO_2 for 2020. However, the REDD+ direct on-site opportunity cost estimates for this study are much higher than the REDD+ opportunity cost estimates in the literature. For example, from a review of 29 regional empirical studies, Boucher (2008) found an average REDD+ opportunity cost of 2.51/tCO_2. A conversion of the area based Grieg-Gran's estimate for the Stern (2006) and Eliasch (2008) Reviews to per-ton costs provides a range of $2.67 to $8.28 per tCO_2 (Boucher, 2008). Estimates based on global economic models range from $6.77 to $17.86 with an average of $11.26 per tCO_2 (Kindermann et al., 2008).

The study also indicated that the conservation area is home to more than 108 tree species with a minimum of 5cm and above in diameter and rich in plant species which are important sources of non-timber forest products. Moreover, the soils of the Ankasa FCA contain about an extra 327 kg available nitrogen nutrient per ha than the threshold level reported as indicator of forest soil health. However, both potassium and phosphorous nutrient levels available in the soils of the Ankasa Forest were found to be below the minimum threshold levels.

To sum up, conserving the Ankasa Forest Conservation area until 2042could provide a global public good of emission reduction level of 316 million tCO2e to the minimum at a direct on-site maximum opportunity cost of $ 1.84 billion to rural communities and local authorities in Ghana. The total opportunity cost would be either higher or lower than this for the fact that our estimate did not take into account two main important factors that would affect the value. These are: 1) net difference in carbon sequestration service between the forest conservation area and each of the alternative land use, which is likely to be positive and hence increase emission reduction level above our estimate, and 2) the indirect opportunity costs associated with not converting the conservation area to other land uses were not taken into account in this study, which include for example the value added forgone by all actors in the supply chain of firms using timber as major input in their production process, due to complete restriction of timber logging from the conservation area. Further studies should take the carbon sequestration services and indirect costs associated with conserving the forest as well as the implementation and transaction costs in order to have a complete estimate on the REDD+ costs for sustainable management of forest conservation areas.

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Appendices

Annex A1: Frequency distribution of commercial timber species in the Ankassa Forest Reserve and other five lands uses (cocoa farm, coconut plantation, rubber plantation, fallow land and wetlands) in the Wet Tropical forest zone of Ghana.

Forest Reserve (N= 21)				Other Land uses (N= 25)			
Commercial timber species	**Frequ.**	**%**	**Cumulative %**	**Commercial timber species**	**Frequ.**	**%**	**Cumulative %**
High value timber				**High value timber**			
Khaya ivorensis	3	2.33	2.33	*Milicia excelsa*	1	0.85	0.85
Lovoa trichiloides	1	0.78	3.10				
Milicia excels	1	0.78	3.88				
Medium value timber				**Medium value timber**			
Piptadeniastrum africanum	5	3.88	7.75	*Terminalia ivorensis*	3	2.54	3.39
Ceiba pentandra	1	0.78	8.53	*Ceiba pentandra*	2	1.69	5.08
Low value timber				**Low value timber**			
Drypetes principum	18	13.95	22.48	*Raphia hookeri*	31	26.27	31.36
Funtumia Africana	15	11.63	34.11	*Macaranga barteri*	15	12.71	44.07
Picralima nitida	14	10.85	44.96	*Hallea ledermanni*	14	11.86	55.93
Carapa procera	11	8.53	53.49	*Anthocleista vogelii*	12	10.17	66.10
Greenwayodendron oliveri	8	6.20	59.69	*Ficus sur*	8	6.78	72.88
Strombosia glaucescens	7	5.43	65.12	*Rauvolfia vomitoria*	5	4.24	77.12
Ficus sur	5	3.88	68.99	*Elaeis guineensis*	3	2.54	79.66
Scottellia klaineana	5	3.88	72.87	*Cola nitida*	2	1.69	81.36
Cola nitida	4	3.10	75.97	*Sterculia tragacantha*	2	1.69	83.05
Elaeis guineensis	4	3.10	79.07	*Anthostema aubryanum*	2	1.69	84.75
Hannoa klaineana	4	3.10	82.17	*Cola nitida*	2	1.69	86.44
Martretia quadricomis	4	3.10	85.27	*Macaranga heudelotii*	2	1.69	88.14
Allanblackia parviflora	3	2.33	87.60	*Piptadeniastrum africanum*	2	1.69	89.83
Blighia sapida	3	2.33	89.92	*Raphia palma-pinus*	2	1.69	91.53
Pycnanthus angolensis	3	2.33	92.25	*Symphonia globulifera*	2	1.69	93.22
Anthonotha fragrans	2	1.55	93.80	*Xylopia rubescens*	2	1.69	94.92
Rhodognaphalon brevicuspe	2	1.55	95.35	*Funtumia africana*	1	0.85	95.76
Amphimas pterocarpoides	1	0.78	96.12	*Anthonotha fragrans*	1	0.85	96.61
Antiaris toxicaria	1	0.78	96.90	*Carapa procera*	1	0.85	97.46
Cleistopholis patens	1	0.78	97.67	*Cleistopholis patens*	1	0.85	98.31
Myrianthus arboreus	1	0.78	98.45	*Coelocaryon oxycarpum*	1	0.85	99.15
Panda oleosa	1	0.78	99.22	*Harungana madagascariensis*	1	0.85	100.00
Petersianthus macrocarpus	1	0.78	100.00	**Total**	118		
Total	129						

