Forest Carbon stock in *Pinus wallichiana* forests of Manaslu Conservation Area, Central Nepal

A Dissertation

For Partial Fulfillment of the Requirements for the Completion of Master's Degree of Science in Environmental Science

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DISCLAIMER

I, Prakash Sigdel, hereby declare that this research work is my original work and all the sources of information are duly acknowledged. This work has not been published or submitted elsewhere for any academic purposes.

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LETTER OF RECOMMENDATION

This is to certify that Mr. PRAKASH SIGDEL has prepared and completed this dissertation work entitled**Forest Carbon stock in *Pinus wallichiana* forests of Manaslu Conservation Area, Central Nepal** for partial fulfillment of the requirement for the completion of Master‘s Degree in Environmental Science and has worked sufficiently well under my supervision and guidance.

This dissertation work contains his own work and fulfills the requirements of GoldenGate International College, Tribhuwan University, Nepal. To the best of my knowledge, this dissertation work has not been submitted for any other degree. I, therefore, recommend the dissertation for acceptance and approval.

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LETTER OF APPROVAL

The dissertation entitled "**Forest Carbon stock in *Pinus wallichiana* forests of Manaslu Conservation Area, Central Nepal"** submitted by **Mr. Prakash Sigdel** is accepted and approved as the partial fulfillment of the requirement for the completion of Master's Degree in Environmental Science.

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ABSTRACT

Carbon stock and carbon sequestration are major approaches for the climate change adaptation and minimization. But the carbon stored in any community differs with the different spatial factors. Aspect and altitude are two of those factors influencing the carbon balance and management.

In Nepal, carbon stock estimation has been generally practiced either in national parks or in community forests. But, the carbon storage in remote protected area have also been playing significant role in carbon management. This study was conducted in the forests of opposite aspect (N and S) of Prok village of Manaslu Conservation Area (MCA) of Nepal. The main objective of the study was to estimate the carbon stock density of different forests in Prok with the variation in aspect and altitude. Transect method was used for the sampling and calculation was done using MS Excel and R- software. Both the tree biomass and Soil Organic Carbon (SOC) were varied with the change in aspect and altitude. *Pinus wallichiana* was the dominant species in both aspects of the study site.

In the forest in northern aspect (F_{NA}) and southern aspect (F_{SA}) carbon in tree biomass was estimated at 74.6 tC/ha and 15.02tC/ha, respectively. Similarly, the average SOC density above 10 cm in F_{NA} and F_{SA} was37.1 tC/ha and 42.6tC/ha, respectively. The seedlings of *Pinus wallichiana* were found more than other species showing the current pattern of the forest structure and composition continue in the future.

Keywords: Biomass, Carbon stock, *Pinus wallichiana*, Soil Organic Carbon, Manaslu Conservation Area

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ABBREVIATIONS AND ACRONYMS

AGB	Above ground biomass
AGSB	Above ground sapling biomass
ANSAB	Asia Network for Sustainable Agriculture and Bioresources
CAMC	Conservation Area Management Committee
CDES	Central Department of Environmental Science
CFs	Community Forests
CO_2	Carbon dioxide
DBH	Diameter at breast height
DFRS	Department of Forest Research and Survey
DNPWC	Department of National Parks and Wildlife Conservation
DoF	Department of Forest
FAO	Food and Agriculture Organization
FECOFUN	Federation of Community Forest User's Group Nepal
FRA	Forest Resource Assessment
GIS	Geographical Information System
GtC	Giga tonnes of carbon
GHG	Greenhouse gas
ICIMOD	International Centre for Integrated Mountain Development
INGOs	International Non-Governmental Organizations
IPCC	Intergovernmental Panel on Climate Change
IUCN	World Conservation Union
KCAP	Kanchenjunga Conservation Area Project
LHG	Litter Herb Grass
MCA	Manaslu Conservation Area
MF	Managed Forest

Mg/ha	Mega gram per hectare
M mt	Million metric tonnes
MtC	Mega tonnes of carbon
NAST	Nepal Academy of Science and Technology
NCCKMC	Nepal Climate Change Knowledge Management Centre
NE	North Eastern
NGOs	Non- Governmental Organizations
NTNC	National Trust for Nature Conservation
PF	Preserved Forest
Pg C/year	Peta gram of Carbon per year
REDD	Reducing Emission from Deforestation & Forest Degradation
SE	Standard Error of estimates
SOC	Soil Organic Carbon
SW	South West
TBD	Tree Biomass Density
TCD	Total Carbon Density
T/ha/year	Tonnes per hectare per year
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
VDC	Village Development Committee
v.n.	vernacular name
WCMC	World Conservation Monitoring Centre
WDPA	World Database on Protected Areas
WWF	World Wildlife Fund for Nature

TABLE OF CONTENTS

List of Figures

Lists of Tables

List of Annexes

Chapter 1

INTRODUCTION

1.1 Background

Forests play an important role in regional and global carbon (C) cycles because they store large quantities of C in vegetation and soil, exchange C with the atmosphere through photosynthesis and respiration, are sources of atmospheric C when they are disturbed by human or natural causes, become atmospheric C sinks during re-growth after disturbance, and can be managed to sequester or conserve significant quantities of C on the land (Brown *et al.* 1996; Sharma *et al*. 2011). This global importance of forest ecosystem emphasizes the need to accurately determine the amount of carbon stored in different forest ecosystem (Nizami 2010).

Carbon is sequestrated by plant photosynthesis and stored as biomass in different parts of the plant (Jana *et al*.2009). Carbon emission from deforestation accounts for an estimated 20% of global carbon emission (IPCC2007), second only to that produces by fossil fuel combustion (Campbell *et al.* 2008). Growing trees and other vegetation capture CO_2 from the atmosphere and combine it with water to produce sugars and carbohydrates. A tonne of carbon in trees is the result of the removal of 3.67 tonnes of carbon dioxide from the atmosphere (Hunt 2009).

CO_2 is a primary Green House Gas (GHG) and its concentration in the atmosphere has been increasing steadily since 1958(Keeling *et al*. 1989; cited in Kumar *et al.* 2013). The Intergovernmental Panel on Climate Change (IPCC) estimates that the level of carbon dioxide in today's atmosphere is 31% higher than it was at the start of the Industrial Revolution about 250 years ago and atmospheric levels of CO_2 have risen from 280 ppm at the pre-industrial to the present level of 375 ppm (Ramachandran *et al*. 2007).Increase of carbon dioxide affecting greenhouse gas emissions and global warming has been a major concern on earth (Karki 2008). Forests can act both as sinks and sources of carbon, depending on the management activities. It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown *et al.* 1996).

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural ‘brake’ on climate change(Gibbs *et al*.2007).Forest ecosystems play a crucial role in regional and global terrestrial carbon (C) cycles because they store large quantities of C in vegetation, detritus, and soil, and exchange large amounts of C with the atmosphere through photosynthesis and respiration(Dixon *et al*. 1994; Zhu *et al*. 2010).Quantifying the substantial roles of forests as carbon stores, as sources of carbon emissions and as carbon sinks has become one of the keys to understanding and modifying the global carbon cycle(Sheikh *et al*. 2011). The major carbon pools to be measured in forest carbon estimation are plant biomass (above and below ground), above ground sapling biomass (AGSB), soil organic carbon (SOC), and litter, herbs, and grass (LHG) (Subedi*et al*.2010). As the tree biomass experience growth, the carbon held by the plant also increases carbon stock (Jana *et al*. 2009). The rate of carbon storage increases in young stands, but then declines as the stand ages (Jana *et al*. 2009).

The ability of forests to both sequester and emit greenhouse gases coupled with ongoing widespread deforestation, has resulted in forests and land-use change being included in the United Nations Framework Convention on Climate Change (UNFCCC) and in the Kyoto Protocol.In Nepal, the projects like Forest Resource Assessment (FRA) conduct periodic inventories of various forest types regarding the forest carbon estimation. Regional and local carbon stock estimation activities are also being carried out from institutional and personal approaches. National level forest biomass carbon stocks estimated by different researches in Nepal are given in Table 1.1.

Table1.1: National level forest biomass carbon stocks estimates of Nepal (MtC)

Based on compilations of harvest data			Based on forest inventory		Total range
Olson *et al*./ Gibbs (2006)	Houghton (1999) /DeFries *et al*. (2002)	IPCC (2006)	Brown (1997)/ Achard *et al.* (2002/2004)	Gibbs & Brown (2007a,2007)	Based on all estimates
246	393	369	337	334	246-393

Source: (Gibbs et al. 2007)

Broadly speaking, protected areas can be defined as areas of land or sea “dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources, managed through legal or other effective means (IUCN 1994; Campbell *et al*.

2008). Protected areas are also being regarded as the significant reservoir of global carbon stock. Protected areas are designated with the objectives of conserving biodiversity, but also fulfill an important role in maintaining terrestrial carbon stock, especially where there is little other remaining natural vegetation cover (Campbell *et al*. 2008). Protected areas worldwide cover 12.2% of the land surface and contain over 312 GtC or 15.2% of the global terrestrial carbon stock (table 1.2) (Campbell *et al*. 2008).

