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Determination of Conservation Benefits and Carbon Sequestration Potential of the Simien Mountains National Park, Ethiopia

Population, Health and Environment Ethiopia Consortium (PHEEC)

By Habtamu Assaye
Lecturer, Bahir Dar University

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List of tables

List of figures

Table of Contents

ACRONYM

AAGL	Afro-alpine Grassland
AAWL	Afro-alpine Woodland
AGB	Above Ground Biomass
AMF	Afro-montane Forest
BGB	Below Ground Biomass
C	Carbon
CDM	Clean Development Mechanism
CO	Carbon Monoxide
COP	Conference of Parties
CO_2	Carbon Dioxide
CRGE	Climate Resilient Green Economy
DBH	Diameter at Breast Height
EPRDF	Ethiopian People's Revolutionary Democratic Front
EWCA	Ethiopian Wildlife Conservation Authority
GHG	Greenhouse Gas
GMP	General Management Plan
Gt	Giga ton
HFC	Hydro-floro-carbons
IBA	Important Bird Area
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
NH_3	Amonia

NMVOC	Non-Methane Organic Volatile Compounds
NO_x	Nitrogen Oxides
N_2O	Nitrous Oxide
PFC	Per-floro-carbons
PHEEC	Population, Health and Environment Ethiopia Consortium
PIN	Project Idea Note
REDD	Reducing Emission from Deforestation and Forest Degradation
SMNP	Simien Mountains National Park
SOC	Soil Organic Carbon
tCO2e	Ton Carbon dioxide Equivalent
UNEP	United Nations Environmental Program
UNESCO	United Nations Education, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Voluntary Carbon Standard

Executive summary

This study has attempted to assess carbon stock and carbon dioxide sequestration potential of Simien Mountains National Park (SMNP) in the context of underlying the roles of the park in climate change mitigation and their general conservation benefits for sustainable development. The park is very important conservation area for diverse and unique wildlife resources. SMNP has different layers of narrow ecological zones that provide unique habitat to rare and endemic fauna and flora. The park has tremendous environmental role to mitigate climate change and its impact in the surrounding areas. It has huge role in hydrological regulation, soil and water conservation and prevention of flood and siltation. It is also important ecotourism destination and provide different products like fuel wood and grass that surrounding communities are highly depending on. It is also important for education and scientific investigation purposes. However, the park is under intense anthropogenic pressure for agricultural land expansion, wood extraction, and grazing and settlement purposes. Population growth, expanding development projects like road and electric transmission lines in the nearby areas have increased the pressure on the park.

The landscape of SMNP was stratified into four different zones based on the vegetation ecology and land uses as Afro-alpine grassland (AAGL), Afro-alpine woodland (AAWL), Afro-montane forest (AMF) and cultivated and overgrazed land (CL). 40 sample plots were taken (10 plots from each zone). Inventory techniques used were in accordance with the IPCC 2006 Good Practice Guide. Nested plot design with maximum size of 50m*50m and subplots of 20m*20m, 10m*10m, 5m*5m, 2m*2m and 1m*1m was used for the measurement of trees above 30cm DBH (Diameter at Breast Height), 10 to 30cm DBH, 5 to 10 cm DBH, 2 to 5cm DBH, regeneration and undergrowth and litter sampling, respectively. DBH and heights were measured for all trees above 5cm DBH, height was measured and number counted for trees of DBH 2 to 5cm. Regeneration was counted and undergrowth weighed and sample of known weight was taken in the 2m*2m subplots. DBH and length of dead wood had been measured, corresponding volume calculated and biomass carbon was determined. Soil sampling was done at the four corners of the 10m*10m subplots to a depth of 30cm using soil auger, soil weight had been measured and one composite sample was taken. Dry matter weight of the undergrowth and SOC content were determined in the laboratory. Allometric equation was used for determination of

AGB carbon (Chave *et al.*, 2005). BGB carbon was determined from AGB carbon using a conversion factor of 0.24. Land cover change was analyzed using satellite images of different periods. In addition field observation and secondary sources were used for identifying general conservation benefits and derivers of deforestation. Shannon Wiever diversity index was used to determine tree species diversity, and the index was correlated with carbon stock.

Although undergoing through rapid deforestation and forest degradation, the park is still important in terms of carbon stock and carbon dioxide sequestration. SMNP has a carbon stock of **4,239,804 tons**, which has a carbon dioxide equivalent of **15,546,091 tons** and corresponding carbon finance value of **US$62,184,364**.

High biodiversity was found in the afro-montane forest zone of the park which has the biggest carbon stock. However, within the afro-montane forest zone, tree species diversity was negatively related with carbon stock. While in the afro-alpine woodland zone of SMNP, there is no clear relationship among the carbon stock and tree species diversity. The AGB together with Soil constitute over 95% of the total carbon stock. Therefore, carbon management is directly related with the forest management and soil conservation.

The carbon balance between emission and sequestration indicated that the park is currently net source of carbon. The amount of carbon stock and ongoing deforestation rates indicated high potential for REDD+ project to be feasible in the SMNP. In addition to reducing emission from deforestation, REDD+ will have many more added benefits that justify the role of REDD+ for SMNP.

1. Introduction

Climate change has appeared to be a global issue as it poses threat to the sustainable development and life of the global society now and in future. As big the threat that climate change incurs, the global community, including politicians, scientists and different organizations, are putting efforts of their capacity to avert the trend. The concern of climate change has begun during the early 1970's, when the gradual increase of accumulation of carbon dioxide and other greenhouse gases in the atmosphere has been apparent. The rate of change in the atmospheric green house gas accumulation and consequent effects of climate change have been, however, very dramatic in the last four decades, during which the highest average global temperature, rapid glacial retreats and snow melts, frequent droughts, unprecedented flooding and tsunami have been registered (IPCC, 2007).

The primary cause of accumulation of green house gas emissions in the atmosphere is due to massive expansion of industrialization (mainly in the developed world) that uses fossil fuels which have been deposited under the earths' crust for millions of years. As a result, the natural balance of carbon dioxide sequestration and release that takes place between sink and sources has been disturbed, and the annual global net emission exceeds the annual sequestration resulting in unnatural gradual accumulation of green house gases in the atmosphere and consequently causing climate change.

Since the atmosphere and global climatic condition is shared resource of the global community, it concerns every individual and society regardless of state of development, political orientation or location on any corner of the planet. Recognizing the global nature of the problem, the United Nations, has taken the leading role and established different organizations that govern the negotiation of climate change issue by its member countries starting from the early 1970's. United Nations Environmental Program (UNEP) has been established in 1972 which is mandated *"to be the leading global environmental authority that sets the global environmental agenda, that promotes the coherent implementation of the environmental dimensions of sustainable development within the United Nations system and that serves as an authoritative advocate for the global environment"*.

UNEP has taken a prominent step in 1992 when it organized the United Nations Framework Convention on Climate Change (UNFCCC), also called the Earth Summit, in Rio Dejenero. Although the treaties of this summit were not legally binding, it elevated the awareness of climate change across global leaders and the concern has become more sensitive ever. This summit has also laid the establishment of the framework (UNFCCC), through which, conference of parties (COP) annual meetings are arranged starting from 1995 and assess progresses made in the negotiations. Specific binding protocols are also developed starting from the Kyoto Protocol (KP) in 1997.

UNEP has also established the Inter Governmental Panel on Climate Change (IPCC) in 1988. The IPCC produces reports that support the United Nations Framework Convention on Climate Change (UNFCCC), which is the main international treaty on climate change. Recent COP meetings; COP 15 of Copenhagen, COP 16 of Cancun, COP 17 of Durban and COP 18 of Doha have strengthened the collective global action on climate change. However, during COP 17 and COP 18 meetings, it was noted that the effort being made to hold global warming below 2 or 1.5^0C relative to the pre-industrial levels is inadequate.

The focus of the different negotiations and treaties made by global leaders and different organizations is to reduce carbon dioxide emissions, mainly that emitted by the developed world and develop different climate change adaptation and mitigation mechanisms that can reduce the effect of climate change on the sustainable development and existence of global community. The tradeoff made among parties in the international negotiations is to seek a mechanism that enable to bring reductions in global emission and at the same time provide opportunities for sustainable development for developing countries. Among other mechanisms, Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Forest Degradation (REDD+) are particularly arranged to meet double objectives of emission reduction and sustainable development by generating certified emission reduction units that can be brought into the international carbon trading systems.

REDD+ particularly focuses on reduction of emissions from deforestation and forest degradation of natural forests which were not included in CDM and at the same time promotes conservation of natural forests in protected areas and outside protected areas. In addition, it promotes conservation and sustainable management of forests and generates financial incentives for improving livelihood of local communities. Hence REDD+ is an opportunity to better manage and improve status of protected areas in developing countries. Included in the REDD+ scheme are five basic pillars.

- Sustainable forest management
- Reduce deforestation
- Reduce forest degradation
- Growth enhancement through assisted regeneration
- Conservation of forests to maintain their carbon stock

To be included in any of the carbon markets through any mechanism, it requires a project based approach that enables to justify new approaches of management that is different from the business-as-usual scenario. To enable to trace amount of emission reductions brought as a result of the new project, reference level emissions of the business as usual approach have to be clearly presented and emission reductions have to be assessed clearly and quantitatively. This requires conducting standard carbon assessments and modeling in temporal and spatial dimensions. Carbon assessments in protected areas include assessment of carbon in above ground biomass (AGB), litter and undergrowth, below ground biomass (BGB) and soil organic matter.

Ethiopia, being party to the United Nations Environmental Program and signatory to its treaties and protocols, is striving to contribute to the international effort of climate change adaptation and mitigation. It has also adjusted its development strategy aiming at meeting net zero emissions by 2025 and developed climate resilient green economy (CRGE) strategy. In addition, the country has made good progress in building institutions that lead the national REDD+ projects. The rate of forest degradation in the country is very high and if properly implemented REDD+ will play vital role in curbing the situation and contributing to the global emission reduction efforts.

Simien Mountains National Park is an internationally gazetted national park of Ethiopia. This park harbors unique but threatened wildlife and have rich ecological, economical, cultural and scientific significance to be conserved. However, the value of the park has declined in recent years due to high rate of human encroachment and effect of climate change. There is rapid rate of deforestation and forest degradation due to increasing demand of resources from the surrounding communities. The management of these protected areas has traditionally been oriented in meeting conservation values. Under the current circumstances, however, the two parks have huge potential to play in climate change mitigation through reducing emission from deforestation and forest degradation and also through the additional sequestration of enhanced regeneration when better management approach is in place. The carbon stock potential of the park has been assessed before (Vrewgdenhil *et al.*, 2012). Despite estimating the total carbon stock, this study has not made any projection of the business-as-usual scenario (BAU), and did not put potential emission reductions from the two parks for upcoming projects. This study, however, provided initial data for the development of project idea note (PIN) for Ethiopian Wildlife Conservation Authority (EWCA), a proponent, to put the two parks in the list of REDD+ project areas in the country. To make those efforts fruitful, and strengthen the claim of the park for REDD+ projects, more work is required to quantify carbon stock, trends, distribution among the different pools and projections in the future both for the BAU and potential project scenarios. The carbon obtained through reduced emission and added sequestration when included under the REDD+ schemes will significantly contribute to the management of the park and improving livelihood of surrounding communities.

Assessment of carbon stock and monitoring amount of emission reductions from reduced deforestation and forest degradation requires resources, expertise and commitment of all relevant stakeholders. As a result, sound carbon assessments that build the win capacity of projects in protected and outside protected areas for REDD+ schemes are by large lacking. As esteemed partner to the park, and as important player in environment, population and health aspects in the country in general, Population, Health and Environment Ethiopia Consortium (PHEEC), is working towards building capacities of SMNP for climate change adaptation, mitigation and resilience. The current initiation to determine conservation benefits and carbon sequestration potential of SMNP, will indeed contribute to assessing future progresses and monitoring emission reductions and building climate change adaptation and mitigation capacities.

1.1 Objectives

The main objective of the study is to estimate the carbon sequestration potential value of Simien Mountains National Park (SMNP) in order to provide technical advice for decision makers that justify the conservation and protection of the parks ecosystems as a mechanism to mitigate and adapt to climate change.