Annex A2: Volume and Stumpage value of commercial and non-commercial timber species by land cover

Land Use	High value timber		Medium value timber		Low value timber		Total	
	Volume in m^3/ha Mean (SE)	Value in $/ha Mean (SE)	Volume in m^3/ha Mean (SE)	Value in $/ha Mean (SE)	Volume in m^3/ha Mean (SE)	Value in $/ha Mean(SE)	Volume in m^3/ha Mean	Value in $/ha Mean
Off-reserve	0.70 (0.70)	3.49 (3.49)	5.80 (4.66)	6.45 (4.60)	98.78 (39.81)	44.59 (17.78	105.28	54.52
Cocoa farm	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00	5.92 (5.92)	2.61 (2.61)	5.92	2.61
Coconut plantation	0.00 (0.00)	0.00 (0.00)	0.00 (0.00	0.00 (0.00	0.00 (0.00)	0.00 (0.00)	0.00	0.00
Rubber plantation	0.00 (0.00)	0.00 (0.00)	0.00 (0.00	0.00 (0.00	0.00 (0.00)	0.00 (0.00)	0.00	0.00
Fallow	3.51 (3.51)	17.42 (17.42)	6.30 (6.30)	12.29 (12.29)	82.88 (33.52)	36.47 (14.75)	92.69	66.18
Wetland	0.00 (0.00)	0.00 (0.00)	22.67 (22.67)	19.96 (19.96)	405.08 (125.81)	183.85 (54.40)	427.75	425.04

Annex A3: Replacement costs of soil nutrient loss in Ankasa Forest Conservation and Off-reserve land uses