Table 1.2: Categorical carbon stock in protected areas

Protected area category	% land cover protected	Total carbon storage (Gt)	% terrestrial carbon stocks in protected areas
IUCN category I – II	3.8	87	4.2
IUCN category I – IV	5.7	139	6.8
IUCN category I- VI	9.7	223	11
All WDPA sites	12.2	312	15.2

Source: (Campbell et al. 2008)

Evidences suggest that protected areas are effective at reducing land cover change within their boundaries (Clark *et al*. 2008) although one issue rarely taken into account is that of the leakage(Campbell *et al*. 2008). Leakage in Reducing Emissions from Deforestation and forest Degradation (REDD) concerns unplanned emissions that could occur outside project boundaries as a result of project activities. Leakage may also occur when a project's output creates new incentives to increase GHGs emissions elsewhere, at a different moment in time. Whilst the current protected area network undoubtedly play the major role in conserving the carbon stock, it is not clear whether existing protected stocks were included in a REDD mechanism(Campbell *et al*. 2008). Currently, there are a number of options on the discussion, including past rates of deforestation; with compensation for existing protected stock not out of the question but appearing less likely.

The present study was carried out to estimate the carbon stock density in the forest patches of Prok VDC of Manaslu Conservation Area (MCA). The forests are being managed by Conservation Area Management Committee (CAMC) under Manaslu Conservation Area Project (MCAP). The forest studied wasthe Pine- dominated temperate forest with the association of other tree species. This research was aimed at quantification of carbon stocks in aforementioned forest types for the proper documentation of carbon pools of the studied forests.

1.2 Objectives of the Study

The major objective of this study was to estimate the carbon stock density of different forests in Prok VDC. The Specific Objectives includes

- To estimate the carbon stored in each carbon pools(AboveGround and BelowGround Biomass (AGB & BGB); Leaf litter, Herb and Grass (LHG); Aboveground Sapling Biomass (AGSB) and Soil Organic Carbon (SOC).
- To determine the altitudinal variation of carbon stock density
- To compare the carbon pools in North and South aspect

1.3 Research Questions

- Does carbon stock density vary with change in aspect and altitude?
- What is the composition of different Carbon pools in overall study area?

1.4 Rationale of the Study

Forest can be a major carbon sink which can effectively reduce the emitted carbon through sustainable management. Several studies have shown that protected areas can be effective at reducing deforestation: for example, analyses that compared deforestation inside and outside protected areas (DeFries *et al*. 2005; Nepstad *et al*. 2006; Joppa *et al.* 2008; cited in Scharlemann *et al*. 2010). Similarly, the carbon stored in protected area network can lead to the effective storage of global carbon.

Few studies have taken places in accessible national parks and conservation areas in Nepal, but the data of the remote protected areas have still lacked. So, the present study of carbon stock estimation in the conservation area in the aboveground as well as belowground carbon pool would provide the baseline data for the future study and also can give the necessary status for the sustainable conservation and management of the conservation area. So, it is important to identify the status of forest in terms of carbon storing capacity in higher elevation which is being managed under different approaches than that of lower elevation by culturally richer local communities.

Conservation areas are generally large, with most of the area in a natural condition, where a proportion of it is under sustainable management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area. So, carbon stock estimation and its management can also be one of the potential strategies for the GHG mitigation.

1.5 Limitations of the study

- Soil sample only upto 10 cm was taken for the analysis because the samples below 10 cm in upper 10 samples of the Northern aspect was not possible to extract due to the rock mass.
- Aboveground biomass of shrubs and herbs were excluded from the study due to time and resource constraint.
- This study was undertaken only in one forest in the protected area of central Nepal. Findings of this research do not necessarily represent the regional or national scenario but the result can be used as a baseline scenario for the future research.
- Diameter at breast height of the tree included bark of the trees for biomass calculation. Previously established regression equations and density for different species have been used for the calculation of the stem volume assuming that the values are same.

Chapter 2

LITERATURE REVIEW

The issues of Global warming and climate change are being widely addressed in global platforms nowadays. The accumulation of GHG in atmosphere due to different human as well as natural activities is leading to the global temperature rise. The IPCC estimates that the level of carbon dioxide in today's atmosphere is 31% higher than it was at the start of Industrial Revolution about 250 years ago (Geider 2001).

Forest resource degradation has been one of the major problems in the 21st century. Deforestation and forest degradation alone accounts for 17.4% of the world's greenhouse gas emissions (Subedi*et al*. 2010).The problem is serious in tropical and subtropical forests where carbon stocks are decreasing at an alarming rate of 1-2 billion tons a year(Subedi*et al.* 2010). Deforestation is contributing to climate change and because of which forests have been identified as a potential ecosystem for measurement to mitigate climate change (DeFries*et al*.2000; FAO 2001; Nizami2010).

2.1 Carbon stock studies around the world

Campbell *et al*. (2008), in their technical report supported by UNEP-WCMC, assessed carbon storage in protected areas integrating the information from the best available data sources, with the aim of informing decision-making at global, regional and national levels. Earth's terrestrial ecosystems were estimated to store around 2,050 gigatons (Gt) of carbon in their biomass and soil (up to 1 m depth). Protected areas worldwide cover 12.2% of the land surface, and contain over 312 GtC, or 15.2% of the global terrestrial carbon stock.

Jina*et al.* (2008) calculated the rate at which CO_2 is being sequestrated in two forest types of Himalaya. They carried out the comparative study in degraded and non-degraded sites of pine and oak forests inKumaun Central Himalaya. Their research showed that the carbon sequestration rate varied from 1.07 t/ha/yr in Pine Degraded site to the 6.66 t/ha/yr in Pine non-degraded site.

Sheikh *et al*. (2009) carried out the study of altitudinal variation of SOC in altitude of 1600m.a.s.l. to 2200 m.a.s.l. in the coniferous subtropical and broadleaf temperate forests of

Garhwal Himalaya. The stocks of SOC were found decreasing with altitude: from 185.6 to 160.8 tC/ha and from 141.6 to 124.8 tC/ha in temperate (*Quercusleucotrichophora*) and subtropical (*Pinusroxburghii*) forests, respectively. They concluded that the ability of soil to stabilize soil organic matter depend negatively on altitude and call for comprehensive theoretical explanation.

Zhu *et al*. (2010) measured C stocks of vegetation, detritus, and soil of 22 forest plots along an altitudinal gradient of 700–2,000 m to quantify altitudinal changes in carbon storage of major forest ecosystems (*Pinuskoraiensis* and broadleaf mixed forest, 700–1,100 m; *Picea*and*Abies* forest, 1,100– 1,800 m; and *Betulaermanii* forest, 1,800–2,000 m) on Mt Changbai, Northeast China. Total ecosystem C density (carbon stock per hectare) averaged 237 tC/ha (ranging from 112 to 338 tC/ha) across all the forest stands, of which 153 tC/ha (52–245 t C/ha) was stored in vegetation biomass, 14 tC/ha (2.2–48 tC/ha) in forest detritus (including standing dead trees, fallen trees, and floor material), and 70 t C/ha (35–113 tC/ha) in soil organic matter (up to 1 m depth).

Pan *et al*. (2011) used the forest inventory data and long-term ecosystem studies and estimated the total forest sink of 2.4 ± 0.4 petagrams of carbon per year (Pg C/year) globally for 1990 to 2007.Their total forest sink estimate was equivalent in magnitude to the terrestrial sink deduced from fossil fuel emissions and land-use change sources minus ocean and atmospheric sinks.

Bayat (2011) performed the modeling and estimating Above Ground Biomass (AGB) and Carbon Stock (CS- AGB) of a beech forests in the Pizzalto Mountain in the Majella National Park using the GIS and remote sensing techniques in combination with field data. Slope angle, slope gradient, altitude, seasonal incoming solar radiation, length of growing season (LGS), MODIS NDVI and EVI values, soil type and forest management types were used in the modeling. The average AGB and CS- AGB were 247 and 123 tonnes/harespectively comparable to values found in beech forest in the Apennines and Europe. Result showed that in the linear regression model, LGS and management are the significant variables providing most of the variation in carbon stock in the AGB.

Gairola*et al*. (2011) undertook a study to estimate the live tree biomass and carbon variation along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya, India and found out that the total live tree biomass density (TBD) varied from 215.5 to 468.2 Mg/ha and TCD varied from 107.8 to 234.1 Mg C/ha. The average values of TBD and TCD for the study area were 356.8 ± 83.0 Mg/haand 178.4 ± 41.5 Mg C/ha respectively. Statistically significant positive correlation of TCD with altitude (r = 0.579) was observed, which could be attributed to dominance of large conifers and hardwoods at higher altitudes compared to lower altitudes.

Sharma *et al*. (2011) carried out the study in seven major forest types of temperate zone (1500 m.a.s.l. to 3100 m.a.s.l.) of Garhwal Himalaya to understand the effect of slope aspects on carbon (C) density.Total C density (SOC+TCD) rangedbetween 118.1 MgC/ha on SW aspect (Himalayan *Pinusroxburghii* forest) and 469.1 Mg C/ha on NE aspect (moist *Cedrusdeodara* forest). SOC and TCD were significantly higher on northern aspects as compared with southern aspects. It was recommended that for C sequestration, the plantation silviculture be exercised on northern aspects, and for C conservation purposes, mature forest stands growing on northern aspects be given priority.

2.2 Carbon stock studies in Nepal

A large number of studies regarding the carbon estimation were found in Nepal but these were mostly done in low land and mid hills(Jati 2012).Very few research works were found regarding the slope gradient studies in available literatures. Some of the studies in Nepal are explained below.

Baral *et al*. (2009) assessed the aboveground carbon stock in the five major forest types, representing two physiographic regions and four districts of Nepal. Results indicated variation in age of the stand (18-75 years), aboveground carbon stock per hectare (34.30-97.86 dry wt. tonnes/ha) and rate of carbon sequestration (1.30-3.21 t/ha/yr), according to different forest types. The rate of carbon sequestration by different forest types depended on the growing nature of the forest stands. Tropical riverine and *Alnus nepalensis* forest types demonstrated the highest carbon sequestration rates in Nepal.