Specific objectives,

- Identify and assess the value and benefits of the conservation of SMNP from a climate change mitigation and adaptation point of view taking into consideration economic, social and environmental factors,
- Assess the role of SMNP in carbon sequestration and storage, and identify factors affecting carbon stock potential of these parks;
- Determine carbon stock potential (including aboveground, belowground and soil), of SMNP, as well as potential greenhouse gas emissions from the destruction and degradation of the habitat;
- Calculate the total carbon finance value of the SMNP under REDD+
- Prepare a report detailing the findings of the study as listed above including methodologies and models used.

2. Description of Simien Mountains National Park

SMNP is located in the northern part of Ethiopia, North Gondar Zone of the Amhara Regional State. It is situated along the Gondar Mountain Massifs that include seven mountain peaks, and among which reaches Mount Ras Dejen, 4620 m.a.s.l, is the highest peak in the area as well as in the country. The park has an area of 412 km^2. Geographically situated around 13° 11'N, 38° 04'E, having the head quarter at Debark, which is 886 km away from the capital Addis Ababa and 123 km from the city of Gondar. The park is surrounded by six Woredas. Based on the elevation differences, the climatic condition within the park ranges from woina dega at lower altitude (1500 – 2400 meters above sea level) to wurch zone at the upper elevations (above 3700 meters above sea level). High-dega and temperate climate zones are found in between the two. Approximately 75% of precipitation in the area falls between June and September as predominantly hail, rain and mist resulting in a mean annual rainfall of 1550mm. Temperatures are relatively consistent throughout the year, however there are large diurnal fluctuations ranging from a minimum of -2.4-4°C at night to a maximum of 11-18°C during the day (GMP 2009, Busby *et al.* 2006, Julia 2005; Falch and Keiner 2000, Friis and Wollensen, 1984).

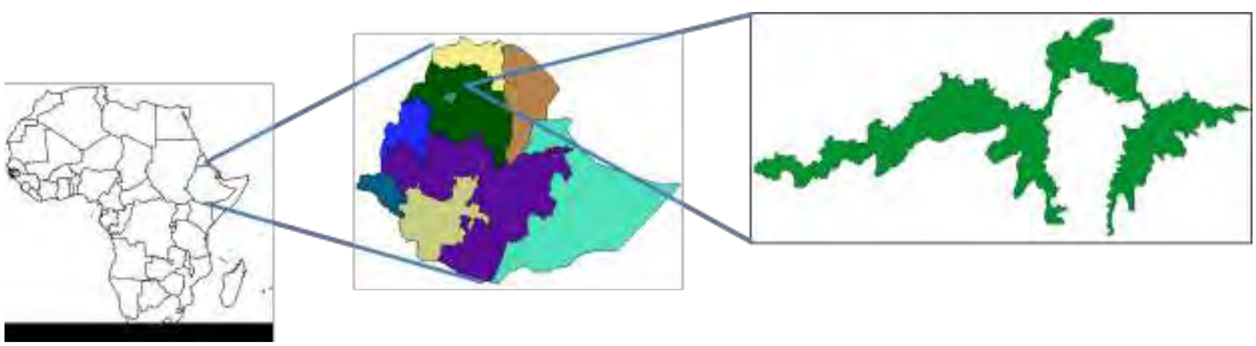

Figure 1: Geographical location and map of Simien Mountains National Park

SMNP was established in 1966 and officially gazetted in 1969 for its rich of rare and endemic wildlife species, diverse fauna and flora composition and for the beauty of its spectacular landscape and unique scenery. The park was inscribed in the World Heritage List for fulfilling criterion III (exceptional beauty) and criterion IV (importance for biodiversity) in 1978. SMNP is the first natural World Heritage Site inscribed in Ethiopia. The civil war in the 1980s has drastically affected the park management and resulted in expansion of settlement inside and around the park. Consequently, wild animal population has reduced rapidly; habitat fragmentation and blocking of ecological corridors have threatened some of the rare and endemic species to extinction. The park is then categorized under the World Heritage in danger list in 1996. UNESCO has set four benchmarks, based on recommendation of the monitoring mission, to be achieved so that the park will be removed from the World Heritage in danger list (Guy *et al.* 2006). These bench marks were:

(1) Realignment of the park's boundary to exclude the villages along the boundary;

(2) Extension of the park to include at least Mesarerya and Lemalimo Wildlife Reserves;

(3) Significant and sustainable reduction in the human population density within the park, especially within the core area;

(4) Effective conservation within the extended national park of a larger population of Walia ibex and Ethiopian wolf.

Efforts are being made by different actors to fulfill the UNESCO benchmarks and finally improve the status and values of the park. However, the joint UNESCO/IUCN mission after the 29th World Heritage Committee meeting in 2004, has found that significant progresses have been made in benchmarks 1, 2 and 4, and there was no progress in benchmark 3. This mission proposed four revised benchmarks to remove the property out of the List of World Heritage in Danger (Guy *et al.* 2006). These are:

''(1) Finalize the extension of SMNP to include the Silki Yared – Kidus Yared Mountains and the Ras Dejen Mountain with the interlinking corridors;

(2) Re-gazetment of the new park boundaries, including the extensions of Lemalimo, Mesarerya, the Silki Yared – Kidus Yared Mountains and the Ras Dejen Mountain as well as the realignment of the boundary to exclude certain villages;

(3) Develop a strategy and action plan, as part of the planned management plan revision, to significantly reduce the impact of livestock grazing on the conservation of the property by introducing "no grazing" and "limited grazing" zones based on ecological criteria and by setting up a strict management regime in zones where grazing will still be tolerated in the short to medium term, and secure funding for its implementation;

(4) Develop a strategy and action plan as part of the management plan to support the development of alternative livelihoods for the people living within the park as well as its immediate vicinity, in order to limit in the medium term their impact on the natural resources of the property, and secure funding for its implementation.''

In view of improving the park management to fulfill these benchmarks and finally remove the park from the List of World Heritage in Danger, the park has developed a 10 year General Management Plan (GMP) for the period 2009-2019, and is striving to achieve its mission in the stated period. The GMP included five management programs which enable to address those bench marks and improve the status of the park (GMP 2009-2019). These are;

1. Ecological Management Programme
2. Settlement Management Programme
3. Park Operations Programme
4. Tourism Management Programme
5. Outreach Programme

Despite the great progress made so far, the park is still under the List of World Heritage in Danger and there remains so much to do to improve its status.

3. Climate change and its causes

Climate change has now been proved by scientific evidences and unequivocally accepted by the global community as a common issue of interest. Since the industrial revolution, the burning of fossil fuels and the destruction of forests have caused the concentrations of heat-trapping green house gases to increase significantly in our atmosphere, at a speed and magnitude much greater than natural fluctuations would dictate. If concentrations of greenhouse gases in the atmosphere continue to increase, the average temperature at the Earth's surface will increase from 1.8 to 4 ^{O}C above 2000 levels by the end of this century (IPCC 2007).

Impacts of climate change, many of which have already been seen, include temperature increase, sea level rise, melting of glaciers and sea ice, increased coral bleaching, changes in the location of suitable habitat for plants and animals, more intense droughts, hurricanes and other extreme weather events, increased wildfire risk and increased damage from floods and storms. People living in marginal poverty- stricken areas are most at risk of being severely and negatively impacted by climate change, as their livelihoods are closely tied to ecosystems which provide water for drinking, wildlife for hunting, fishing and medicinal plants. The impact of climate change is particularly more sever in tropical ecosystems where there are diverse but fragile ecosystems.

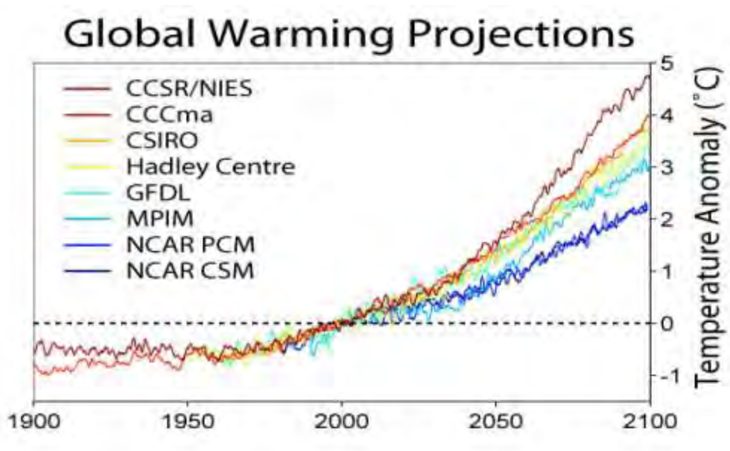

Figure 2 Global temperature projections indicating unusual increase in the atmospheric temperature

3.1 Green house gases and climate change

Guided by the UN Framework Convention on Climate Change (UNFCCC), global leaders have started global negotiations aiming at 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (IPCC, 2007, UNFCCC, 2000). The first major attempt to curb or at least stabilize greenhouse gas (GHG) emissions was made with the Kyoto Protocol in 1997, the first commitment period which has ended in 2012.

Key GHGs:

The Kyoto protocol (KP) has identified six GHGs and put targets of reduction of those GHGs for the first commitment. To enable achieve those targets, KP has identified developed countries which are the main emitters as annex 1 countries, and less developed countries which have insignificant contribution to the global emission, but have a shared responsibility, as non-annex 1 countries. As stated by the KP, the six GHGs are carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Sulfur hexafluoride (SF_6), Hydro-floro-carbons (HFC) and Per-floro-carbons (PFC).

i) Carbon dioxide (CO_2): uptake through plant photosynthesis, release via respiration, decomposition and combustion of organic matter

ii) Nitrous oxide (N_2O): primarily emitted from ecosystems as a by-product of nitrification and de-nitrification

iii) Methane (CH_4): emitted through methanogenesis under anaerobic conditions in soils and manure storage, through enteric fermentation, and during incomplete combustion while burning organic matter.

However, there are other gases that directly or indirectly contribute to greenhouse gas accumulation in the atmosphere, although their contribution is relatively too small. These gaseous compounds include Nitrogen oxides (NO_X), Ammonia (NH_3), non-methane organic volatile compounds (NMVOC) and Carbon monoxide (CO) (precursors for the formation of GHG in the atmosphere).

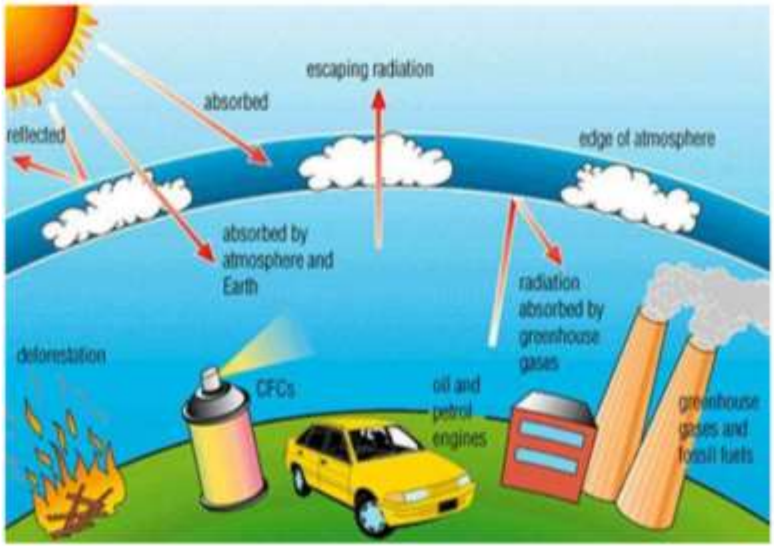

Figure 3 Greenhouse gas effect

Table 1 Major greenhouse gases and their contribution to global warming (adopted from UNFCCC, 2000: IPCC, 2007, UNEP, 2012)

GHG	Main sources	% sources	Contribution to global warming	Share of Annex 1 countries
CO_2	- Fossil fuel - Industrial processes	95% 5%	60-70%	82%
CH_4	- Fossil fuel - Agriculture - Waste	33% 33% 33%	21-22%	12%
N_2O	- Agriculture - Fossil fuel - Industrial processes	40 25 35	6-7%	4%
HFCs, PFCs, SF_6	- Industrial processes		<1	2%

3.2. How GHGs contribute to global warming?

There are two scientific opinions towards the ultimate impact of accumulation of GHGs to the atmospheric temperature, global cooling and global warming. Scholars that support global cooling justify that although the atmosphere shows temporal warming trend, accumulation of GHG will gradually act as reflectance to the solar radiation before interring to the atmosphere and hence global cooling will be the ultimate fate of the global atmosphere. However, the widely accepted opinion is global warming, which is justified by the fact that most of the solar radiation that comes from the sun is in the form of shortwave radiation which has the capacity to penetrate the GHGs layer. Part of this radiation is reflected back from the earth's surface to the outer space in the form of long wave radiation. When the amount of GHGs in the atmosphere increases, the reflected long wave radiation cannot penetrate the atmosphere and instead will be absorbed by the GHGs which then increase the global temperature. The trend of GHGs accumulation and global temperature records in the past and related future projections generally prove global warming. Different studies have proved that global warming is indeed an ongoing reality, and average warming, across all scenarios, is estimated 0.2°C per decade.