Nutrient Type by land use (n=sample size)	Available nutrient in soil by soil depth in cm (N in %; P in mg/kg; K in mg/kg) (SE)				Available nutrient in Kg/ha	Nutrient loss in kg/ha at Threshold:		Nutrient-fertilizer conversion ratio	Price per nutrient ($/kg) at 0.499 $/kg of fertilizer	Replacement cost ($/ha) at:	
	0-20	20-40	40-60	Average		1: (N=0.1%; P=10 mg/kg; K=100 mg/kg	2: (N=0.2%; P=20 mg/kg; K=100 mg/kg			Threshold1	Threshold2
Forest Reserve (n=21)											
Nitrogen(N)	0.19 (0.02)	0.10 (0.01)	0.05 (0.01)	0.11	2513.92	-326.58	1860.75	0.150	0.075	-24.47	139.41
Phosphorous (P)	3.99 (0.72)	3.15 (0.61)	2.23 (0.49)	3.12	6.89	14.98	36.85	0.066	0.033	0.49	1.21
Potassium (K)	17.71 (1.67)	11.85 (0.98)	10.14 (1.18)	13.24	29.11	80.26	189.62	0.125	0.062	11.79	11.79
Off-Reserve (n=25)											
N	0.20 (0.02)	0.11 (0.01)	0.05 (0.01)	0.12	2651.29	-450.22	1750.85	0.150	0.075	-33.73	131.18
P	4.20 (0.50)	2.98 (0.41)	2.37 (1.46)	3.19	7.00	15.01	37.02	0.066	0.033	0.49	1.21
K	25.93 (5.30)	19.26 (4.19)	10.90 (1.23)	18.70	41.07	68.98	179.03	0.125	0.062	11.13	11.13
Cocoa (n=5)											
N	0.21 (0.00)	0.10 (0.02)	0.06 (0.01)	0.12	3508.80	-702.13	2104.53	0.150	0.075	-52.61	157.68
P	5.75 (1.08)	4.45 (1.46)	9.02 (7.03)	6.41	18.39	9.68	37.75	0.066	0.033	0.32	1.23
K	27.66(12.88)	16.57 (9.65)	13.32 (5.47)	19.19	54.26	86.07	226.41	0.125	0.062	14.08	14.08
Coconut (n=5)											
N	0.18 (0.05)	0.10 (0.01)	0.05 (0.02)	0.12	1904.00	-204.00	1496.00	0.150	0.075	-15.28	112.09
P	3.29 (1.00)	2.43 (0.71)	0.94 (0.48)	3.71	3.73	13.27	30.27	0.066	0.033	0.43	0.99
K	13.19 (3.23)	9.74 (1.48)	8.11 (1.48)	16.55	17.62	67.38	152.38	0.125	0.062	9.47	9.47
Rubber (n=5)											
N	0.20 (0.02)	0.11 (0.02)	0.06 (0.02)	0.11	2375.80	-449.13	1477.53	0.150	0.075	-33.65	110.70
P	5.69 (1.23)	2.92 (0.86)	0.65 (0.35)	5.59	5.92	13.35	32.62	0.066	0.033	0.44	1.07
K	19.68 (3.28)	14.95 (1.04)	12.17 (1.60)	14.36	29.97	66.36	162.69	0.125	0.062	10.11	10.11
Fallow (n=5)											
N	0.22 (0.07)	0.09 (0.01)	0.06 (0.01)	0.12	2995.47	-528.80	1937.87	0.150	0.075	-39.62	145.19
P	2.20 (0.80)	2.07 (0.86)	0.34 (0.26)	3.02	4.00	20.66	45.33	0.066	0.033	0.68	1.48
K	15.22 (2.28)	13.05 (3.08)	11.16 (1.74)	12.51	32.51	90.82	214.15	0.125	0.062	13.31	13.31
Wetland (n=5)											
N	0.21 (0.03)	0.12 (0.06)	0.04 (0.01)	0.13	2480.59	-375.25	1730.08	0.150	0.075	-28.12	129.62
P	4.08 (0.87)	3.05 (0.28)	0.89 (0.39)	1.92	5.49	15.57	36.62	0.066	0.033	0.51	1.20
K	53.90 (19.34)	42.00 (15.91)	9.74 (1.80)	14.11	72.10	33.17	138.43	0.125	0.062	8.61	8.61

Annex A4: Frequency distribution of tree species in 21 plots in Ankasa

Species	Frequency	Percent	Cumulative Percent
Allanblackia parviflora	3	0.70	0.70
Allexis cauliflora	5	1.20	2.00
Amphimas pterocarpoides	1	0.20	2.20
Anthonoth amacrophylla	1	0.20	2.50
Anthonotha fragrans	2	0.50	3.00
Antiaris toxicaria	1	0.20	3.20
Baphia pubescens	3	0.70	3.90
Beilschmiedia mannii	1	0.20	4.20
Berlinia occidentalis	6	1.50	5.70
Berlinia tomentella	1	0.20	5.90
Blighia sapida	3	0.70	6.70
Blighia unijugugata	2	0.50	7.10
Blighia welwitschii	2	0.50	7.60
Buchholzia coriacea	1	0.20	7.90
Calpocalyx brevibracteartus	1	0.20	8.10
Carapa procera	11	2.70	10.80
Cassipourea hiotou	4	1.00	11.80
Ceiba pentandra	1	0.20	12.10
Chidlowia sanguinea	1	0.20	12.30
Chrysophyllum albidum	5	1.20	13.50
Chrysophyllum giganteum	1	0.20	13.80
Cleistopholis patens	1	0.20	14.00
Cola chlamydantha	4	1.00	15.00
Cola gigantean	2	0.50	15.50
Cola lateritia	2	0.50	16.00
Cola nitida	4	1.00	17.00
Coula edulis	5	1.20	18.20
Cynometra ananta	7	1.70	20.00
Dacryodes klaineana	13	3.20	23.20
Daneillia thurifera	6	1.50	24.60
Dialium aubrevillei	4	1.00	25.60
Diospyros kamerunensis	4	1.00	26.60
Diospyros sanza-minika	17	4.20	30.80
Drypetes aylmeri	9	2.20	33.00
Drypetes principum	18	4.40	37.40
Elaeis guineensis	4	1.00	38.40
Enantia polycarpa	1	0.20	38.70
Englerophytum aubanguiense	1	0.20	38.90
Ficus sur	5	1.20	40.10
Funtumia africana	15	3.70	43.80
Garcinia smeathmannii	8	2.00	45.80
Gilbertiodendron bilineatum	5	1.20	47.00
Gilbertiodendron limba	1	0.20	47.30
Gilbertiodendron preussii	6	1.50	48.80
Gilbertiodendron spp	2	0.50	49.30
Greenwayodendron oliveri	8	2.00	51.20
Hannoa klaineana	4	1.00	52.20
Heritiera utilis	10	2.50	54.70
Hexalobus crispiflorus	2	0.50	55.20
Hunteria umbellata	1	0.20	55.40
Hymenostegia gracilipes	2	0.50	55.90
Khaya ivorensis	3	0.70	56.70
Leptaulus daphnoides	2	0.50	57.10
Lovoa trichiloides	1	0.20	57.40
Macaranga heterophylla	1	0.20	57.60
Maesobotrya barteri	3	0.70	58.40
Mammea africana	3	0.70	59.10