Oliand Shrestha (2009) tried to provide information about the total carbon stock in the forests of Nepal. Total carbon stock of Nepal was estimated to be 880 M mt in 1990, 961 M mt in 2000 and 897 M mt in 2005, according to FAO (2006). It was concluded that forestry and related statistics such as growing stock, biomass and carbon stock should be updated regularly at national level to safeguard the estimation of carbon emission and carbon sequestration.

Shrestha (2009) carried out the study to quantify total carbon sequestration in two broad leaved forests (*Shorea* and *Schima-Castanopsis* forests) of Palpa district. Total biomass carbon in *Shorea* and *Schima-Castanopsis* forest was found 101.66 and 44.43 t/ha respectively. Soil carbon sequestration in *Schima-Castanopsis* and *Shorea* forest was found 130.76 and 126.07 t/ha respectively. Total carbon sequestration in *Shorea* forest was found 1.29 times higher than *Schima-Castanopsis* forest. The study found that forest types play an important role on total carbon sequestration.

ANSAB, ICIMOD and FECOFUN (2010) jointly studied at 105 CFs of three different watersheds having an area of 10,266 ha of Chitwan (Khayarkhola Watershed), Dolakha (Charnawati Watershed) and Gorkha (Ludhikhola Watershed) district. It was found that the carbon stock in dense and sparse forest of Khayarkhola Watershed to be 296.44 and 256.70 t/ha where as it was 228.56 and 166.76 t/ha for Charnawati Watershed of Dolakha and in Ludhikhola Watershed it was 216.26 t/ha and 162.98 t/ha for dense and sparse forest respectively.

Aryal (2010) tried to estimate the status of carbon stock at ToudolChhap Community Forest, Sipadol, Bhaktapur. The study was focused in two forest types, Pine forest and mixed broad leaf forest. The carbon content of pine forest i.e. 113.29 t/ha was found to be higher than that of mixed broad leaf forest i.e. 31.4 t/ha. But, SOC was found higher in mixed broad Leaf forest (70.51 t/ha) than in the pine forest (53.75 t/ha). Also, in both forest type, SOC decreases with increasing depth. Therefore, total carbon stock of pine forest and mixed broad leaf forest was found to be 167.04 t/ha and 101.91 t/ha respectively. In addition, CO_2 equivalent was estimated to be 612.48 and 373.67 t CO_2/ha for pine forest and mixed broad leaf forest. It was found that both forest types have high potential to store carbon in biomass and soil with efficient management.

Bhusal (2010) estimated total carbon content in 14 hector sampled area of the Nagmati Watershed (Shivapuri National Park) soil and was found to be 9782.11±25.18 t/ha corresponding to a total of 167442.26±42076.82 tonnes of carbon content in the Nagmati Watershed (1406 ha). According to the estimation, the total carbon content of Shivapuri National Park (5860.8 ha i.e. 40% of total area of park which is forest) excluding soil is 699961.20±175894.32 tonnes.

Chhetri (2010) studied the carbon stock status of Syalmati Watershed of Shivapuri National Park andcalculated that the Syalmati watershed had storage of 226.8±23.8 t/ha above ground biomass, 27.9±5.8 t/ha below ground biomass and 0.28 ±0.06 t/ha litter biomass. Therefore, total biomass in the forest of Syalmati was estimated to be 254.8±52.69 t/ha. It was concluded that the more the forest matures, less carbon is sequestered.

Jati (2012) carried out the comparative study of the carbon assessment in Kumvakarna Conservation Community Forest, KCAP, Taplejung. He carried out the comparative study in Preserved Forest (PF) and Managed Forest (MF) and found out the tree biomass carbon to be 109.10 t/ha and 177.44 t/ha respectively. It was concluded that PF was less efficient for carbon storage since it stored 93.88 t/ha less carbon than MF though the disturbances such as fuel wood collection, grazing, timber harvesting and fodder collection were found more in MF.

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Chapter 3

MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Description of the Manaslu Conservation Area

With experience from the Annapurna Conservation Area Project (ACAP), National Trust for Nature Conservation (NTNC) started its program in the Manaslu region from the beginning of 1997 as the Manaslu Ecotourism Development Project with funding support of the Governmentof Nepal and the Asian Development Bank under the Ministry of Culture, Tourism and Civil Aviation's Second Tourism Infrastructure Development Project. The project was able to develop basic eco-tourism infrastructure in the area. MCAP completed the Ecotourism Project in 2001. (NTNC 2009)

Manaslu is a mountainous region in north of Gorkha District and has a fragile natural resource base and a rich cultural environment. In order to conserve the unique environment and extremely rich biodiversity, a protected area status – "Conservation Area" – was given to the Manaslu region. Manaslu Conservation Area (MCA), declared on 28th December 1998, is the third conservation area in Nepal. MCA encompasses a 1663 sq.km. area with 7 VDCs. There are about 9,000 inhabitants living in MCA and 2,000 species of plants, 33 mammals, 110 birds, 3 reptiles and 11 butterflies in 11 types of forest have been reported from the area. (NTNC 2009)

3.1.2 Description of the Study area

The study area, Prok VDC, lies in Manaslu Conservation Areain the Mahabharat Range of Nepal. It is located about 63 km NE from the Gorkha Bazaar. It is located at an average altitude of 2440 m.a.s.l. with an area of 146 sq.km.Prok VDC consists of 221 households and has 5 village settlements.

Pinus wallichiana forest was selected for the study that is a lower temperate forest (http://www.forestrynepal.org/notes/silviculture/forest-types) (Figure 3.1).The study was carried out in two forest patches of the opposite aspect. The forest patches on the northern aspect is known as Thanye and Sharkeforest while that of the southern aspect is called Chhak forest. The total forest area of theProk VDC was estimated to be 34.65 sq.km. Forests of both aspects were in the same VDC .The forest on northern aspect was comparatively more dense than that of the southern aspect. The forest was managed by the Conservation Area Management Committee (CAMC) of Prok VDC.

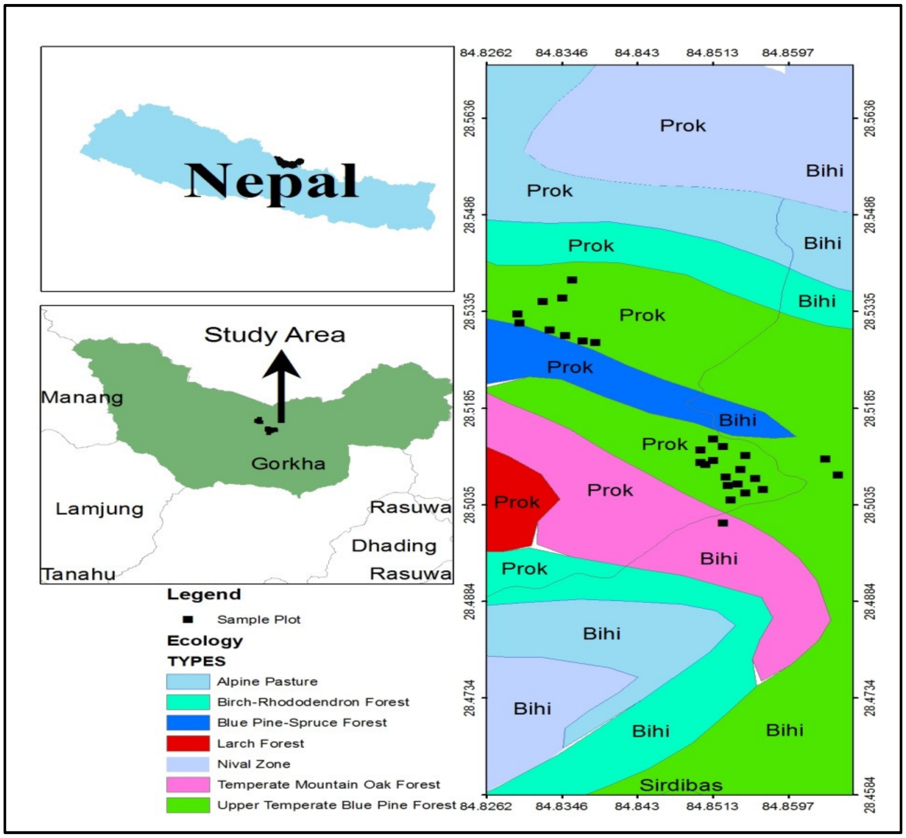

Fig 3.1: Location map of the study area

The study area (Figure 3.1) lies in the temperate region of Nepal.The precipitation data recorded at the LarkeSamdoStation, the nearest meteorological station from the study area, were taken to be acquainted with the climatic conditions. The LarkeSamdo station is 26 km North-West of the study area having altitude of 3650 m.a.s.l.Due to the fact that LarkeSamdo Station does not have the temperature records, the temperature data from the Gorkha station were used which is the second nearest meteorological station from the study area.

3.2 Selection of the study area

Thanye and Sharke forest on the northern aspect and Chhak forest in the southern aspect of the Prok VDC were chosen as the study area. The approximate area of the forest block under study on the southern aspect was estimated to be 30 ha while that on the northern aspect was 70 ha. Prok VDC is located between longitudes 84º43’28” E and 84º52’04” E and latitudes of 28º27’00” N and 28º36’46” N. The elevation of the sample plot ranged from 2100 m to 2700 m.a.s.l. in both the aspects. Prok VDC covers 8.7% of the area of MCA.

Precipitation analysis

The average annual precipitation is in decreasing trend while analyzing for the period of 1980-2009 (Fig 3.2). The maximum precipitation in that period was 2485.6 mm in 1989.