Global carbon stock balance

The total global carbon stock is distributed in different forms of reserves. Carbon is normal found in diverse forms (in living things, air, water bodies, rocks etc.), in different forms of organic and inorganic compounds. The natural global carbon stock in the different carbon reserves is estimated as (Canadell *et al.* 2007);

- Carbonated rocks 65,000,000 Gt
- Fossil fuel reserves 4,000 Gt
- Deep ocean 38,000 Gt
- Surface ocean 1,020 Gt
- Terrestrial ecosystems 2,070 Gt (vegetation 610 Gt, soils 1,400 Gt & litter 60 Gt)
- Atmospheric ecosystem 750 Gt

While the natural carbon stock in the atmosphere is estimated as 750 Gt, there is a gradual increase of over 3Gt carbon per annum as indicated in Figure 3. This unnatural shift of the carbon stock from the terrestrial ecosystem to the atmosphere is the main reason for climate change and related chaos on the environment, terrestrial and aquatic ecosystems, temporal socioeconomic disturbances and threats to the long term existence of humans and other living things on the planet.

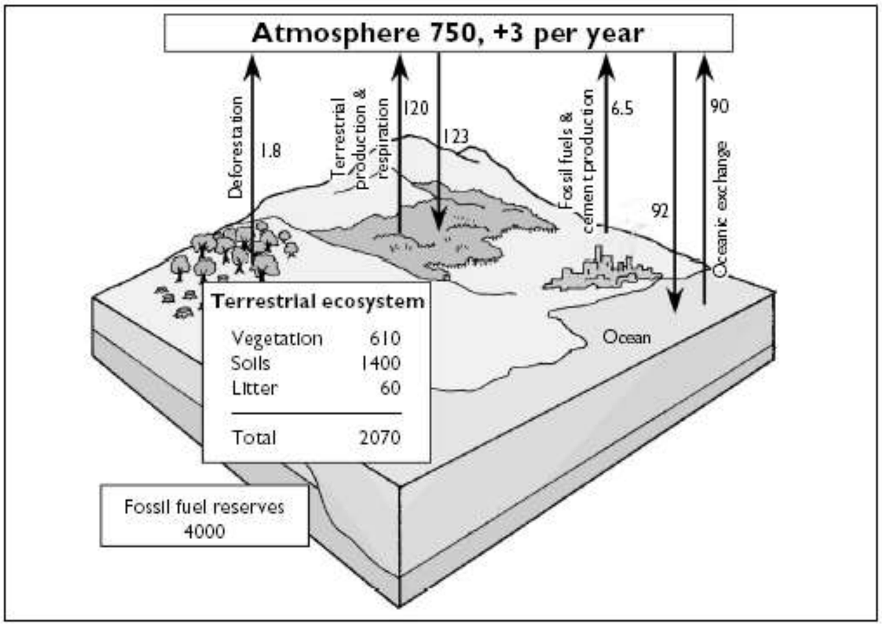

Figure 4: Carbon dynamics between the terrestrial ecosystems and their atmosphere (Canadell *et al.,* 2007)

Terrestrial ecosystem carbon pool

From the global carbon reserves, fossil fuel and the terrestrial ecosystem are currently primary sources of carbon that is released to the atmosphere as other reserves are not easily accessible. Carbonated rocks, although they are the biggest carbon reserves, only coal is being used as source of energy and are technically difficult to be easily accessed and converted into energy. The terrestrial carbon stock is distributed in three basic pools as vegetation (aboveground and belowground), soil (as SOC) and litter (Figure 4). Unlike fossil fuels, terrestrial ecosystems naturally serve as both source and sink to carbon, though generally it is regarded as net sequester as there is more annual sequestration than emission (release) of carbon. However, the increasing rate of deforestation, particularly that in the tropics is leveling the carbon flux of the terrestrial ecosystem, and if this continues the rate of emission may surpass the rate of sequestration aggravating the climate change problem to a point of no return.

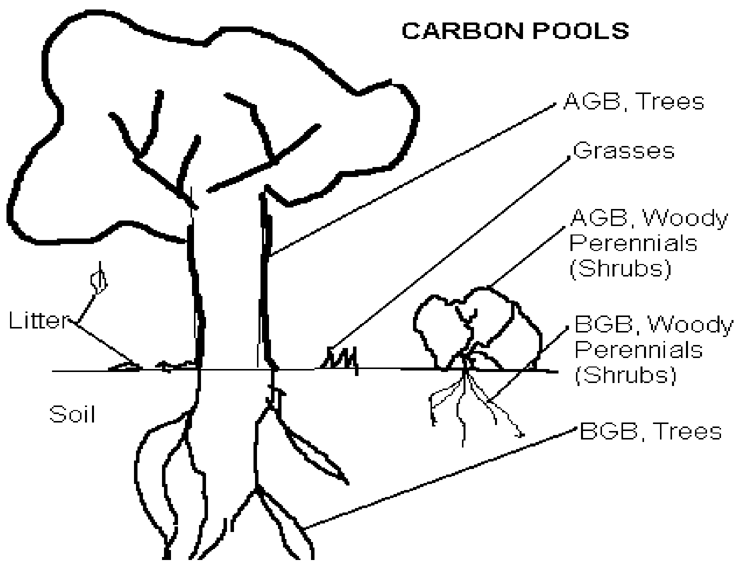

Figure 5: Graphical representation of the different forest carbon stock

Table 2 the share of tropical forests to the global forest carbon stock (Canadell *et al.,* 2007**)**

Biome	Area (10^9 ha)	Global carbon stocks (Gt C)		
		Vegetation	Soils (< 1 m)	**Total**
Tropical forests	1.76	212	216	**428**
Temperate	1.04	59	100	**159**
Boreal forests	1.37	88	471	**559**
Tropical	2.25	66	264	**330**
Temperate	1.25	9	295	**304**
Deserts & semi	4.55	8	191	**199**
Tundra	0.95	6	121	**127**
Wetlands	0.35	15	225	**240**
Croplands	1.60	3	128	**131**
Total	**15.12**	**466**	**2011**	**2477**

Soil is the largest pool of organic carbon in the terrestrial biosphere, and minor changes in soil organic carbon (SOC) storage can impact atmospheric carbon dioxide concentrations (Girmay *et al.*, 2009).

Emission Inventories

National Greenhouse Gas Inventories are complete estimates of the anthropogenic annual emissions and removals of greenhouse gases from a country developed source-by-source and sink-by-sink. Inventories are a valuable tool for many users. Not only are they needed for reporting greenhouse gas emissions, they are a key input to policy makers and also to developing the scientific understanding of climate change. Good knowledge of emissions and removals of greenhouse gases:-

- enables reduction policies to be developed in a cost effective way,
- allows different policy options to be compared,
- provides a simple monitoring mechanism to monitor implementation of these policies, are a key input to scientific studies of many environmental issues.

The IPCC 2006 GPG provides 2 methods to estimate annual carbon stock changes in any pool (Estrada, 2011):

The Gain–Loss Method, which includes all processes that bring about changes in a pool. Gains can be attributed to growth (increase of biomass) and to transfer of carbon from another pool (e.g. transfer of carbon from the live biomass carbon pool to the dead organic matter pool due to harvest or natural disturbances). Losses can be attributed to transfers of carbon from one pool to another (e.g. the carbon in the slash during a harvesting operation is a loss from the aboveground biomass pool), or emissions due to decay, harvest or burning. The Gain–Loss Method requires the biomass carbon loss to be subtracted from the biomass carbon gain.

The Stock-Difference Method: requires carbon stock inventories for a given land area at 2 points in time. Annual stock change is the difference between the stock at time t2 and time t1, divided by the number of years between the inventories. The Stock-Difference Method requires greater resources and is suitable for higher precision estimations.

4. Methodology

Carbon inventories for the purpose of REDD+ or other mechanisms follow six steps that are developed by the IPCC 2006 GL, and that have been used by the Voluntary Carbon Standards (VCS) (Estrada, 2011). This study has considered these steps into account.

Step 1 Definition of the project type

Step 2 Definition of the project boundary

Step 3 Projection of LU/LC in the baseline

Step 4 Estimation of baseline carbon stock changes

Step 5 Estimation of baseline GHG emissions

Step 6 Estimation of the baseline net GHG emissions and removals

4.1 Definition of the project boundary

This project considered the jurisdictional boundary of Simien Mountains National Park. As stated previously, this park is important conservation area not only for rare and endemic wildlife resources conservation, but also as high floral diversity center of the afro-alpine and montane ecosystems. Besides its conservation role, the park is vital for carbon dioxide sequestration and related climate change mitigation efforts.

4.2 Stratification of the project area using GIS techniques

Considering vegetation differences and land uses within the study area, Simien Mountains National Park was stratified into four zones. These zones include the alpine grassland (AAGL) occupying the highest altitude ranges, afro-alpine woodland (AAWL) that is dominated by the *Erica arborea* trees, the high afro-montane forest (AMF) surrounding the mountain base and steep slopes, and cultivated and overgrazed lands (CL). Stratification was done using satellite image with Arc GIS.

4.3 Inventory techniques

Sampling technique and sample size

A square grid of 1km*1km was drawn on the map of the park considering the outer gridlines as reference. 10% of the square grids were considered for the sampling and proportionally distributed to the different vegetation zones. Accordingly, 41 samples were needed for SMNP, which would have been distributed as 7, 9, 5 and 20 plots for the afro-alpine grassland (AAGL), afro-alpine woodland (AAWL), afro-montane forest (AMF) and cultivated and overgrazed land (CL) respectively. However, taking into consideration of the fact that there is high variability and carbon stock in the AAWL and AMF zones as compared to the CL, and also in consideration of taking fairly equal minimum number of plots, 10 samples were taken from each zone making it 40 total sample plots.

Sample plot design

There are varieties of sample plot designs that are applicable in forest inventory for the purposes of timber volume, biomass or carbon assessments. The two general designs are single plot design, which is appropriate for monoculture plantations which are homogenous in tree size and distribution, and are in most cases single storey, and nested plot designs which are appropriate for inventories in natural forests where there is high variability in tree size, distribution and structure. Forest carbon assessments in particular usually use nested plot designs that present variable size subplots for the different tree size classes and also for the different forest carbon pools.

There is high variability in topography and vegetation types in SMNP. Hence, a nested plot design which is appropriate to incorporate the variable tree sizes at different plot size was used (Figure 5). Accordingly, 50m*50m plot was used for trees above 30cm DBH, 20m*20m subplot was used for trees with DBH between 10cm and 30cm, 10m*10m subplot was used for trees between 5cm and 10cm DBH, 5m*5m subplot was used for small trees of DBH between 2cm and 5cm, 2m*2m subplot was used for regeneration and undergrowth and 1m*1m subplot was used for litter. Soil samples were taken at four corners of the 10m*10m subplot to a depth of 30cm, and one composite sample was taken for soil carbon determination.