Cintinue...			
Maranthes chrysophylla	5	1.20	60.30
Maranthes glabra	2	0.50	60.80
Martretia quadricomis	4	1.00	61.80
Memecylon lateriflorum	1	0.20	62.10
Microdesmis puberula	2	0.50	62.60
Milicia excelsa	1	0.20	62.80
Millettia chrysophylla	1	0.20	63.10
Millettia rhodantha	1	0.20	63.30
Musanga cercropioides	2	0.50	63.80
Myrianthus arboreus	1	0.20	64.00
Myrianthus libericus	1	0.20	64.30
Nawtonia aubrevillei	1	0.20	64.50
Newtonia duparquetiana	1	0.20	64.80
Ouratea calophylly	1	0.20	65.00
Panda oleosa	1	0.20	65.30
Parkia bicolor	1	0.20	65.50
Pentachlethra macrophylla	1	0.20	65.80
Pentadesma butyracea	13	3.20	69.00
Petersianthus macrocarpus	1	0.20	69.20
Picralima nitida	14	3.40	72.70
Piptadeniastrum africanum	5	1.20	73.90
Plieocapa mutica	4	1.00	74.90
Protomegabaria stapfiana	12	3.00	77.80
Pycnanthus angolensis	3	0.70	78.60
Rhodognaphalon brevicuspe	2	0.50	79.10
Sacoglottis gabonensis	1	0.20	79.30
Samanea dinklagei	2	0.50	79.80
Scaphopetalum amoenum	2	0.50	80.30
Scottellia klaineana	5	1.20	81.50
Scytopetalum tieghemii	13	3.20	84.70
Spondianthus preussii	1	0.20	85.00
Strephonema pseudocola	5	1.20	86.20
Strombosia glaucescens	7	1.70	87.90
Strombosia postulata	8	2.00	89.90
Strychnos spp	1	0.20	90.10
Synsepalum afzelii	1	0.20	90.40
Tabernaemontana africana	8	2.00	92.40
Talbotiella gentii	1	0.20	92.60
Tieghemella heckelii	1	0.20	92.90
Tricalysia chevalieri	1	0.20	93.10
Trichilia monadelpha	1	0.20	93.30
Trichocypha albiflora	1	0.20	93.60
Trichoscypha arborea	4	1.00	94.60
Uapaca esculanta	4	1.00	95.60
Uapaca guineensis	5	1.20	96.80
Vepris soyauxii	1	0.20	97.00
Vitex micrantha	3	0.70	97.80
Vitex rivularis	1	0.20	98.00
Voacanga tabernaemontana	2	0.50	98.50
Warneckia guineese	5	1.20	99.80
Xylopia staudtii	1	0.20	100.00
Total	406	100.00	

Annex A4: Frequency distribution of tree species in 25 plots in the off-reserve land uses around the Ankasa Forest