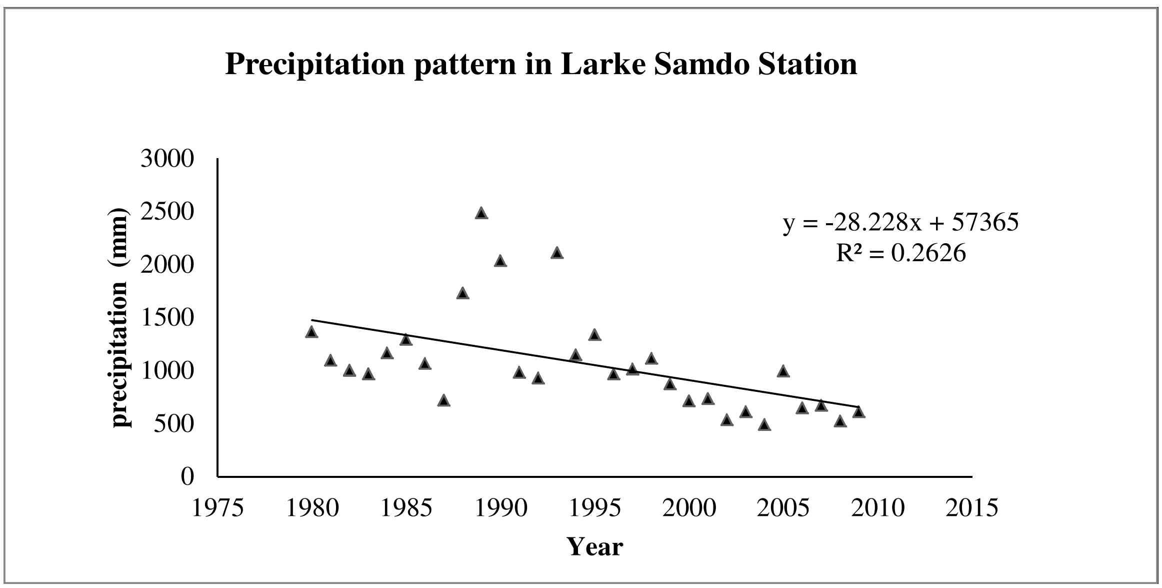

Fig 3.2: Precipitation pattern (1980- 2009) recorded at Larke Samdo Station (3650 m a.s.l.)

Source: DHM 2010

Temperature pattern Figure 3.3 shows that the average annual maximum temperature (Tmax) is increasing but the minimum annual temperature (Tmin) are decreasing in recent years. The highest value of Tmax was 28.1 ºC in 2006 and the lowest value of Tmax was 24.43 ºC in 1982.

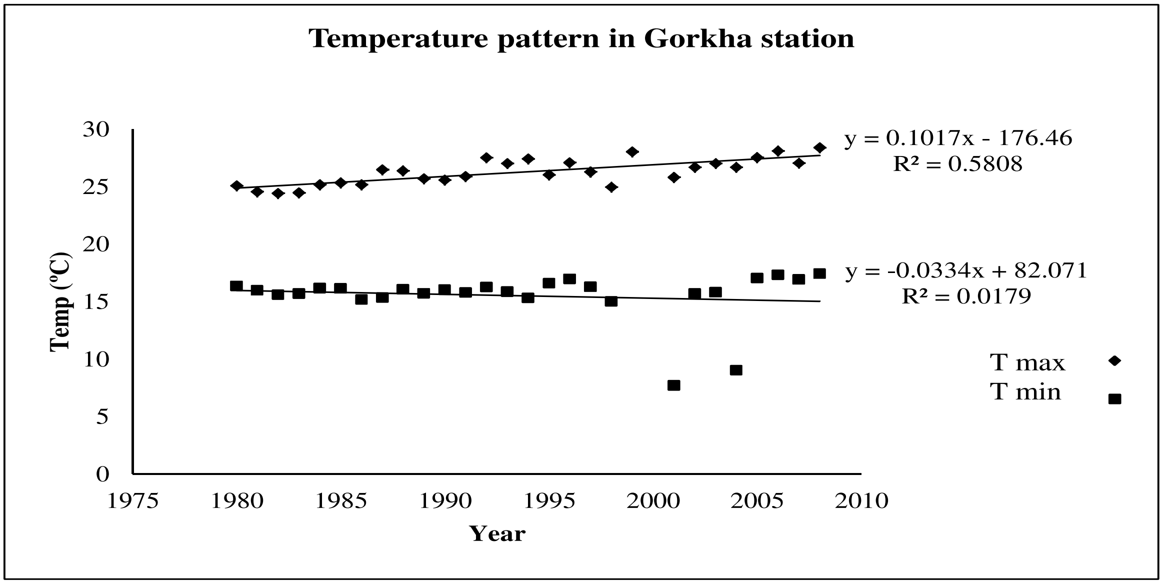

Fig 3.3: Temperature pattern (1980 - 2008) recorded at Gorkha Station (1097 m a.s.l.)

Source: DHM 2010

3.3 Methods of Data Collection

3.3.1 Data collection

3.3.1.1 Sampling Design

Transect sampling method was used for collection of the data for biomass calculation. The distance between two plots was 150m on the same contour and the distance between two contours was 200m. The study was carried out in two forest patches of opposite aspect and sample plots of equal area were laid out on the field. The total study area is estimated to be 70 ha on northern aspect and 30 ha on southern aspect. The minimum sampling intensity of 1% was taken (Rana *et al*. 2008) for the determination of the required number of plots for the study. The quadrate size of 20mx20m for trees and shrubs and 1mx1m for LHG were laid out and individual trees inside the plots were measured following the Guidelines given by Subedi *et al.* (2010). The total forest area under study is 7200 sq. m on the northern aspect and 3600 sq.m.on the southern aspect. The number of plots on each aspect and its status are listed in Table 3.1.

Table 3.1: Sample design in different strata of forest

Forest aspect	Forest area (ha)	Sample plot size(m^2)	No. of plots	Vegetation status
Northern aspect	70	20x20	18	Pine- dominated forest
Southern aspect	30	20x20	9	Pine - dominated forest having small dbh trees

In the corner of each replicate plot, nested quadrate of size 1m x1m was laid out for the regeneration study. Each trees and shrubs inside the plots were recorded using its vernacular name and known species of plants were translated later to the scientific name. Tree height (h) and diameter at breast height (dbh) (1.3m from ground level) were measured for individual stands inside the plot.

3.3.1.2 Sample Plot Measurement

Diameter at breast height (dbh) of each tree within each plot was measured using Million Diameter Tape. The sample plot was prepared using the normal Fiber glass measuring tape. Similarly, height of each tree was measured using Silva Clinometer (Silva- Clino Masters, Made in Sweden). The data collected was recorded in the prescribed format.

3.3.1.3 Sapling and seedling measurement

Saplings were measured 1.3 m above the ground level as the over bark diameter and seedlings were counted within nested quadrate for the regeneration. For the saplings, the dbh was in the range of 1-5 cm and the plants having height of less than 1 m were considered seedlings.

3.3.1.4 Soil Sampling

Soil samples were taken from every sample plots. Soil profiles were dug out and collected at 0-10, 10-20, and 20-30 cm depths using the guidelines given by Subedi *et al.* (2010).

3.4 Data Analysis

3.4.1 Vegetation Parameters

3.4.1.1 Shannon - Wiener Diversity Index (H')

The species diversity of the forest community was calculated to get the better quantitative description of the community. For the calculation of the species diversity, Shannon -Weiner diversity index (H') was applied. Shannon-Wiener index (H') is one of the widely used diversity index and can be manipulated as-

$$H' = -\sum (ni/N)\ln(ni/N) = -\sum pi \ln pi$$

Where, N=Total no of species.

ni= no. of individuals of species.

Pi= ni/N

3.4.1.2 Index of Dominance(c)

Index of dominance can be calculated by following formula

$c = \sum (\frac{ni}{N})^2$ (Simpson 1949)

Where, ni = number of individuals of each species

N = total of individuals

3.4.1.3. Evenness Index (e)

$e = H' / \log S$ (Odum1967)

Where, H' = Shannon -Wiener Diversity Index

S = numbers of species

3.4.2 Quantitative Data Analysis

3.4.2.1 Density and relative density

Density shows the number of individual trees per unit area and it indicates the numerical strength of a species in a community (Zobel *et al*. 1987).

$$\text{Density}\left(\frac{\text{no}}{\text{ha}}\right) = \frac{\text{No. of individuals of species}}{\text{Total no. of plots studied x area of each plot}} \text{ x } 1000$$

The proportion of density of species with respect to total density of all the species within an area is referred to as relative density. In other words it is the numerical strength of a species in relation to the total no. of individuals of all species.

$$\text{Relative density (R. D.)(\%)} = \frac{\text{Density of species A}}{\text{Total densities of all species}} \text{ x } 100$$

3.4.2.2 Frequency and relative frequency

Frequency indicates the dispersion of species in a community. It is the percentage of sampling units in which a particular species occurs.

$$\text{Frequency(\%)} = \frac{\text{No. of plots in which species A occured}}{\text{Total no. of plots sampled}} \text{ x100}$$

Relative frequency is the frequency of a particular species in relation to total frequency of all the species present in the community.

$$\text{Relative Frequency (R. F.)(\%)} = \frac{\text{Frequency of species A}}{\text{Total frequency of all the species}} \text{ x100}$$

3.4.2.3 Basal area and relative basal area

Basal area refers to the ground actually penetrated by the stems (Hanson & Churchill 1961). It is one of the characters that determine the dominance.

$$\text{Basal area } (\text{m}^2) = \frac{(3.1416)\text{x }(\text{dbh})^2}{4}$$

Similarly,

$$\text{Relative basal area (R. B. A)(\%)} = \frac{\text{Basal area of sp. A}}{\text{Total basal area of all species}} \text{ x } 100$$

3.4.2.4 Importance Value Index (I.V.I.)

In order to express the dominance and ecological success of any species, with a single value, the concept of Importance Value Index has been developed. It can be calculated by adding the relative values of the three parameters density, frequency and basal area. (Curtice 1959).