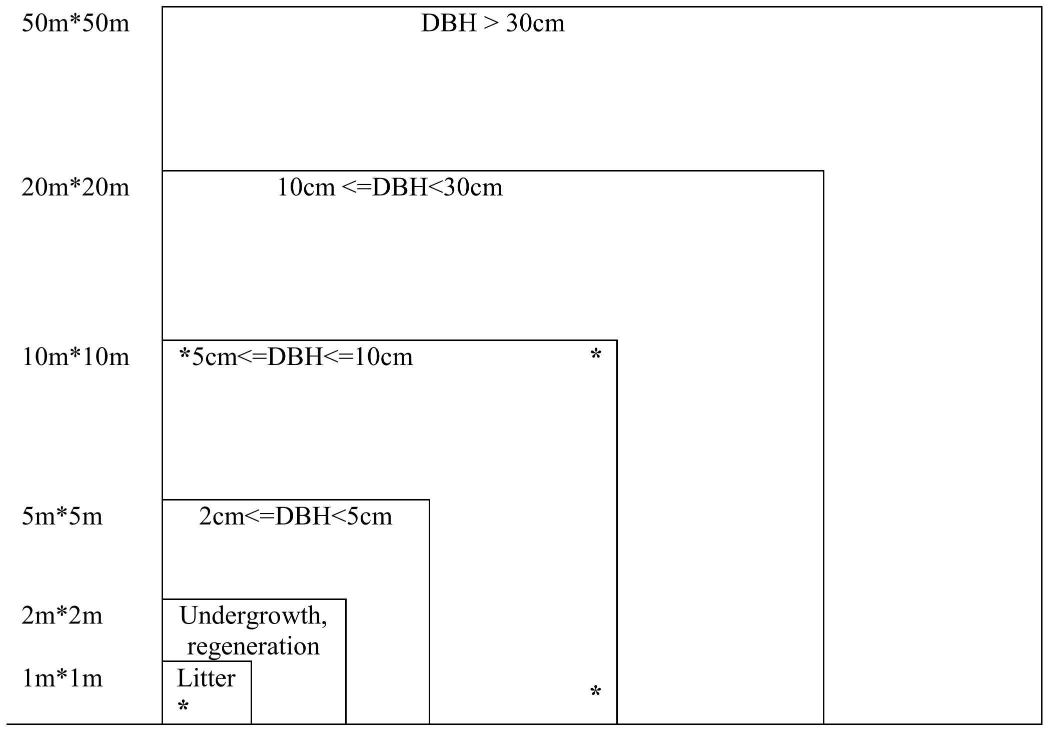

Figure 6: Nested plot sampling design;* soil sampling points

4.4 Carbon pools considered

Carbon stock has been assessed in five forest carbon pools, which is in accordance with the IPCC 2006 GL (Estrada 2011). These forest carbon pools are:

1. **Aboveground vegetation:** carbon stocked in live and standing vegetation (trees, shrubs, undergrowth and regeneration)

2. **Belowground vegetation:** carbon stored in roots

3. **Dead wood:** carbon stored in standing and fallen dead trees and shrubs

4. **Litter:** carbon in shed leaves and fine branches

5. **Soil:** carbon stored as soil organic matter

Aboveground vegetation biomass (AGB) carbon

Carbon in the AGB was assessed through measurement of standing trees and shrubs using proper mensuration techniques. Diameter at breast height (DBH) and height of trees were measured according to their size class in the respective subplots as stated in sample plot design section. Therefore, species type, DBH and height of trees had been the interest of measurement for trees. Fresh weight of all the undergrowth had been measured in the 2m*2m subplot and a small sample of known weight were taken for dry matter analysis. Regeneration was counted in this subplot. Tree biomass and respective carbon stock were calculated using allometric equations, and dry matter content of the undergrowth was determined after oven drying the fresh undergrowth sample and converting that proportionally to the 2m*2m subplot, hectare and project area levels. Therefore, the AGB is the sum of the two vegetation biomasses. Then the AGB carbon is calculated from the AGB using a biomass-carbon conversion factor of 0.5 (Lui *et al*., 2014).

Belowground biomass (BGB) carbon

Below ground biomass carbon is directly derived from aboveground vegetation carbon using known conversion factors. Below ground root biomass is estimated using root to shoot ratio which varies 20 to 50% depending on species. However, for carbon accounting purposes conservative values are recommended. Accordingly 24% was used as a conversion factor for belowground biomass from above ground biomass as also recommended by other authors (Cairnset *et al.*, 1997, Ciais *et al.*, 2011).

Dead wood carbon

Dead wood carbon was estimated by applying general log volume estimation techniques using Smalian formula, and converting estimated volume to biomass and then to carbon.

Dead wood volume $\mathbf{(V) = f(Ds^2+Dl^2)*L/2}$**,**

Where V, is volume of the wood (m^3), Ds is small diameter (cm), Dl is large diameter (cm), L is length (m), f is adjustment factor = 0.00007854.

Litter

Fallen leaf and fine branches were considered as litter. The carbon content under the litter was assessed from the 1m*1m subplot. Litter from the subplot was collected and weighed. Sub sample was taken and the fresh weight measured. The sub-sample litter was then oven dried and the dry weight was extrapolated to sub-plot, ha and project level. The carbon content was then considered to be 50% of the dry mass of the litter (Lui *et al.*, 2014).

Soil organic matter

Soil organic matter contributes to more than 50% of the forest carbon stock in some forest types (Roshetko 2002). In some conditions the soil carbon stock is less dynamic and hence is less interesting to carbon stock assessment although it is the largest forest carbon pool. However, when there is high anthropogenic impact on the soil, particularly when there is a land use change, it is important to address the soil carbon content change related with land use changes. In the current study, soil organic carbon (SOC) was assessed as there is dynamic process of land use change, forest land being converted to agriculture or grazing field, and hence it was found important to assess SOC content. Soil samples were taken at four corners of the 10m*10m subplot using 10cm diameter core sampler to a depth of 30cm. The four subsamples were then mixed together and weighed for the soil bulk density determination. Then a composite sample of 100g was taken. Soil bulk density has been determined by drying soil samples in oven at 103^{o}c for 24 hours. Then, SOC was determined following the loss-on-ignition method through putting soil samples in a Furnas at 555^{o}c for 8 hours.

4.5 Allometric modeling of the carbon stock

Carbon stock assessments in Africa are highly variable and have high degree of uncertainty due to lack of consistency in techniques of inventory and lack of site and species specific allometric equations (Ciais et al 2011). There are few specific allometric equations developed in Africa, and most of the carbon stock assessments used general allometric equations despite the high degree of variability in site growth conditions and growth characteristics of species (Ciais et al 2011, Henry 2011). Chave 2005, Brown 1997, Brown 1989, Henry 2011 are some of the most used general allometric equations in Africa for the purpose of biomass and carbon stock assessments. Chave *et al.,* 2005 is particularly used by many studies and has been the best general model for carbon stock assessment in Africa so far (Henry 2011, Ciais et al 2011). The allometric equation (Chave 2005) that was used for this study is;

Y(kg)= exp(-2.187+(0.916*ln(ρD2H))),

Where, H = tree height (m), D = DBH (cm) and ρ = Wood density (kg/m3)

While DBH and tree height are directly measured, wood density of species is obtained from other studies and databases. Average wood density value of the known species is used for species which wood density was not found.

4.6 Uncertainties

Uncertainties are factors that reduce the reliability of the carbon stock assessment. These uncertainties generally originate from different sources.

1. Sampling errors

The sampling technique, intensity, and sample plot size and design vary across different approaches. Stratified random sampling technique which reduces bias has been applied. More weight was given to stratum of high carbon stock. A nested plot design was used to give proper consideration to different size trees.

2. Measurement errors

Proper mensurational techniques were followed to reduce measurement errors. DBH was measured in two different directions using caliper and averaged. Height was measured using hypsometer to a proportional distance of tree height.

3. Type of allometric equation used to determine biomass

Although species specific allometric models are more reliable and have less degree of uncertainty, it is not feasible in the context of the diverse tropical forest as there are few species that have allometric equations (only 15% of the 850 species in Africa) (Henry *et al.*, 2011).

4.7 Leakage and non-permanence

There are two important risk categories in emission reduction accounting, leakage and nonpermanence. Leakage refers to the risk of relocation of emission outside the project area. When there is no proper accounting of the impact of REDD+ project outside the project area, there is high risk of reduced emissions obtained within the project area to be at the expense of increased emissions outside the project area. At SMNP, there are forest and woodlands outside the park boundary, thus there would be high possibility that emission reductions within the park could aggravate emissions in those forests outside the park. Nonpermanence is a type of risk that may happen unprecedentedly, either naturally or due to political instability or other uncontrolled human activities such as fire, war etc. Instabilities during the military activities of EPRDF's movement to overthrow the Derg regime, had contributed for the wide scale deforestation, settlement and agricultural expansion inside and around the park. It is difficult to quantify these two risks in future circumstances. 25% and 40%of the emission reduction is set aside as insurance for possible leakage and nonpermanence respectively, as had been done for Bale Mountains National Park (Watson *et al.*, 2013).

4.8 Carbon finance value

The carbon finance value has great disparity across different marketing mechanisms and across time. It is partly governed by the supply and demand of carbon offsets. In 2012-2013, most of the carbon projects had an offset values between \$3-\$6/tCO_2e, while the average value was \$4.2/ tCO_2e. Most of the carbon offsets were REDD+ projects, and currently there is an increasing trend of market saturation which would even make the carbon offset value to be lower (Nicholas, 2014). Hence a little conservative value of 4\$/ tCO_2e was used for the carbon finance value calculation.

5. Results

5.1 General conservation benefits of SMNP

SMNP is important as a unique habitat to unique and endemic wildlife such as Walia ibex (*Capra ibex walie*) and Gelada baboon (*Theropithecus gelada*).

In addition to the wildlife resources conservation, the national park is also an important area of floral diversity and endemism. There are over 550 recorded taxa of angiosperms in the SMNP, in three distinctive vegetation zones; Simien lowlands (afro-montane vegetation), afro-alpine belt (moorland) at high altitudes with low species diversity, and the afro-montane woodland (*Erica arborea* belt) in between. From the identified plants, at least 12 are endemic including *Rosularia semiensis* (afro-alpine zone) and *Maytenus cortii* (afro-montane zone) (Puff and Sileshi 2001). The SMNP is and has been important plant specimens collecting area and important attraction for botanists and biologists. 240 afro-alpine and afro-montane species were collected from the Simien which represent 40% of existing species there. The Simien lowlands (afro-montane zone) is particularly rich in floral diversity and endemism. From biodiversity conservation point of view, the afro-montane forest is the primary important forest zone, while the afro-alpine grassland and the afro-alpine woodland zones are also important in harboring rare and endemic plants.

SMNP is hydrologically very important region serving as the water tower to the economically important lowlands of the northern areas. Irrigation along the river sides has significant role for the livelihood of lowland inhabitants. Ground water flows also contribute to the lowland springs, vegetation and agricultural productivity. In addition most of the rivers that originate from the mountains are tributary to Tekeze River thus contributing to the functional operation of Tekeze hydropower dam. Other development projects such as the Wolkayit sugar industry are being developed on the Zarema River which originates from the Simien Mountains. Therefore, SMNP has huge hydrological regulation role which is directly related with livelihood of thousands of lowland communities and contributing to sustainable operation of new projects.

The afro-alpine and afro-montane vegetations have crucial ecosystem service in soil conservation and mitigation of climate change. Since SMNP is characterized by high topographic variability with steep slopes, there is high risk of soil erosion which could cause soil erosion and land degradation in the highlands and unprecedented flooding and siltation in the lowlands. Reduced vegetation cover in the highlands and steep slopes will cause soil erosion and reduced soil organic matter. This in turn reduces soil water infiltration and water holding capacity ultimately increasing the flood water during heavy rain periods which can be catastrophic to lowland areas, and significantly reducing the ground water system. Therefore, conservation of the afro-montane and afro-alpine vegetation is directly related with disaster and risk management for both the highland and lowland areas.

SMNP is one of the top tourism destinations in the country for its breathtaking scenery and endemic wildlife resources. As a result, the tourism sector has become one important player in the livelihood of the park-adjacent communities and local and national economy. In order to sustain the benefits that come due to the well being of the forest, it is crucial to conserve both the afro-alpine and afro-montane forests.