Species	Frequency	Percent	Cumulative Percent
Aidia genipiflora	1	0.30	0.30
Anthocleista nobilis	8	2.30	2.60
Anthocleista vogelii	12	3.50	6.10
Anthonotha fragrans	1	0.30	6.40
Anthostema aubryanum	2	0.60	6.90
Carapa procera	1	0.30	7.20
Cecropia peltata	3	0.90	8.10
Ceiba pentandra	2	0.60	8.70
Ceropia peltata	7	2.00	10.70
Cleistopholis patens	1	0.30	11.00
Cocos nucifera	32	9.20	20.20
Coelocaryon oxycarpum	1	0.30	20.50
Cola nitida	4	1.20	21.70
Daneillia thurifera	1	0.30	22.00
Elaeis guineensis	3	0.90	22.80
Ficus sur	8	2.30	25.10
Funtumia africana	1	0.30	25.40
Hallea ledermanni	14	4.00	29.50
Harungana madagascariensis	1	0.30	29.80
Hevea brasiliensis	73	21.10	50.90
Macaranga barteri	15	4.30	55.20
Macaranga heterophylla	3	0.90	56.10
Macaranga heudelotii	2	0.60	56.60
Macaranga hurifolia	3	0.90	57.50
Macranga barteri	1	0.30	57.80
Maranthes glabra	1	0.30	58.10
Milicia excels	1	0.30	58.40
Musanga cercropioides	15	4.30	62.70
Piptadeniastrum africanum	2	0.60	63.30
Raphia hookeri	31	9.00	72.30
Raphia palma-pinus	2	0.60	72.80
Rauvolfia vomitoria	5	1.40	74.30
Spathodea campanulata	1	0.30	74.60
Sterculia tragacantha	2	0.60	75.10
Symphonia globulifera	2	0.60	75.70
Terminalia ivorensis	3	0.90	76.60
Tetrorchidium didymostomon	2	0.60	77.20
Theobroma cacao	77	22.30	99.40
Xylopia rubescens	2	0.60	100.00
Total	346	100.00	

Annex A5.1: Frequency distribution of plant species of Non-Timber Forest Product in a total of 18 circular sample plots (r=4m; area = 500 m2 per plot) taken from the Ankasa Forest Reserve of Wet Tropical Forest of Ghana

Use as a NTFP	Species	Frequency	Percent	Cumulative
Medicinal	*Acridocarpus longifolius*	2	0.50	0.50
	Guarea cedrata	1	0.25	0.75
	Khaya ivorensis	15	3.76	4.51
	Landolphia owariensis	10	2.51	7.02
	Sphenocentrum jollyanum	118	29.57	36.59
	Uapaca guineensis	2	0.50	37.09
Food	*Allanblackia parviflora*	10	2.51	39.60
	Chrysophyllum albidum	99	24.81	64.41
	Cola lateritia	1	0.25	64.66
	Dacryodes klaineana	5	1.25	65.91
	Elaeis guineensis	9	2.26	68.17
	Myrianthus arboreus	1	0.25	68.42
	Reneaimia bettenbergiana	2	0.50	68.92
	Sphenocentrum jollyanum	7	1.75	70.68
	Uvariodendron angustifolium	2	0.50	71.18
Medicinal and Food	*Cola nitida*	6	1.50	86.72
	Piper guineense	9	2.26	88.97
	Raphia hookeri	2	0.50	89.47
	Xylopia aethiopica	1	0.25	89.72
Construction and ornamental	*Ancistrophyllum opacum*	10	2.51	73.68
	Ataenidia conferta	6	1.50	75.19
	Cercetis afzelii	4	1.00	76.19
	Diospyros kamerunensis	2	0.50	76.69
	Eremospatha hookeri	13	3.26	79.95
	Eremospatha macrocarpa	5	1.25	81.20
	Hypselodelphys poggeana	1	0.25	81.45
	Maesobotrya barteri	1	0.25	81.70
	Myrianthus arboreus	1	0.25	81.95
	Strombosia glaucescens	13	3.26	85.21
Other uses (resin, fodder, ...)	*Baphia nitida*	7	1.75	91.48
	Baphia pubescens	1	0.25	91.73
	Cissus producta	5	1.25	92.98
	Napoleonaea vogelii	14	3.51	96.49
	Olyra latifolia	3	0.75	97.24
	Sphenocentrum jollyanum	11	2.76	100.00
	Total	399	100.00	

Annex A5.2: Frequency distribution of plant species of Non-Timber Forest Product in a total of 10 circular sample plots (r=4m; area = 500 m2 per plot) taken from five land uses (cocoa farm, coconut plantation, rubber plantation, fallow land, and wetland) outside of the Ankasa Forest Reserve of Wet Tropical Forest of Ghana