I.V.I. is calculated by

I.V.I. =Relative Density (R.D.) + Relative Frequency (R.F.) + Relative Basal Area (R.B.A.)

The Importance Value Index provides the picture of the relative contribution of a species to the entire community.

3.4.3 Biomass Estimation

3.4.3.1 AboveGround Biomass (AGB)

The dbh (1.3 m) and height of individual tree greater than or equal to 5 cm dbh were measured in each square plots with 400 sq. m. area using diameter tape and clinometers. Each tree was marked individually to prevent double counting. Each tree were numbered and recorded with its species name as much as possible. Trees on the border were included if >50% of their basal area falls within the plots and excluded if < 50% of their basal area falls outside the plot. Trees overhanging to the plots were excluded, but with their trunk inside of the sampling plots and branches out were included. Care was taken to ensure that the diameter tape is put around the stem exactly at the point of measurement.

According to the framework of the research study, equation suggested by Chave (2005)

(for dry forest stand) was selected.

$$AGTB = 0.112x\ (\S D^2 H)^{0.916}$$

Where,

AGTB = aboveground tree biomass (kg)

§ = wood specific gravity (kg m^{-3})

D = tree diameter at breast height (dbh) [cm]; and

H = tree height (m) (Subedi *et al*. 2010)

The wood specific gravity values were taken from the Volume Equations and Biomass Prediction of Forest Trees of Nepal by Sharma and Pukkala (1990).

The wood specific gravity of the tree species were taken and calculated. After taking the sum of all the individual biomass weights (in kg) of a sampling plots and dividing it by the area of sampling plots (400sq.m.), the biomass stock was obtained in kg m^{-2}.This value wasthen converted to t/ha by multiplying it by 10. The biomass stock was converted into carbon stock after multiplication with the IPCC (2006) default carbon fraction of 0.47.

3.4.3.2 BelowGround Biomass (BGB)

One of the most common descriptors of the relationship between roots (belowground) and shoot (aboveground) biomass is the root-to-shoot ratio, which has become the standard method for root biomass from the more easily measured shoot biomass. Belowground biomass estimation is much more difficult and time consuming than estimating aboveground biomass. Measurements of root biomass are indeed highly uncertain, and lack of empirical values for this type of biomass has for decades been a major weakness in ecosystem models (Geider *et al*. 2001). To simplify the process for estimating Below Ground Biomass (BGB), it is recommended to follow MacDicken(1997) root-to-shoot ratio value of 1:5 that is to estimate BelowGround Biomass as 20% of AboveGround Tree Biomass.(Subedi *et al*. 2010)

3.4.3.3 AboveGround Sapling Biomass (AGSB)

To determine the AboveGround Sapling Biomass (AGSB) (<5cm DBH), same equation used for the calculation of AGTB was used.

3.4.3.4 Leaf litter, Herb and Grass (LHG) biomass

To determine the biomass of the litter, herb and grass (LHG), samples were taken destructively in the field within a small area of $1m^2$. Fresh samples were weighed in the field; and a well - mixed sub sample was then placed in a marker bag. The sub sample was used to determine an oven-dry-to-wet mass ratio that was used to convert the total wet mass to oven-dry mass. A sub sample was taken to the lab and oven dried until constant weight to determine the water content. For the forest floor (herbs, grass, and litter), the amount of biomass per unit area is given by:

$$LHG = \frac{Wfield}{A} . \frac{Wsubsample,dry}{Wsubsample,wet} X\ 10$$(Subedi *et al*. 2010)

Where,

LHG = biomass of leaf, litter and grass [t/ha]

$Wfield$ = weight of the fresh field sample of leaf litter, herbs, and grass destructively sampled within an area of size A [gram]

A = size of the area in which leaf litter, herbs, and grass were collected [m^2]

$Wsubsample, dry$ = weight of the oven-dry sub sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [gram]; and

$Wsubsample, wet$ = weight of the fresh sub sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [gram]

The carbon content in *LHG, C (LHG),* was calculated by multiplying LHG with the IPCC 2006 default carbon fraction of 0.47.(Subedi *et al.* 2010)

3.4.3.5 Soil Organic Carbon (SOC)

Soil samples were collected from 0-10, 10-20 and 20-30 cm depths. Samples were taken from the field and transferred to the pre-weighed sampling bags. Wet weights of soils were determined in the field. Bulk density was estimated through core sampler method (Prikner*et al.* 2004). Bulk density of soil is required for the calculation of soil organic carbon. Soil sample collected were oven dried at 80 °C for 48 hours in hot air oven at the laboratory. Bulk density of soil was calculated by dividing oven-dried weight of soil by volume of the core sampler.

Bulk Density = Weight of Oven-dried Soil / Volume of Core Sampler (USDA-NCRS, 2013).

Soil organic carbon was determined by the titrimetric method developed by Walkley and Black (1934). For its determination, following procedure was followed:

- Air dried soil samples were passed through a 2 mm sieve to prepare sample for determining soil organic carbon.
- 0.5 gm of dried soil was weighed and transferred to the well labeled oven dried 500 ml conical flask.
- 10 ml 1 N potassium dichromate solution and 20 ml concentrated sulphuric acid was added and mixed by gentle swirling.
- The flask was kept for about 30 minutes to react with the mixture.
- After the reaction was over, the mixture was diluted with 200 ml of distilled water and 10 ml of phosphoric acid was added followed by 1 ml of diphenylamine indicator.
- The sample was titrated with 0.4 N ferrous ammonium sulphates, until end point is marked with changed color from black to the brilliant green.
- The blank was run as followed by above procedure without soil sample.

% Soil Organic Carbon is calculated as:

$\% C= 3.951/g [1 - T/S]$

Where,

g=weight of sample in gram,

T=ml ferrous solution with sample titration,

S=ml ferrous solution with blank titration.

The carbon stock density of soil organic carbon wascalculated as (Pearson *et al.* 2007

SOC = § x d x %C

Where,

SOC = soil organic carbon stock per unit area [t/ha]

§ = soil bulk density [g cm^{-3}]

d = the total depth at which the sample was taken [cm], and

%C = carbon concentration [%] (Subedi*et al*.2010)

3.4.3.6 Total carbon stock density

The carbon stock density is calculated by summing the carbon stock densities of the individual carbon pools of that stratum using the following formula. It should be noted that any individual carbon pool of the given formula could be ignored if it did not contribute significantly to the total carbon stock.

Carbon stock density of a stratum:

C (LU) = C (AGTB) +C (AGSB) + C (BB) + C (LHG) + SOC

Where,

C (LU) = carbon stock in density for a land us category [Mg C/ha]

C (AGTB) = carbon in AboveGround Tree Biomass [Mg C/ha]

C (AGSB) = carbon in AboveGround Sapling Biomass [Mg C/ha]

C (BB) = carbon in BelowGround Biomass [Mg C/ha]

C (LHG) = carbon in Leaf litter, Herb and Grass [Mg C/ha], and

SOC = Soil Organic Carbon [Mg C/ha]

The total forest carbon stock was then converted to tons of CO_2 equivalent by multiplying by 44/12, or 3.67.

3.5 Statistical Analysis

Microsoft Excel was used for the data recording and database preparation and R(R Development Team 2013)software was used for the statistical analysis. Statistical analysis such as t-test and linear regression were performed to study the significant difference between two variables. Parameters such as standard deviation were calculated using the respective formula.

3.5.1 Standard Deviation (s)

$$(s) = \frac{\sqrt{(x^2 - \bar{x}\sum x)}}{\sqrt{(N-1)}}$$

Where, Σx= total number of individuals of a speciex   =mean number of individual of a species

N= number of observation

3.5.2 Standard Error (S.E.)

$$(S.E.) = \frac{s}{\sqrt{N}}$$

Where, s = Standard deviation

N = number of observation

Chapter 4

RESULTS

4.1 Vegetation parameters

Different parameters were analyzed for the vegetation analysis in the forest of both aspects. Number of species was found higher (11) in the forest of northern aspect (F_{NA}) as compared with the forest of southern aspect (F_{SA}) with 2species. Similarly, higher tree density (300 trees/ha) was observed in F_{NA} followed by 225 trees/ha in F_{SA}. Some of the important vegetation parameters analyzed are presented in Table 4.1

Table 4.1:Vegetation parameters with variation in aspect

Parameters	**Forest on northern aspect(F_{NA})**	**Forest on southern aspect (F_{SA})**
Number of species	11	2
Shannon-Wiener Index (H')	1.54	0.16
Index of Dominance (c)	0.34	0.93
Evenness Index (e)	1.6	0.28
Mean dbh (cm)	23.71	16.89
Mean height (m)	14.27	7.74
Tree density(number/ha)	300	225
Mean basal area (m^2/ha)	18.6	6.53

Density of tree species in different dbh class is shown in figure 4.1

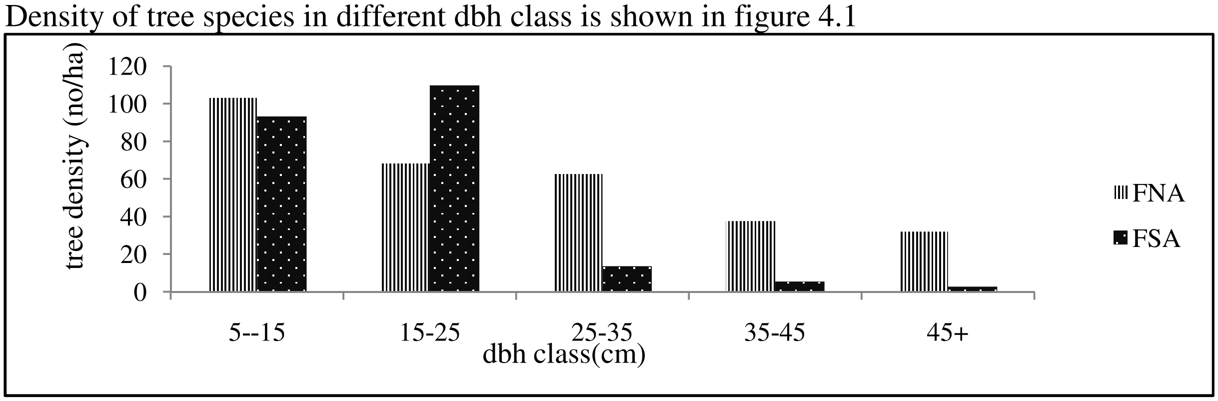

Fig 4.1:dbh class in the forests of opposite aspects

4.2 Quantitative data

The relative density, relative basal area and relative frequency were calculated and summed to calculate the Importance Value Index (I.V.I.). The I.V.I. of different species in the forests of opposite aspect is shown in Table 4.2.