The SMNP has also important cultural and historical values that have strong association with the park. In addition, the park is unique area for ecosystem education and scientific study purposes. The general conservation benefits of SMNP, have been summarized below (Table 3).

Table 3 Exceptional resource values of SMNP (source: GMP 2009)

Type	Exceptional Resource Value	Rank
Natural	**Rare, endangered and endemic species** ***(Reason for WHS inscription criterion x)***	**1**
	Altitudinal habitat diversity	**3**
	Afroalpine vegetation	**4**
	Biodiversity hotspot	8
	Geological formations	9
	Montane forest	13=
	Ericaceous belt	13=
Scenic	**Escarpment landscape** ***(Reason for WHS inscription criterion vii)***	**2**
	Mountains peaks	7

	Wildlife viewing	11
Social	**Water catchment (also has natural value)**	**5**
	Tourism benefits	**6**
	Climate stabilization	12
	Climate change reference site	15=
Cultural	Walia kend and Kidus Yared (spiritual sites)	10
	Old trade route (Axum-Lalibela)	15=
	Ras Dejen name in legends	15=

Source: SMNP, General Management Plan (GMP 2009)

5.1.3 Derivers of deforestation and forest degradation at SMNP

To claim emission reductions for REDD+, it is mandatory to indicate the business-as-usual (BAU) scenario and different alternatives of project scenarios that enable to achieve emission reductions. These two scenarios have to be presented in clear terms of quantitative and scientific evidences. There are two ways to predict the BAU scenario. The first is backward approach which is based on analyzing the general historical trend of the forest stock, primarily based on satellite image land cover analysis. The second is the forward looking approach that only uses current and future circumstances that will affect the emission from deforestation and forest degradation. In this study, it has been tried to make use of both approaches in complementary manner. Therefore, the land cover trend analysis was made using satellite images and is presented in figures 7 and 8. Major derivers of deforestation and forest degradation are discussed using secondary information and field observations that are related with:

1. Population growth
    - Firewood collection,
    - Construction,
    - Agricultural expansion,

2. Free grazing
3. Charcoal production
4. New development projects

SMNP has a small area of only 412 square kms. It has not only small area coverage, but has also a narrow and fragmented shape that exposes the park to be accessed by wide range of communities. The boundary of the park is 368km long which gives 1.12 sq. km area per km of boundary which nearly means the park is stretched with only 2.25 km width. It is the inaccessible nature of the topography that assisted the protection of the park. Otherwise, the park is highly vulnerable and forest degradation is inevitable for its shape has scattered nature of topography that opens access to wider community and is difficult for management as well. The underlying reason for deforestation and forest degradation is the high rate of population growth associated with the level of poverty that ever increased the dependence of adjacent communities on the park and consequently added the pressure on the remaining resources of the park. Consequently there is high rate of deforestation and forest degradation undergoing in the park. The general deforestation rate of the AMF and AAWL zones is expressed by a linear model developed from the general land cover change that has been prevailed using satellite image analysis (Figures 7 and 8).

AMF (area in ha) = 8268 – 72.9x, ……………………………………eq1

AAWL (area in ha) = 22790.4 – 251.3x,……………………………...eq2

Where; x is the number of years starting from 1972

According to the above equations, the annual deforestation rate in the AMF and AAWL is estimated to be about 73ha and 251.3ha respectively. Using those equations it is possible to predict the size of the forests in future. Accordingly, the AMF is predicted to be completely deforested in 71 years and the AAWL to be lost in only 49 years if no management is improved. Therefore REDD+ projects can be designed in consideration of the total loss of the carbon stock in the AMF and AAWL zones in 71 and 49 years respectively. Or the amount of emission from deforestation for a shorter time horizon can be calculated and considered for BAU scenario. For example, the amount of forest that will be lost in the next 20 years is 1460ha for the AMF and 5026 ha for AAWL zones respectively.

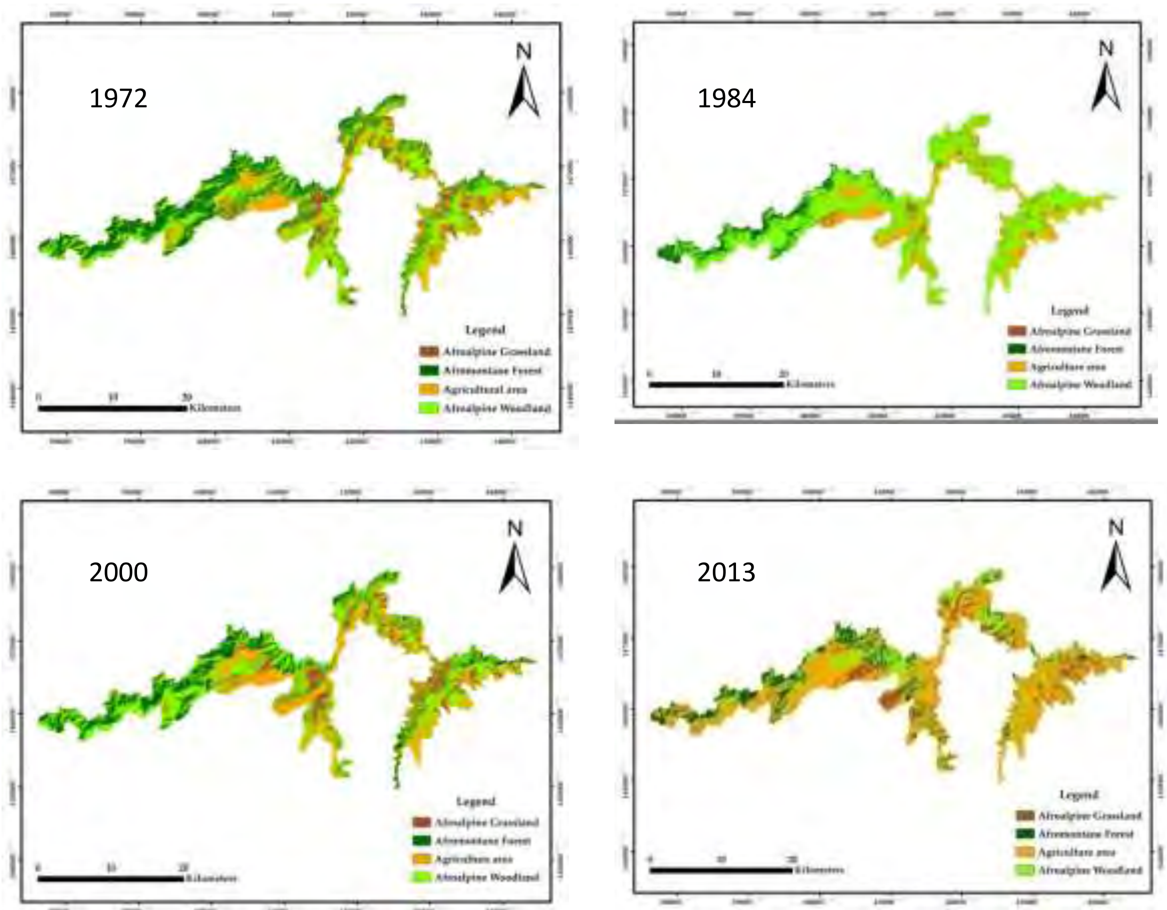

Figure 7: Land cover change of SMNP since 1972

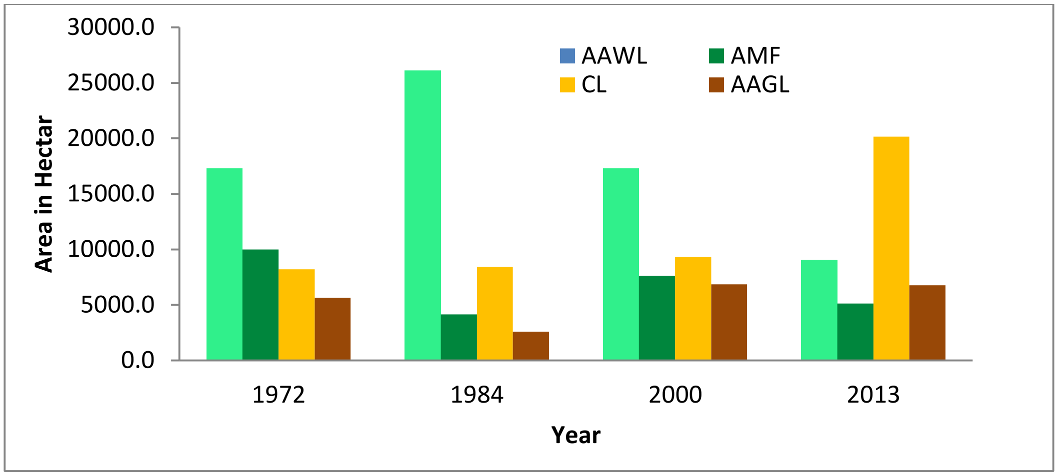

Figure 8: Land cover change trend of SMNP

- **Agricultural expansion**

As the satellite image analysis of this study revealed, the cultivated and overgrazed land has increased from 20% in 1972 to 48% in 2013 (Figures 7 and 8). As a result, the afro-montane forest and afro-alpine woodland have shrunk by nearly 50%. The afro-montane forest and afro-alpine wood land have been shrinking, on average, by 118.4 and 200.8 ha per annum, respectively. And future projection indicated 73ha and 251.3ha of annual deforestation in the AAWL and AMF zones, respectively. If this rate of deforestation continues, it will take only 71 and 49 years for the afro-montane forest and afro-alpine woodland, respectively, to be completely lost. However, with increasing population and diminishing resources, rate of deforestation will increase and it may not take that long unless swift management approaches are implemented on the ground. Agricultural land has been expanding at the expense of the natural vegetation both from within inhabitants and adjacent communities. 80% of the total park is directly affected by human activities such as settlement, cultivation and grazing (GMP, 2009).

- **Grazing expansion**

There are about 717 households that live inside the park at Gichi and Arquasiye, and other 1477 households live around park adjacent areas, totally 2194 households live inside and around the park. In 2007 an estimated 38,270 cattle, 59,639 sheep, 17,414 goats, 13,490 equines and 46,664 poultry were found in 17 Kebeles of the three woredas around SMNP with an average of 2.7 TLU per household (GMP, 2009-2019). Household level livestock holding is reducing due to increasing population and related resource scarcity, however, the total livestock of the communities is increasing. Considering average population growth rate of about 3% per annum, there will be 5924+(5924*0.03)*2.7*10 = 10722 TLU, which is nearly double the size of the current livestock population in just one decade. This will be catastrophic to the grass resource base and grass species diversity in the park. This will also significantly affect not only the grazing field, but the regeneration capacity of forest and woodland zones. The side effect of grazing on the regeneration capacity of forests has also been observed in this study. In the high forest areas far from villages, grazing is common experience and regeneration has already been affected. Since other interests like agricultural land expansion will also increase, the potential grazing land will shrink adding more grazing pressure on grasslands and also forests, which will ultimately lead to forest degradation and then to land degradation.

- **Fuel wood and construction wood extraction**

Most of household energy of inhabitants is obtained from the forest and woodlands of the park. Although many farmers are growing trees around the homestead, still the majority depend on the natural forest for fulfilling their energy demand for cooking and other purposes. Construction of houses and fences is also dependent on wood resources of the park. Protection of the park is generally perceived to be strict, yet illegal logging of valuable trees is still going on. Therefore, fuel wood and selective logging of construction wood, together with grazing are contributing to the forest degradation of the park.

- **Ongoing development activities in the area**

There are some development projects that directly and indirectly affect the forest condition of SMNP. There is an ongoing road being constructed around the park, and that crosses the park which breaks an important wildlife corridor. This road is being constructed as a substitute to an old road which used to pass through the park. It will on one side reduce the traffic and mobility of people through the park, but on the other side will improve access to the park which may then promote more deforestation and forest degradation. Electric transmission lines that go through the park have contributed for deforestation and forest degradation in addition to the ecosystem disturbance and consequences on birds and other wildlife.

5.2 Carbon stock of SMNP

SMNP was divided into four zones, for there is clear difference in the carbon stock of the different zones and respective carbon pools. The carbon stock of the different zones is presented separately here below. As was already expected, the carbon stock in the Afro-montane vegetation zone was found to be significantly higher than the other zones, while the carbon stock in cultivated land was found to be the lowest (Tables 4, 5, 6 and 7).