Use as a NTFP	Species	Frequency	Percent	Cumulative
Medicinal	*Acridocarpus longifolius*	4	0.57	0.57
	Aframomum stanfieldii	260	37.30	37.88
	Alchornea cordifolia	14	2.01	39.89
	Alstonia boonei	2	0.29	40.17
	Anthocleista nobilis	28	4.02	44.19
	Anthocleista vogelii	6	0.86	45.05
	Baphia nitida	36	5.16	50.22
	Carpolobia lutea	1	0.14	50.36
	Chromlaena odorata	219	31.42	81.78
	Elaeis guineensis	9	1.29	83.07
	Ficus sur	10	1.43	84.51
	Hoslundia opposita	1	0.14	84.65
	Mareya micrantha	1	0.14	84.79
	Microdesmis puberula	1	0.14	84.94
	Milicia excels	3	0.43	85.37
	Ocimum gratissimum	2	0.29	85.65
	Rauvolfia vomitoria	31	4.45	90.10
	Secamone afzelii	1	0.14	90.24
	Solanum erianthum	5	0.72	90.96
Food	*Cnestis ferruginea*	1	0.14	91.10
	Cola caricifolia	1	0.14	91.25
	Elaeis guineensis	17	2.44	93.69
	Manihot esculenta	2	0.29	93.97
	Musa acuminata	3	0.43	94.40
Medicinal and Food	*Bombax buonopozense*	1	0.14	98.71
	Psidium guajava	4	0.57	99.28
	Solanum tolvum	1	0.14	99.43
Construction and ornamental	*Hypselodelphys poggeana*	1	0.14	94.55
	Nauclea diderrichii	1	0.14	94.69
	Raphia hookeri	27	3.87	98.57
Other uses (resin, fodder, ...)	*Baphia nitida*	4	0.57	100.00
	Total	697	100.00	

Annex A6: Crop output, farm gate value, input costs and net income from mixed crop farming system on farm household plots around the Ankasa forest reserve in wet tropical forest areas of western Ghana.

Major crops	N	Total area in ha	Season (I=main, II=second)	Output: Mean (SE)		Input costs: Mean (SE)			Net income in $/ha
				Quantity in Kg/ha	Farm gate value in $/ha	Hired labour In $/ha	Fertilizer In $/ha	Herbicides and pesticides in $/ha	
Cocoa	64	306.15	I	447.90 (68.94)	496.09 (44.64)	11.21 (2.05)	1.27 (0.15)	74.15 (20.60)	409.47 (46.38)
	64	306.15	II	274.83 (74.66)	239.67 (39.36)	8.38 (1.54)	0.86 (0.22)	37.46 (5.46)	192.98 (39.44)
	64	**306.15**	**Sum**	**722.73 (128.21)**	**735.76 (78.23)**	**19.58 (3.23)**	**2.12 (0.28)**	**111.61 (23.68)**	**602.45 (79.01)**
Cassava	38	56.86	I	2452.10 (577.68)	747.19 (209.34)	19.24 (3.79)	3.20 (2.79)	23.29 (10.40)	701.47 (211.24)
	38	56.86	II	1014.30 (239.12)	330.96 (91.28)	8.45 (2.42)	0.13 (0.08)	4.79 (3.65)	317.59 (90.70)
	38	**56.86**	**Sum**	**3466.40 (673.68)**	**1078.20 (257.92)**	**27.69 (5.80)**	**3.33 (2.78)**	**28.07 (10.74)**	**1019.10 (259.31)**
Other crops	41	135.77	I	2021.10 (524.28)	987.40 (317.18)	22.57 (4.39)	0.21 (0.09)	4.69 (2.25)	959.93 (315.88)
	41	135.77	II	594.97 (206.01)	358.26 (112.22)	25.01 (11.38)	0.09 (0.05)	4.80 (2.25)	328.36 (111.57)
	41	**135.77**	**Sum**	**2616.10 (674.94)**	**1345.70 (380.15)**	**47.58 (13.13)**	**0.30 (0.11)**	**9.49 (4.09)**	**1288.30 (274.47)**
Aggregate	143	498.79	I	1431.60 (227.93)	703.68 (108.89)	16.60 (1.89)	1.48 (0.74)	40.72 (9.94)	644.89 (109.35)
	143	498.79	II	563.12 (95.60)	297.93 (43.84)	13.16 (3.43)	0.45 (0.11)	19.41 (3.02)	264.91 (43.74)
	143	**498.79**	**Sum**	**1994.70 (285.33)**	**1001.60 (134.03)**	**29.76 (4.39)**	**1.92 (0.75)**	**60.13 (11.67)**	**909.79 (133.53)**