Table 4.2: I.V.I. of different species

S.N.	Species	Importance Value Index (I.V.I.)	
		Northern aspect (F_{NA})	Southern aspect (F_{SA})
1	*Castanopsis*sp	28.24	
2	*Cedrusdeodara*	44.84	
3	*Celtus*sp	7.35	24.56
4	Garam (v.n.)	3.55	
5	*Piceasmithiana*	8.71	
6	*Pinuswallichiana*	153.68	275.44
7	*Rhododendron arboreum*	24.06	
8	Thamali (v.n.)	3.33	
9	Toksang (v.n.)	10.28	
10	Unknown	4.76	
11	Unknown 1	11.2	

4.3 Biomass estimation

4.3.1 Total carbon stock density

Total average forest carbon stock in F_{NA} was calculated to be 112.34 ± 13.87tC/ha and that of F_{SA} carbon stock was calculated to be 58.04 ± 6.25tC/ha. From this estimation, it can be concluded that the total carbon stored in 70 ha of forest in F_{NA} would be 7863.8 ton and that in F_{SA} would be 1741.2 ton in 30 ha. Table 4.3a and 4.3b show the average carbon stock density of all the measured components in opposite aspects.

Table 4.3a: Carbon Stock density in F_{NA}

S.N.	Average carbon stock density ± S.E. (tC/ha)		Standard Deviation
1.	AGTB + BGB	74.6 ± 13.58	57.63
2.	AGSB	0.054 ± 0.017	0.05
3.	LHGB	0.61± 0.06	0.25
4.	SOC (upto 10cm depth)	37.1± 0.7	2.96
	Total	**112.34** ± 13.87	58.87

Table 4.3b: Carbon Stock density in F_{SA}

S.N.	Average carbon stock density ± S.E. (tC/ha)		Standard Deviation
1.	AGTB + BGB	15.02± 6.14	6.14
2.	AGSB	0.06± 0.02	0.05
3.	LHGB	0.33± 0.031	0.094
4.	SOC (upto 10cm depth)	42.6± 0.83	2.5
	Total	**58.04**± 6.25	18.75

4.3.2 Carbon stock variation in altitude

4.3.2.1 Northern Aspect (F_{NA})

In northern aspect, the maximum value of carbon stock density was found at the altitude of 2300m and the lowest value of carbon stock was at the altitude of 2700m.The trend of carbon stock density variation with altitude from 2100m to 2700m was found downward curved type indicating that carbon stock density decreases with increasing altitude except in the first contour of 2100m. Fig 4.3a shows carbon stock variation in northern aspect (F_{NA}).

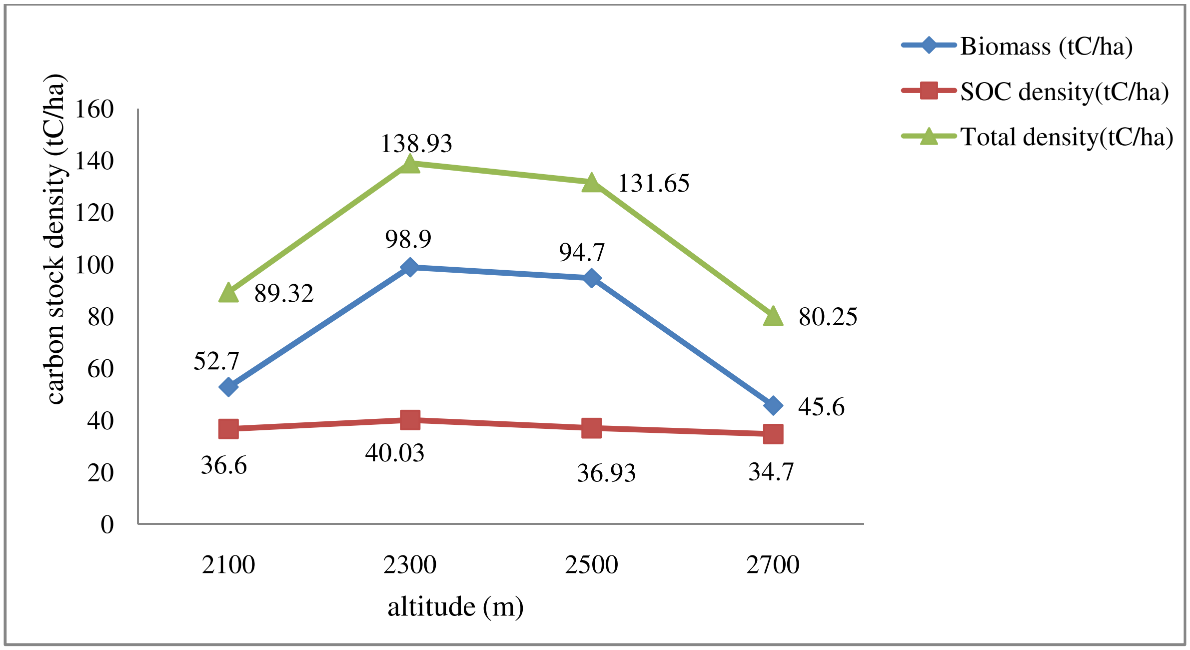

Fig4.3a: Carbon stock in different altitudes in F_{NA}

4.3.2.2 Southern Aspect (F_{SA})

In forest of southern aspect (F_{SA}), the trend of carbon variation with respect to altitude was different than that of the F_{NA}. The average carbon stock density was lowest at the 2500m, i.e. 50.25tC/ha. At that altitude, biomass stock and SOC also had the least value. Similarly, the maximum value of Carbon stock density was calculated at the highest altitude measured, i.e. at 2700m and the value was measured to be 101.01tC/ha. Fig 4.3b shows the carbon stock variation in different altitudes in southern aspect (F_{SA}).

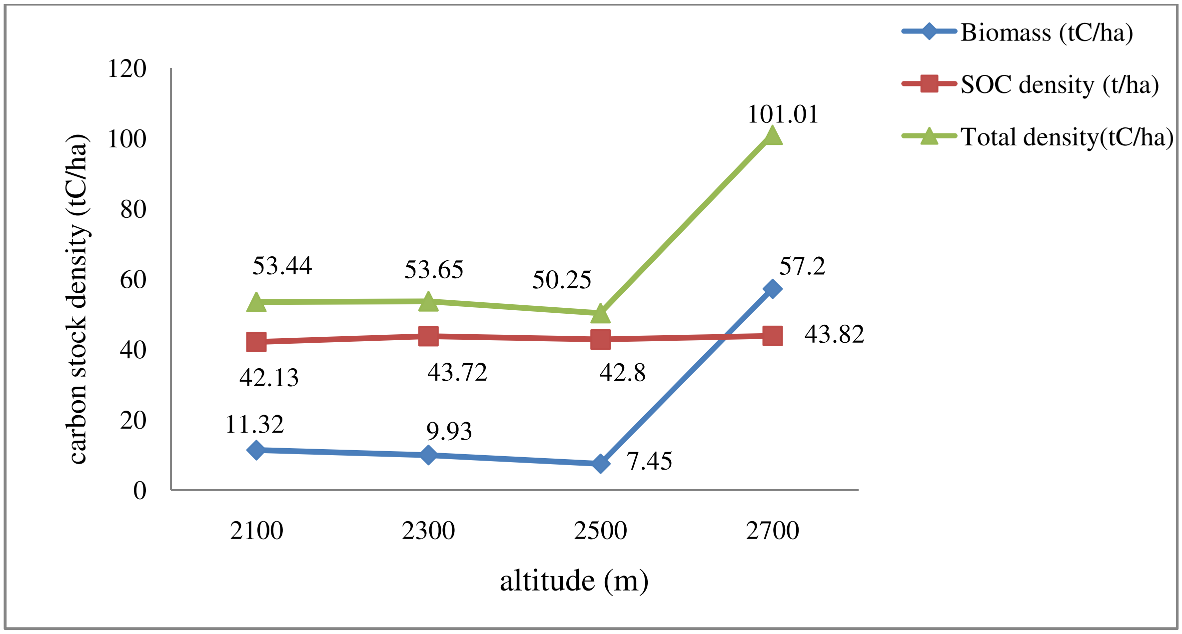

Fig 4.3b: Carbon stock in different altitudes in F_{SA}

4.4 Statistical analysis of carbon stock variation in aspects

The variation in carbon stock density was analyzed using box and whisker models by R-software and Microsoft Excel. The parameters compared were AGTB+BGB, SOC and LHG. AGSB was not compared because in some plots, the saplings were absent and the value of sapling was also very low. The parameters were compared to carry out whether the values were significantly different in the opposite plots. The significance was tested using the box and whisker model.