Table 4 Carbon stock of the plots in the afro-alpine wood land zone of SMNP (Source: field measurements and laboratory analysis)

	Carbon pools						
Plot No	**AGC ton/ha**	**BGC ton/ha**	**Dead wood C ton/ha**	**Litter C ton/ha**	**Soil C ton/ha**	**Total C ton/ha**	**Total tCO2e/ha**
SMNP_AAlW1	31.71	7.61	0.21	0.00	101.03	140.56	515.39
SMNP_AAlW2	0.00	0.00	0.00	0.00	97.17	97.17	356.29
SMNP_AAlW3	25.95	6.23	0.73	0.00	103.69	136.60	500.87
SMNP_AAlW4	21.78	5.23	1.33	0.00	11.12	39.45	144.65
SMNP_AAlW5	16.74	4.02	0.00	0.00	75.41	96.17	352.62
SMNP_AAlW6	20.80	4.99	0.66	0.00	80.61	107.06	392.55
SMNP_AAlW7	29.97	7.19	1.54	0.00	86.05	124.74	457.38
SMNP_AAlW8	25.44	6.11	0.36	0.00	110.58	142.49	522.46
SMNP_AAlW9	18.21	4.37	0.00	0.00	180.19	202.78	743.53
SMNP_AAlW10	19.25	4.62	0.35	0.00	29.97	54.20	198.73
Mean	**20.98**	**5.04**	**0.52**	**0.00**	**87.58**	**114.12**	**418.45**
Standard Devi	**8.88**	**2.13**	**0.55**	**0.00**	**45.95**	**46.91**	**172.02**
Standard Error	**2.81**	**0.67**	**0.17**	**0.00**	**14.53**	**14.84**	**13.09**
Range	**31.71**	**7.61**	**1.54**	**0.00**	**169.08**	**163.33**	**144.97**
Minimum	**0.00**	**0.00**	**0.00**	**0.00**	**11.12**	**39.45**	**0.71**
Maximum	**31.71**	**7.61**	**1.54**	**0.00**	**180.19**	**202.78**	**145.68**
CI (95%)	**5.50**	**1.32**	**0.34**		**28.48**	**29.08**	**25.66**
Median	**21.29**	**5.11**	**0.36**	**0.00**	**91.61**	**115.90**	**100.78**

Per hectare basis average carbon stock in the afro-alpine woodland is 114.12ton/ha which has about **418.45** tons of carbon dioxide equivalent. The afro-alpine woodland has an area of 9071 ha. Thus the total carbon dioxide equivalent of this zone is estimated to be **3795759.95** tons.

Table 5 Carbon stock of the plots in the afro-montane forest zone of SMNP (source: field measurement and laboratory analysis)

Plot No	Carbon pools						
	AGC ton/ha	BGC ton/ha	Dead wood C ton/ha	Litter C ton/ha	Soil C ton/ha	Total C ton/ha	Total tCO2e/ha
SMNP_AMF1	182.18	43.72	0.00	0.36	82.42	308.69	1131.86
SMNP_AMF2	48.72	11.69	8.25	0.00	24.90	93.56	343.05
SMNP_AMF3	36.90	8.86	0.00	5.14	95.11	146.00	535.33
SMNP_AMF4	68.92	16.54	6.16	0.00	132.58	224.19	822.03
SMNP_AMF5	121.49	29.16	0.42	0.00	159.65	310.72	1139.31
SMNP_AMF6	95.42	22.90	1.25	1.83	74.81	196.21	719.44
SMNP_AMF7	156.59	37.58	7.28	1.56	48.58	251.59	922.50
SMNP_AMF8	84.81	20.36	2.52	3.91	118.56	230.15	843.88
SMNP_AMF9	169.27	40.62	15.03	5.55	101.03	331.51	1215.54
SMNP_AMF10	269.15	64.60	23.13	2.93	141.40	501.21	1837.77
Mean	**123.35**	**29.60**	**6.40**	**2.13**	**97.90**	**259.38**	**951.07**
Standard Devi	**71.65**	**17.20**	**7.59**	**2.15**	**42.01**	**113.16**	**414.92**
Standard Eror	**22.66**	**5.44**	**2.40**	**0.68**	**13.29**	**35.78**	**131.21**
Range	**232.25**	**55.74**	**23.13**	**5.55**	**134.75**	**407.65**	**1494.72**
Minimum	**36.90**	**8.86**	**0.00**	**0.00**	**24.90**	**93.56**	**343.05**
Maximum	**269.15**	**64.60**	**23.13**	**5.55**	**159.65**	**501.21**	**1837.77**
CI (95%)	**44.41**	**10.66**	**4.70**		**26.04**	**70.14**	**257.17**
Median	**108.46**	**26.03**	**4.34**	**1.69**	**98.07**	**240.87**	**883.19**

Per hectare average carbon stock of the afro-montane forest zone is **259.38** tons/ha, and the corresponding carbon dioxide equivalent is **951.07** tons. Considering the area coverage of the afro-montane forest zone, 5132ha, the total carbon dioxide equivalent (tCO_2e) value of the carbon in this zone is estimated to be **4,880,891.21** tons.

Table 6 Carbon stock of the plots in the cultivated and over grazed zone of SMNP (source: field measurements and laboratory analysis)

Plot No	AGC ton/ha	BGC ton/ha	Dead wood C ton/ha	Litter C ton/ha	Soil C ton/ha	Total C ton/ha	Total C tCO2e/ha
SMNP_CL1	0.00	0.00	0.00	0.00	46.7	46.7	171.23
SMNP_CL2	0.00	0.00	0.00	0.00	57.8	57.8	211.93
SMNP_CL3	0.00	0.00	0.00	0.00	46.3	46.3	169.77
SMNP_CL4	0.00	0.00	0.00	0.00	59.6	59.6	218.53
SMNP_CL5	0.00	0.00	0.00	0.00	44.2	44.2	162.07
SMNP_CL6	0.00	0.00	0.00	0.00	51.5	51.5	188.83
SMNP_CL7	0.00	0.00	0.00	0.00	61.2	61.2	224.40
SMNP_CL8	0.00	0.00	0.00	0.00	40.6	40.6	148.87
SMNP_CL9	0.00	0.00	0.00	0.00	63.4	63.4	232.47
SMNP_CL10	0.00	0.00	0.00	0.00	51.9	51.9	190.30

Mean	**0.00**	**0.00**	**0.00**	**0.00**	52.32	52.32	191.84
Standard Dev	**0.00**	**0.00**	**0.00**	**0.00**	7.86	7.86	28.84
Standard	**0.00**	**0.00**	**0.00**	**0.00**	2.48689	2.49	9.12
Range	**0.00**	**0.00**	**0.00**	**0.00**	22.80	22.80	83.60
Minimum	**0.00**	**0.00**	**0.00**	**0.00**	40.60	40.60	148.87
Maximum	**0.00**	**0.00**	**0.00**	**0.00**	63.40	63.40	232.47
CI (95%)	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**	4.874305	4.87	17.87
Median	**0.00**	**0.00**	**0.00**	**0.00**	51.70	51.70	189.57

Per hectare carbon stock of the cultivated land lies only on SOC, as there are no trees found inside farmland areas. The area coverage of the cultivated land including the overgrazed area is 20158ha. The corresponding carbon dioxide equivalent is therefore equal to **3,867,110.72** tons.

Table 7 Carbon stock of the plots in the afro-alpine grass land zone (source: field measurements and laboratory analysis)

Plot No	AGB C ton/ha	BGC ton/ha	Dead wood C ton/ha	Litter C tone/ha	Soil C ton/ha	Total C ton/ha	Total C tCO2e/ha
SMNP_AGL1	0.75	0.18	0.00	0.00	108.6	109.53	401.61
SMNP_AGL2	0.96	0.23	0.00	0.00	126.5	127.69	468.20
SMNP_AGL3	0.85	0.20	0.00	0.00	147.2	148.25	543.58
SMNP_AGL4	0.65	0.16	0.00	0.00	74.4	75.21	275.77
SMNP_AGL5	0.79	0.19	0.00	0.00	113.1	114.08	418.29
SMNP_AGL6	0.98	0.24	0.00	0.00	138.3	139.52	511.57
SMNP_AGL7	0.66	0.16	0.00	0.00	121.4	122.22	448.14
SMNP_AGL8	0.98	0.23	0.00	0.00	116.2	117.41	430.50
SMNP_AGL9	0.82	0.20	0.00	0.00	134.7	135.72	497.64
SMNP_AGL10	0.87	0.21	0.00	0.00	118.6	119.68	438.83
Mean	**0.84**	**0.20**	**0.00**	**0.00**	**119.90**	**120.93**	**443.41**
Standard Dev.	**0.12**	**0.03**	**0.00**	**0.00**	**20.02**	**20.11**	**73.73**
Standard	**0.03**	**0.01**	**0.00**	**0.00**	**6.33**	**6.36**	**23.32**
Range	**0.33**	**0.08**	**0.00**	**0.00**	**72.80**	**73.04**	**267.81**
Minimum	**0.65**	**0.16**	**0.00**	**0.00**	**74.40**	**75.21**	**275.77**
Maximum	**0.98**	**0.24**	**0.00**	**0.00**	**147.20**	**148.25**	**543.58**
CI (95%)	**0.07**	**0.02**	**#NUM!**	**#NUM!**	**12.41**	**12.46**	**45.70**
Median	**0.84**	**0.20**	**0.00**	**0.00**	**120.00**	**120.95**	**443.48**

Average carbon dioxide equivalent per hectare in the alpine grassland zone is **443.41** tons. This zone covers 6771 ha of land. Therefore the total carbon dioxide equivalent of the zone is

3,002,329.1 tons. The total carbon dioxide equivalent of the different zones is summarized below (Tables 8 and 9).

Table 8 Summary of per hectare and total carbon stock for the different pools at SMNP (source: tables 5, 6.7 and 8)

Zone	AGB C ton/ha	BGB c ton/ha	Dead wood C ton/ha	Litter C ton/ha	SOC ton/ha	Average C ton/ha	Average tCO2e/ha
AAGL	0.8	0.19	0	0	119.9	120.93	443.41
CL	0	0	0	0	52.32	52.32	191.84
AMF	**123.35**	**29.60**	**6.40**	**2.13**	**97.9**	259.38	951.07
AAWL	**20.98**	**5.04**	**0.52**	**0.00**	87.58	114.12	418.45
Total values							
AAGL	5416.8	1286.49	0	0	811842.9	818546.2	3001336
CL	0	0	0	0	1054667	1054667	3867112
AMF	633032.2	151907.2	32844.8	10931.16	502422.8	1331138	4880840
AAWL	190309.6	45717.84	4716.92	0	794438.2	1035183	3795669
Total	**828,758.6**	**198,911.5**	**37,561.72**	**10,931.16**	**3,163,371**	**4,239,534**	**15,544,958**

Table 9 Total carbon stock and carbon dioxide equivalent values of SMNP in tone and US$ (adopted from table 8)

Zone	Area (ha)	Average C ton/ha	Total carbon stock (tone)	Carbondioxide equivalent (tone)	Carbon value (US$), at a rate of US$4/tone CO2e
AAGL	6771.0	120.93	818817.03	3002329	12009316
CL	20158.0	52.32	1054666.56	3867111	15468443
AMF	5132.0	259.38	1331138.16	4880891	19523565
AAWL	9071.0	114.12	1035182.52	3795760	15183040
Total carbon stock of SMNP	**41132**	**546.75**	**4239804**	**15,546,091**	**62,184,364**

Carbon stock of the different pools

One of the important points regarding carbon management is to identify the carbon pool that has high stock as well as one that is highly dynamic and sensitive. As seen in figure 11 below, most of the carbon stock is concentrated in two carbon pools.

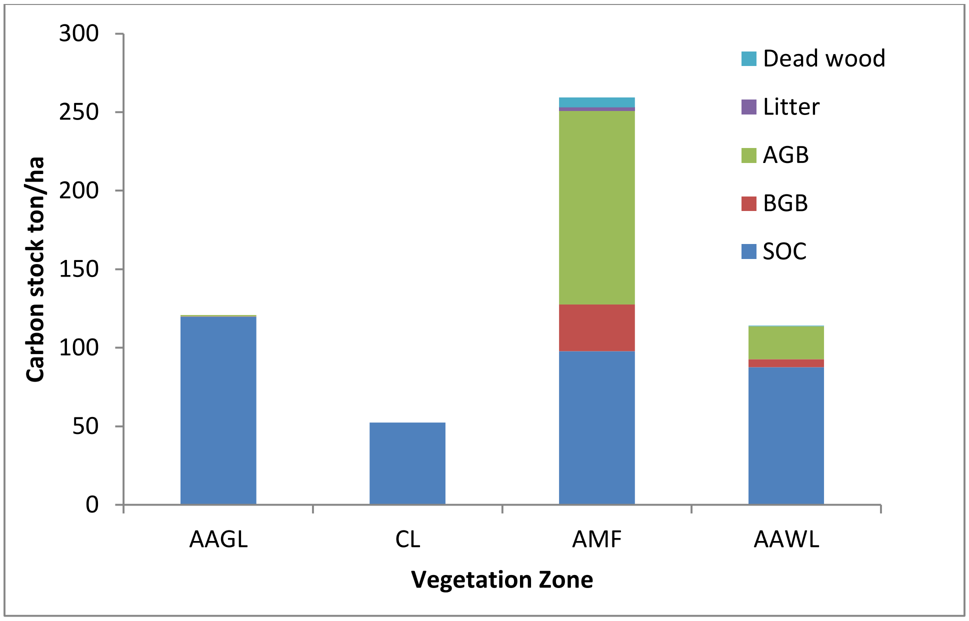

Figure 9: Distribution of the total carbon stock among the different forest carbon pools in the different vegetation zones (source: field measurement and laboratory analysis result)

Above ground biomass (AGB) and soil are pools that hold the large proportion of the forest carbon stock. 74.6% of the total carbon stock of SMNP is found in the soil. The second largest pool is AGB, which holds about 20 % of the total carbon stock. AGB and soil together constitute 94.1% of the total carbon stock. In the AMF vegetation zone, AGB holds 47.6% of the carbon stock, while soil holds about 37.7%. In other zones, the proportion of soil carbon is above 75%. Therefore the carbon management should focus on soil preservation and reduction of deforestation as these components are the largest carbon pools. This implies that removal of trees and soil erosion of the top soil is apparently removal of the bulk of the carbon stock from the system. Conservation of forests for sustaining their carbon stock and assisting regeneration has to be the central focus of any carbon management project. The afro-alpine grassland zone, although has low level of AGB carbon stock, it is found to be the most important in SOC (Figure 10). From figure 10, it is evident that conversion of any form of natural vegetation to cultivated and overgrazed field results in reduced SOC content which will affect the general holding capacity and sustainability of the area. Deforestation does not only reduce the AGB and BGB carbons, but soil carbon too. The difference in soil carbon stock between the cultivated and over grazed land and other vegetation zones ranges from 35.3 tons per hectare from that of the AAWL zone to 67.6 tons/ha from that of the AAGL.

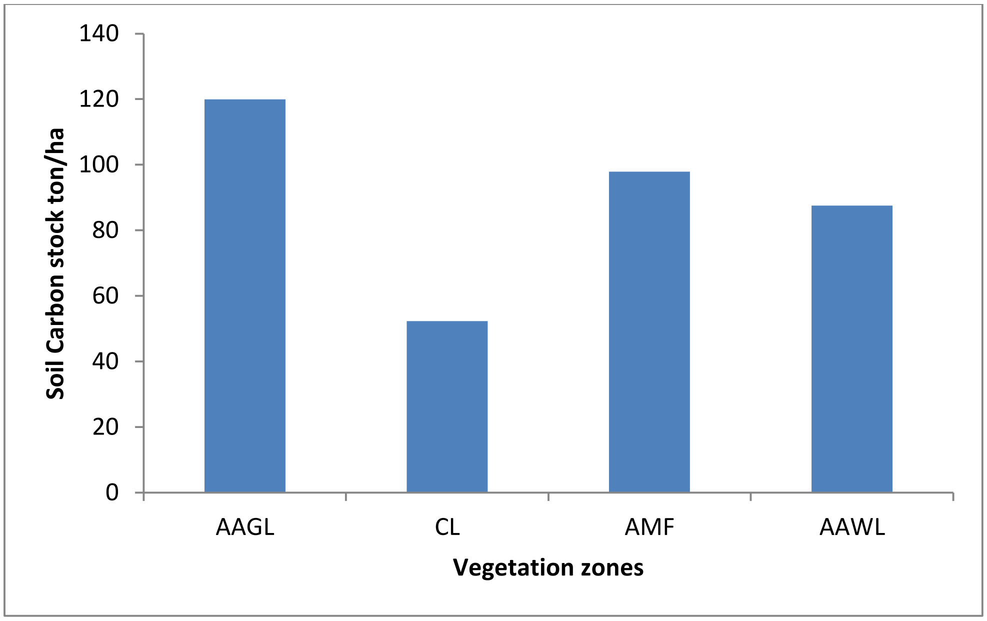

Figure10: Soil carbon stock tone per ha in the different zone (source: field measurement and laboratory analysis result)

Relation between carbon stock and tree species diversity

Biodiversity is one important issue in the management of forests for carbon dioxide sequestration and carbon stock purposes. It is generally required if there is direct relationship between diversity and carbon stock, so that the carbon stock management and biodiversity conservation can go hand in hand. However, there is no general conclusion reached at so far regarding the relationship between biodiversity and carbon stock. As it is seen in figure 11 below, there are variations among different forest types.

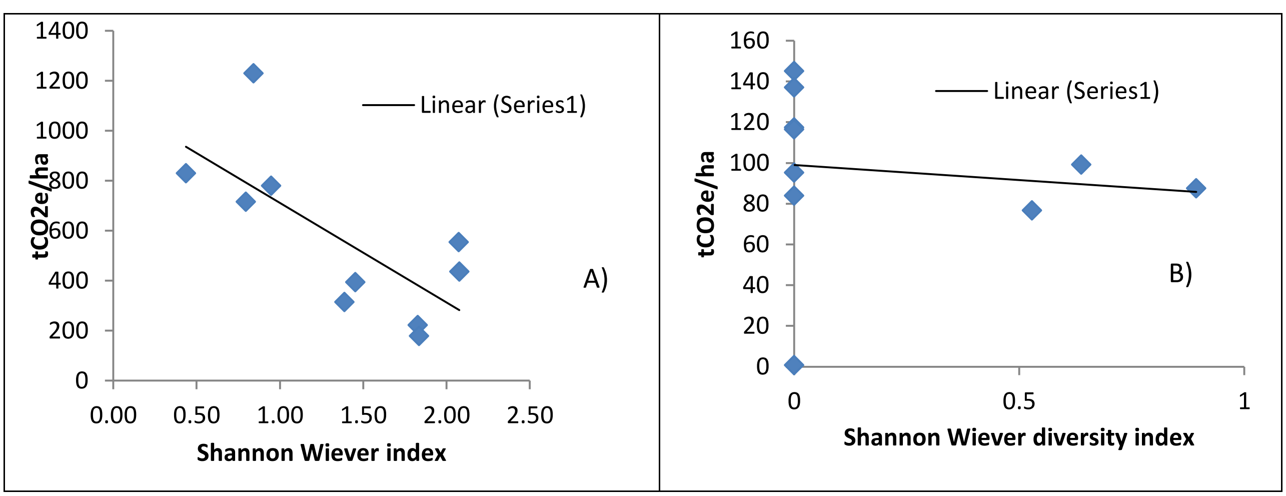

Figure 1 Tree species diversity and carbon stock in A) AMF and B) AAWL zones of SMNP

The Shannon Wiever diversity index prevailed that there is high tree species diversity in the AMF zone as compared to the AAWL. However, the AMF has shown strong and indirect relationship of biodiversity and carbon stock within that zone. The more diverse the forest implies less carbon stock. The AMF has the highest carbon stock per hectare. This could be due to the fact that in the AMF zone, there are big trees which occupy the upper canopy and discourage other trees not to grow. In addition, the larger tree sizes are the fewer in number so that reducing the diversity index. In this context, it is important that some gap is created in the AMF zone either naturally or artificially so that biodiversity is promoted, which has direct side effect on the carbon stock. In the other zones, there are no big trees that cause dominance over the others for solar radiation or space. As a result there is no visible relationship between carbon stock and tree species diversity.

Carbon dioxide sequestration potential in the AMF and AAWL zones of SMNP

Average annual increment (m^3/ha) in high forests in Ethiopia is roughly estimated to be 5.65 (Yitebitu *et al.*, 2010). Considering the average wood density in the AMF zone of this study (490 kg/m3), average annual biomass production per ha is 490*5.65, which is equal to 2768.5kg (2.77tones). Considering 50% of the biomass as carbon, the annual per ha carbon sequestration rate in the AMF zone is (2.77*0.5) equal to 1.38 tons or 5.1 ton of carbon dioxide equivalent. Taking the average carbon stock of 161.7 tons per ha, and annual carbon sequestration rate of 1.38 tons per ha of the AMF zone, it simply takes 117.2 years for the current carbon stock to be accumulated. This is without considering the carbon loss through decay. If 10% of the annual carbon sequestered is assumed to be lost through decay, the net annual carbon sequestration remain to be 1.24 tons per ha. When the current carbon stock is divided by the net carbon sequestration, it had taken at least 130 years for the current carbon stock to be accumulated in this zone.

Similarly, the average annual increment in woodlands is 0.79 m3/ha/year (Yitebitu et al., 2010). Average wood density in the AAWL is 410 kg/m3. Therefore, the average annual biomass production in this zone is 324kg (0.324 tons). Using the 50% carbon factor, the average per hectare annual carbon sequestration potential of this zone is 0.162 tons or 0.594 carbon dioxide equivalents. Average carbon stock per ha is 26.72tons. Hence it will take 165 years for the current carbon stock to be accumulated in the AAWL zone. Although the annual rate of decay in this zone is expected to be very small due to low temperature and bacterial activities, the existing carbon stock ones lost will take over 165 years to be sequestered back. The total carbon dioxide sequestration potential of the two zones is summarized below (table 10).

Table 10 Carbon dioxide sequestration potential in the AMF and AAWL zones of SMNP

Zone	Area in ha	Carbon sequestration (ton/ha/year)	Carbon sequestration in the zone (ton/ha/year)	Carbon dioxide sequestration (ton/ha/year)	Carbon dioxide sequestration in the zone (ton/ha/year)
AMF	5132	1.38	7082	5.1	26172
AAWL	9071	0.162	1469.5	0.594	5388.2
Total	**14203**		**8551.5**		**31560.2**

The total annual carbon dioxide sequestration potential of SMNP, in the two major carbon stock zones is estimated to be **31560 tons**, which is equivalent **to 8551.5** tons of carbon. Therefore, in the process of the undergoing deforestation, it is not only the accumulated carbon stock that is going to be lost, but the carbon dioxide sequestration potential also declines significantly. The carbon finance value of the annual sequestered carbon dioxide, at a rate of 4US$/ tCO2e, is estimated to be **126,240.8 US$**. However, if the deforestation continues, the forest area gradually diminishes and the annual carbon dioxide sequestration capacity will be reduced.

Emission from deforestation

The annual deforestation rate has been estimated for the AMF and AAWL zones using linear regression models. The annual emission is considered to include the annual deforestation of the ABG, and the loss of carbon from soil, litter, dead wood and BGB in the same area. The estimated amount of emission has only considered general trends starting from the 1972, and has not considered uncertainties and emission from forest degradation of the remaining forests. The soil carbon loss is assumed to be equivalent with the difference in soil carbon stock of the respective vegetation zones and the cultivated land.