4.4.1.AboveGround Tree and Belowground Biomass(AGTB+BGB)

The Aboveground Tree Biomass andBelowground Biomass (AGTB+BGB) carbon of both aspects were compared and were found significantly different ($p > 0.05$) (Fig 4.4 a).

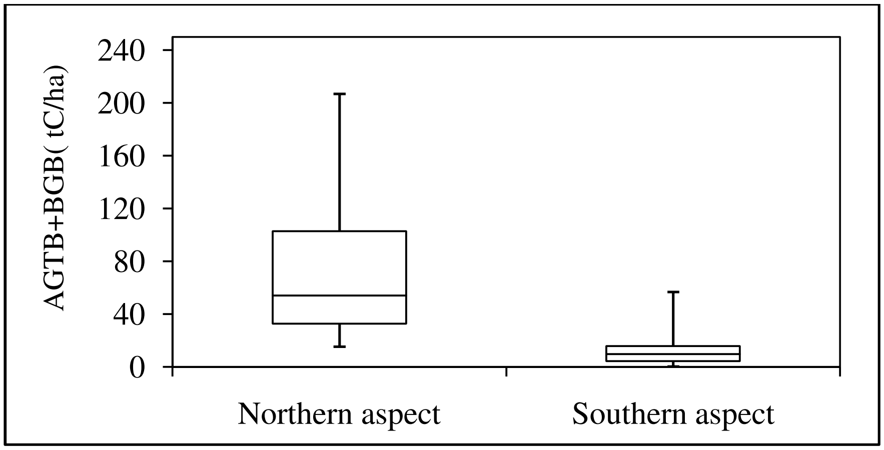

Fig 4.4a: Variation of AGTB+BGB Carbon with change in aspect

4.4.2. Leaf litter, Herb and Grass Biomass (LHGB)

Comparison of LHG biomass also showed the similar result. The LHG biomass density (tC/ha) was significantly higher in Northern aspect (0.61± 0.06tC/ha) than on southern aspect (0.33 ± 0.031tC/ha). The values of LHGB in opposite aspects were varied significantly ($p > 0.05$) (Fig 4.4b).

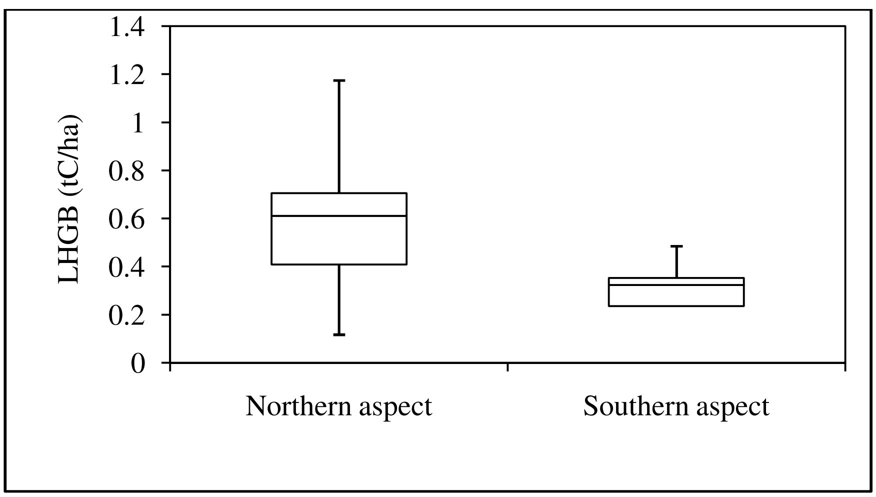

Fig 4.4b: Variation of LHGB Carbon with change in aspect

4.4.3. Soil Organic Carbon (SOC)

The Soil Organic Carbon density (tC/ha) showed the opposite pattern unlike the previous observed parameters. The SOC content of the southern aspect was higher than that of the northern aspect. Analysis of Fig 4.4c indicated that the value of SOC were not significantly different ($p < 0.05$).

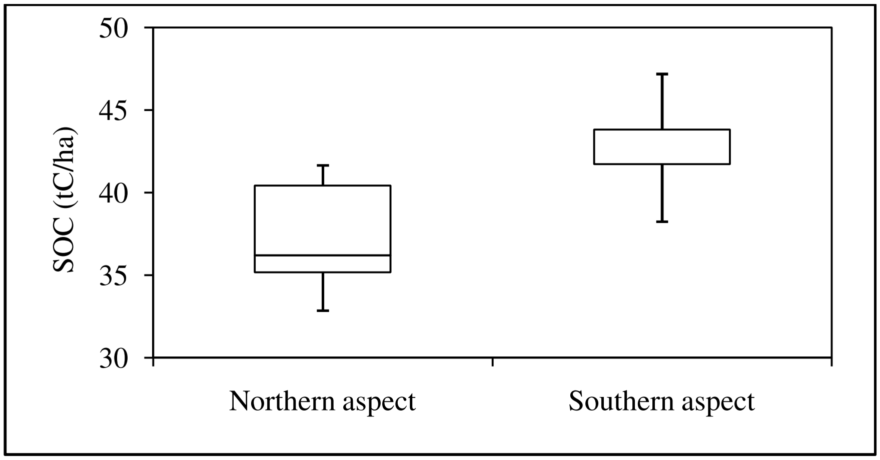

Fig 4.4c: Variation of SOC with change in aspect

4.5 Regeneration of different species

4.5.1 Regeneration in northern aspect

The forest in the northern aspect (F_{NA}) contained the seedling of 6 species from the studied plots. The highest number of seedling was of *Castanopsis*sp, followed by Toksang, *Cedrusdeodara* and *Pinus wallichiana* (Table 4.5 a).

Table 4.5a: Regeneration of species in northern aspect (F_{NA})

S.N.	**Species name**	**Regeneration (number/ha)**
1.	Toksang (v.n.)	325
2.	*Cedrus deodara*	180
3.	*Pinus wallichiana*	116
4.	*Rhododendron arboreum*	75
5.	*Castanopsis* sp	500
6.	Unknown 1	150

4.5.2 Regeneration in southern aspect

The regeneration status of the forest on southern aspect was not prominent as compared with the forest on the northern aspect. Only the seedlings of *Pinus wallichiana* were observed in the studied plots (Table 4.5b).

Table 4.5b: Regeneration of species in southern aspect (F_{SA})

S.N.	**Species name**	**Regeneration (number /ha)**
1.	*Pinus wallichiana*	160

Chapter 5

DISCUSSION

5.1 Vegetation parameters

More species were found in forest of northern aspect (F_{NA}) than on southern aspect ($F_{SA)}$. This might be due to the favorable condition and moist environment in northern aspect, as slope aspect also plays a key role in determining the temperature regime and microclimate (Sharma *et al*. 2011). The southern aspect was relatively dry and was under the direct exposure of sunlight. Similarly, Shannon- Wiener diversity index was also higher in F_{NA}. In contrast, Index of dominance was lower in F_{NA}. Generally, dominance and diversity are reciprocal to each other. Higher diversity means more variety of species whereas high dominance index means only few species is dominant in the specific community. Similarly, analysis of evenness index showed that evenness was high in F_{NA}indicating that the species are relatively evenly distributed in F_{NA}. Mean dbh and mean height of tree species were recorded higher in F_{NA}. This might be due to the fact that F_{NA} contained higher number of *Pinuswallichiana* and were towards maturity. In case of F_{SA}, most of *Pinuswallichiana* trees were smaller in size due to the relatively harsh environmental condition and human disturbances.

While analyzing diameter distribution in forest types, number of stem per hectare decreased with the increase in dbh in the case of F_{NA}. But the trend was irregularin F_{SA} as the number of trees in 5-15 cm dbh class was less than that in the 15-25 cm dbh class. It could be due to the natural and human disturbances against the lower dbh plants. Except this alteration, the overall graph was inverse J-shaped indicating the immature condition of the forest.

5.2 Quantitative data analysis

I.V.I. values express the dominance and ecological succession of any species with the single value. In the northern aspect (F_{NA}), *Pinus wallichiana* had the highest value of I.V.I. followed by *Cedrus deodara* and *Castanopsis*sp. This showed that *Pinus wallichiana* is dominant species on the basis of I.V.I. value as well. Similarly, other tree species associated were *Cedrusdeodara* and *Castanopsis*spwhich are suitable on that altitude in the Pine-dominated forest. Southern aspect (F_{SA}) contained only two species in the studies plots, *Pinuswallichiana*was dominant in terms of Importance value and was found to be associated with *Celtis*sp.This indicates that the F_{SA} is facing the relatively harsh environment and is suitable for very few tree species.

5.3 Biomass carbon estimation

5.3.1 Aboveground and belowground biomass carbon

Trees are the plants that can develop a large biomass and capturing a large amount of carbon over a growth cycle of many decades. So, forest can capture and retain a large volume of carbon for a long period of time. The carbon sink and storage in the forest are dependent with each other.

Many trees in the studied forests had the dbh of less than 15 cm. Trees in forest (including plantation) if well stocked, typically sequester carbon at a maximum rate between about age 10 and 20-30. As an indicator, at age 30 years, about 200-520 tonnes Carbon dioxide(CO_2-e) are sequestered per ha in forests with productivity ranging from low to high (Australian Greenhouse office 2001) (Johnson & Coburn 2010). So, the studied forest might have the potentiality to sequester more carbon.