Table 11 Estimating emission from deforestation and related annual carbon value

Zone	Area (ha) to be deforested	Total carbon (ton/ha)	tCO2e (ton/ha)	Total tCO2e to be lost	Total financial value (US$)*
AMF	73	207.06	759.22	55423.1	221692.2
AAWL	251.3	61.8	226.6	56944.58	227778.3
Total					**449470.6**

*Carbon unit price of 4US$ has been used for tCO2e. As carbon markets have high variability and uncertainty, the total value might earn better in future

If emission reduction efforts are streamed targeting at reducing 50% of the deforestation that would take place in 20 years, that means protecting 730ha of AMF and 2513ha of AAWL from being deforested, that will have an equivalent of **4,494,700 US$.** If 40% is set aside for nonpermance and 25% for leakage as insurance, implying there will be **1,573,145 US$**, net carbon value left for REDD+ project. This would mean that on average there will be 78,657.3 **US$** carbon value that can be generated from a target of reduction in deforestation. If project establishment and implementation costs are high, a REDD+ project may end up to be not feasible. However, uncertainties related with nonpermance can be reduced as there is better stability in the park currently and the probability of such uncertainties is minimal. In addition leakage can be also minimized with different activities, and a reduced proportion can be considered. Under such considerations, there is high probability that REDD+ project be feasible, and will have substantial role in both emission reduction and conservation roles in the park.

Potential emission reduction activities

1. Resettlement program which is important pillar of the GMP (2010 -2019GC)

Resettlement of residents inside the core areas of the park will significantly reduce both deforestation and forest degradation in the park and significantly contribute for emission reduction. As current resettlement activities have not secured enough finance for compensation and establishment of the people in new areas, integrating those efforts with REDD+ will be vital.

2. Supporting management of communal forests and private plantings

For farmers that are particularly living around the park, it is necessary to support individual farmers to grow their own trees for their own consumption so that their dependence will be reduced and related emission too.

3. To support better agricultural practices in the area so that deforestation for agricultural development would be reduced
4. To strengthen the capacity of the park for better control, management and law enforcement in and around the park so as to control illegal logging and agricultural expansion

The carbon balance between emission and sequestration in SMNP

Forest ecosystems are both sources and sink to carbon dioxide. When there is no deforestation and forest degradation, a forest is generally net-sequester. But when the rate of deforestation exceeds the rate of sequestration a forest acts as a net source to carbon dioxide. It is therefore important to assess whether a forest is a net emitter or sequester at particular year.

Table 12. Current carbon balance at SMNP

Zone	Total area (ha)	Annual sequestration (tons/ha)	Total annual sequestration (tons)	Annual deforestation rate (ha)	Forest carbon stock (tCO2e/ha)	Annual loss (ton)	Status
AMF	5132	5.1	**26173.2**	73	759.22	55423.1	Net emission
AAWL	9071	0.594	**5388.2**	251.3	226.6	56944.58	Net emission
Total			**31561.4**			**112367.6**	**Net emission**

As shown in Table 12, the park is currently under negative annual carbon balance of about 80806.4 tons of carbon dioxide and this gap will widen in future as the forest area shrinks, reducing carbon sequestration potential and on the other hand the rate of deforestation increases as the share of resource declines.

Potential carbon for REDD+

The total sum of annual emission reduction and annual sequestration potentials of the park would provide the potential carbon finance value to be generated from SMNP. Accordingly, the total annual carbon dioxide emission is **112367.7** tons. It is generally very difficult to completely stop the deforestation, and under any project scenario there will only be part of the deforestation to be reduced under real circumstances. The amount of potential reduction depends on the scale and effectiveness of project activities. If a REDD+ project targets at 50% reduction in deforestation, then there will be 56,183.84 tons of carbon dioxide potential to be saved from deforestation annually. Similarly, there is an annual carbon dioxide sequestration of 31,561.4 tons. Therefore the combined amount of carbon dioxide that potentially can be claimed annually for REDD+ project is **87,745.3 tones**. Yet certain amount has to be left aside for leakage and non-permanence.

The issue of leakage

The effect of any carbon management activity either to reduce the rate of deforestation or to increase the rate of carbon dioxide sequestration, may incur an effect on the carbon emission-sequestration balance outside the project area. Such an effect is generally considered as leakage. Leakage usually is negative as emission reduction in a project area is generally compensated in an increase in emission outside the project area. But there are sometimes positive leakages where the project activities lead to emission reductions or increased sequestration outside the project area. In this condition, however, leakage is generally expected to have negative effect outside the park area since limited access to the park resources triggers destruction of forest resources outside the project area. Generally expansion of agricultural fields, grazing and wood extraction from the park would be shifted to other forests (planted or natural) outside the park area. In order to minimize the effect of leakage, project activities such as promotion of energy efficient cooking stoves, improved agricultural productivity on available farmlands, promotion of modern livestock management than the traditional free grazing and provision of alternative livelihood to the communities that live inside and surrounding areas of the park is necessary. As it is generally very difficult to completely control and compensate the effect of leakage, 25% of the potential carbon value is kept as insurance for leakage.

The issue of non-permanence

Unexpected events (due to natural or anthropogenic reasons) that suddenly destroy the carbon stock such as fire, volcanic eruption, investment, instability etc. are generally regarded as non-permanence. Under the current conditions, the direct large scale conversion of the forest land to another is unlikely. Forest fire and other natural wide scale disturbances do not happen very often. But climate change is a major threat that may cause wide scale destruction through soil erosion, drought, heavy wind etc. 40% of the carbon stock is therefore reserved for such unexpected circumstances.

Therefore when leakage and non-permanence are reduced from the potential carbon for carbon finance (65%), only 35% remains to be traded at the carbon markets. Therefore the final amount of carbon dioxide equivalent that can be traded is equal to 30710.9 tones, which has an annual carbon finance value of **122,843.4** US$.

6. Conclusions

Protected areas have a wide range of conservation benefits related with the provision of direct goods like wood resources, grazing resources, food etc., and indirect benefits that come through the service roles. The conservation benefits of SMNP are apparently deep and wide. It is the center of the hydrological system of the northern Ethiopia, it is high biodiversity hotspot area with rare and endemic animals, it has huge cultural and historical values, it has unique landscape and is one of the top tourist attraction areas in the country, it has also immense educational and scientific study benefits.

The park has, however, been under continued pressure from the communities that live in and around the park. The pressure has grown gradually and has threatened the sustainability of the park related with the ever increasing population and ever diminishing resources. Climate change has also marking its impact and aggravating the pressure that has already been severed.

While the management of the park has strongly oriented towards the protection of wildlife and their habitat, there is now a tendency to integrate the traditional management with climate change adaptation and mitigation strategies. Although deforestation, forest degradation and habitat fragmentation are peculiar phenomenon of SMNP, the park still holds huge forest area that has ample carbon stock to be conserved and traded in the different carbon markets.

REDD+ can be considered as an ideal strategy for integrating conservation efforts and reducing emissions that emanate from deforestation and forest degradation. The total carbon stock of the park is estimated to be **4,239,804** tons of carbon and **15,546,091**tons of carbon dioxide equivalent. At 4US$ rate of a ton of carbon dioxide, the current carbon value (US$) is estimated to be **62,184,364**. The afro-montane forest zone is found to be a high carbon stock area with a carbon density of **259.38** tons/ha of carbon or **951.07tCO2e**. The afro-alpine woodland zone has a carbon stock of **114.12** tons of carbon per ha, which has **418.45**tCO2e. The afro-alpine grassland zone is found to have the highest stock of soil carbon. It has been found also that cultivated and overgrazed areas to have the list stock of both above ground and below ground carbon indicating the risk of land use change from natural ecosystems to cultivated areas, not only from the point of view of climate change mitigation but from the overall reduction of the area in holding capacity and productivity and then sustainability point of view.

Afro-montane forest zone not only has the high stock of carbon, but has also the highest tree species diversity as it has different storey structure. Therefore, conservation of this zone is particularly relevant in meeting double objectives of emission reduction from deforestation and biodiversity conservation purposes. In this study it was found that there is an annual degradation of 73ha and 251.3ha in the AMF and AAWL zones respectively. This rate of deforestation indicated that under the current trend (BAU), the AMF will be completely lost in 71 years and the AAWL in 49 years. The carbon-flux in the park has already passed its natural balance, and there is a net annual emission in the park in general and in each of the two forest vegetation zones. Thus the park is currently considered as net-emitter as it is losing more carbon than it is sequestering annually.

There is high potential for REDD+ project to be integrated in the park management, and have a paramount significance in emission reduction, enhancement of regeneration and carbon stock preservation from climate change adaptation and mitigation point of view. In addition a REDD+ project will assist the protection of wildlife resources, stabilizing the ecosystem and enhancing the sustainability of the park, its resources and surrounding communities.

7. Recommendations

1. The deforestation undergoing in the park is alarming and threat to overall status of the park and its resources which need urgent measures. Although, the park is in principle protected by EWCA, wide scale deforestation and degradation is still undergoing as there is short of management capacity of the park administration and lack of alternatives for local communities.
2. The carbon stock in the park and its carbon finance value may not feasibly fit REDD+, but rapid deforestation rates, and other added benefits of wide scale ecological services, direct economic and social benefits of the park to local and national communities should be given particular recognition so that a REDD+ project to be implemented feasibly in an integrated approach to existing management practices. Rehabilitation of degraded areas of the park could be included to “enhance regeneration” that could be added to the reduction in deforestation, and hence REDD+ project would be feasible economically.
3. REDD+ or other similar carbon offset mechanisms, if implemented in the park in an integrated manner, would significantly contribute to the sustainability of the park and improved livelihood of local inhabitants.

4. Alternative technologies such as improved cooking stoves, modern agricultural technologies and livetock management can be integrated as a project activity.
5. Already planned activities like resettlement programs, which however are progressing slowly due to financial limitation, can be well integrated with a REDD+ project
6. If implemented in the park, REDD+ will contribute significantly towards the effort of removing the park from the "List of in danger" of the UNESCO.

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Appendix

Table 1 summary of tree measurements of the plots in SMNP

Plot	No of trees			Average DBH			Average height		
	DBH> 30cm	10cm<DBH<30cm	5cm<DBH<10cm	DBH> 30cm	10cm<DBH<30cm	5cm<DBH<10cm	DBH> 30cm	10cm<DBH<30cm	5cm<DBH<10cm
SMNP_AMF1	52	700	800	79	14	7.75	31	10.5	4.75
SMNP_AMF2	64	175	200	47.5	14.5	7	25.8	5.3	4.5
SMNP_AMF3	0	1425	1700	0	13.16	6.2	0	7	4.5
SMNP_AMF4	8	1625	400	36	15.9	5.75	15	11.2	4.5
SMNP_AMF5	72	1975	600	38.6	15.8	7	22.7	11.3	5
SMNP_AMF6	72	650	800	55.2	18.3	7	21.4	8	4.6
SMNP_AMF7	112	125	300	63.8	20.6	7.3	28	11.9	4.3
SMNP_AMF8	48	825	300	34.6	17	6.2	25.7	14.4	4
SMNP_AMF9	156	200	0	47.1	21.9	0	32.4	10.7	0
SMNP_AMF10	160	425	100	56.6	17.2	9	32.4	13.9	7
SMNP_AAlW1	0	1244	500	0	12.5	6.5	0	5.3	4.3
SMNP_AAlW2	0	0	0	0	0	0	0	0	0
SMNP_AAlW3	112	225	0	9.4	7.6	0	0.35	0.35	0
SMNP_AAlW4	128	125	500	34.6	23.2	6.9	9.25	7	4
SMNP_AAlW5	76	150	0	36.3	23	0	9.8	6.2	0
SMNP_AAlW6	0	1275	1400	0	12.8	7.1	0	5.7	4.4
SMNP_AAlW7	40	900	500	37	15.4	8.4	11.4	6.7	5.4
SMNP_AAlW8	0	1300	1000	0	13.6	7.65	0	6.6	5.25
SMNP_AAlW9	0	725	100	0	16.4	7	0	6.9	4

SMNP_ AAlW10	0	675	500	0	16.6	7.2	0	6	4.3

List of identified tree species at SMNP

Hypericum revulutum

Erica arborea

Rosa abbyssinica

Hagenia abbyssinica

Schefflera abyssinica

Bersama abyssinica

Mimusops kummel

Mytenus arbutifolia

Olea africana

Croton macrostachys

Buddleja polystachya

Allophylus abbysinicus

Acockantera shimperi