In the studied forest of Manaslu Conservation Area (MCA), the F_{NA} got the higher tree biomass stock than F_{SA}. Due to the higher stem density (300 tree/ha), high mean basal area (18.6 m^2/ha) than the F_{SA}, the forest in this aspect had higher biomass/ha.

The biomass carbon of F_{NA} was comparable other similar forests. Jati (2012) had carried out the study in *Betula utilis* forest in KCAP and found out that the biomass carbon stored in tree biomass was 166.81 t/ha. Similarly, among the species present in the F_{NA}, *Pinuswallichiana, Cedrusdeodara* and *Castanopsis*sphad covered almost 96.9% of total carbon stock and the species density of the above mentioned tree species was 76.25%. So, *Pinuswallichiana* have played the important role in the vegetation composition in F_{NA}.

In $F_{SA,}$ the stem density was lower than the F_{NA}, having 228 trees/ha. Similarly, mean basal area of F_{SA} was 6.53 m^2/ha. So, these factors have led to the lower value of biomass per ha in F_{SA}, i.e. 15.02± 6.14tC/ha. *Pinuswallichiana* had covered almost 98.6% of the total carbon stock in $F_{SA}$and species density of *Pinuswallichiana* was almost 96%. So, *Pinuswallichiana* was dominant species in the F_{SA} also.

Many environmental factors (e.g. temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity) change systematically with altitude (Gairola*et al*. 2011). In F_{NA}, the increase in altitude has led to decrease in biomass density and so as the SOC. Low biomass in lower altitudes might be the cause of decreased SOC. Similarly, in F_{SA}, increase in altitude has also increased the biomass content but SOC value has not changed significantly in altitudinal gradient. The results obtained on F_{SA} were similar with the findings of Jati, 2012 in KCCF where minimum carbon amount was found in altitude of 3200-3400 m.a.s.l. and maximum carbon content was found in altitude above 3800 m a.s.l.

5.3.2 Soil carbon

Soil, being the largest carbon reservoir of the terrestrial carbon cycle, about three times more carbon is contained in soil than in the world's vegetation and soils hold double the amount of carbon that is present in the atmosphere (Sheikh *et al.* 2009).But the SOC value of F_{NA} is less than that of F_{SA}. There might be different factors for such results. SOC is determined by the solar radiation, ground vegetation, biomass content and microbial activities and so on. One aspect of the organic carbon pool that remains poorly understood is its vertical distribution in the soil and accompanying relationship with climate and vegetation (Jobbagy & Jackson 2000). The increase in temperature leads to the increase in production and decomposition. This might be the reason for the slight variation in the SOC content in the two opposite aspect.

The result obtained by Sheikh *et al.* (2009) was different from this study because SOC density (185 tC/ha) in lower altitude (1600-1800 m) was obtained higher than the SOC (160.8tC/ha) in higher altitude (2000-2200 m). Hence, SOC might vary in altitudinal gradient but it is dependent to the altitude as increase in altitude leads in increased SOC.

The Soil Organic Carbon of below 10 cm was excluded from the study to maintain regularity because in 10 higher plots on F_{NA}, i.e. 2700 m and 2500 m, soil samples were not possible to extract due to presence of intact rock mass.

5.3.3 Total Carbon Comparison

The average carbon stock in F_{SA} and F_{NA} was 112.34tC/ha and 58.04tC/ha respectively. The values of carbon stock of this study are lower than the values obtained by ICIMOD, ANSAB and FECOFUN (2010), in*Shorearobusta* mixed sub- tropical hill deciduous forest in Ludikhola of Gorkhawas (165.91 tC/ha to 216.16tC/ha). The avoidance of SOC results below 10 cm in both aspects is one of major causes for the lowering of Carbon stock density.

Similarly, the C-stock densities estimated by different studies were different. Baral*et al.*(2009) have calculated the Total Aboveground carbon stock of Pine forest 38.70 tC/ha. The value was lower than the F_{NA} but higher than F_{SA}. This indicates that the F_{SA} is not well developed in terms of biomass stock.

Similarly, Shrestha (2009) studied in two different forests and concluded that the soil carbon value is significantly higher than the biomass carbon stock. The soil carbon composition was 55% in *Shorea* forest and it was 74% in *Schima- Castanopsis* forest. This result is different in in the case of F_{NA} as the share is 33.02% but similar with F_{SA} whose share was 73.4%.

5.4 Variation of C-pools in altitude and aspect

Altitude is one of the main factors for the vegetation type because of the variation in temperature, humidity, rainfall, soil and slope (Jati 2012). Many factors are involved in the variation of carbon stock density in the slope. The biomass carbon stock density and SOC were also varied in the slope. Therefore, altitude plays significant role in the variation of carbon in the forest.

Aspect also plays a major role in C-stock variation. The F_{NA} has the greater share of all C-pools than F_{SA} except SOC. The result obtained in the present study was applicable with the study by ICIMOD, ANSAB & FECOFUN (2010) as northern aspect has led all other aspects in Ludikhola in terms of aspect wise per hectare forest carbon stock and south aspect holds the least forest carbon stock.

5.5 Regeneration Status

The number of stems and seedlings per ha have not varied in F_{NA}. The stem density of *Pinuswallichiana*was highest but the regeneration of *Castanopsis*spand*Cedrusdeodara* wasfound higher. But, seedlings of *Pinuswallichiana* were regular and having higher frequency (44%) than *Castanopsis*sp (6%) and *Cedrusdeodara* (27%). This indicated that the seedlings of *Pinuswallichiana*are uniforn in distribution andso the forest structure and composition might not change in coming years.

In the F_{SA}, only the seedlings of *Pinuswallichiana* were observed indicating the current pattern of forest structure in $F_{SA.}$

Chapter 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The Thanye and Sharke forest, referred as the forests on the northern aspect (F_{NA}), and the Chhak forest on the southern aspect (F_{SA}) were studied and their vegetation parameters along with carbon stock density were assessed. It can be concluded that the forest on both the aspect can sequester more carbon as the trees have still lower dbh values having greater tendency to grow in the future. *Pinuswallichiana* was the dominant tree species in both aspects on the basis of Importance Value Index (I.V.I.) as well as carbon stock density. The F_{NA} had more tree density, trees having larger dbh and higher carbon stock density than $F_{SA.}$. But, the SOC was found to be higher slightly in $F_{SA.}$

Altogether 11 tree species were found in $F_{NA.}$ Shannon -Weiner diversity index was also higher in F_{NA} but dominance index was low in F_{NA}. Similarly, the tree density was also found higher in F_{NA}, having 300trees /ha. The mean basal area of F_{NA} was estimated to be 18.6 m^2/ha, significantly higher than the F_{SA} whose mean basal area was 6.53 m^2/ha and tree density was 225 trees/ha.

The carbon stock density of F_{NA} (112.34tC/ha) was higher than that of the F_{SA}(58.77 tC/ha). All the values of C-pools except SOC were higher in F_{NA}. The SOC in F_{NA} was 37.1tC/ha whereas the value was 42.6tC/ha in F_{SA} measuredupto the depth of 10 cm. The value of SOC was analyzed only upto the depth of 10 cm due to the inability to extract soil samples below 10 cm in higher 10 samples of F_{NA} due to the presence of intact rock.

6.2 Recommendation

The study of carbon stock and sequestration has been largely carried out in the community forests of Nepal but very few research works have been carried out them in the protected areas of Nepal. So, the study of the forest composition and carbon issues should be encouraged to conduct in the protected area by the government.

REFERENCES

ANSAB.2010. *Report on Forest Carbon Stock of Community Forest in three watersheds (Ludikhola, Kayarkhola and Charnawati)*. Asia Network for Sustainable Agriculture and Bioresources, Federation of Community Forest Users, Nepal, International Centre for Integrated Mountain Development & Norwegian Agency for Development Cooperation.49 pp.

Aryal, C. 2010. *Status of carbon Stock at ToudolChhap Community Forest, Sipadol, Bhaktapur.*Central Department of Environmnetal Science, Tribhuwan University.

Baral S.K., R.Malla and S.Ranabhat .2009.Above-ground carbon stock assessment in different forest types of Nepal. *BankoJankari**19**:10-14.*

Bayat, A.T.2011.*Carbon Stock in an Apennine Beech Forest.*Faculty of Geo-Information Science and Earth Observation, University of Twente.

Bhusal, R.P. 2010. *Carbon Stock Estimation of Nagmati Watershed (Shivapuri National Park).*Central Department of Environmental Science, Tribhuwan University.

Brown, S., J.Sathaye, M. Cannell,&P. Kauppi.1996. Mitigation of carbonemission to the atmosphere by forest management.*Complete Forestry Review **75:** 80-91.*

Campbell, A., L. Miles, I. Lysenko, A. Hughes, &H. Gibbs. 2008.*Carbon storage in protected areas: Technical report*. United Nations EnviromentProgram-World Conservation Monitoring Centre.

Chave, J., C. Andalo, S. Brown, M. Cairns, J. Chambers, D. Eamus, H. Folster, F.Fromard, N. Higuchi, T. Kira, J.-P. Lescure, B. Nelson, H. Ogawa, H. Puig, B. Riera & T.Yamakura. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia **145:** 87-99.*

Chhetri, M. R. 2010.*Status of the Carbon Stock at Syalmati Watershed, Shivapuri National Park*.Central Department of Environmental Science, Tribhuwan University.

Clark, S., K. Bolt & A. Campbell. 2008. *Protected areas: an effective tool to reduce emissions from deforestation and forest degradation in developing countries?*Working Paper, UNEP World Conservation Monitoring Centre, Cambridge, U.K.

Curtice, J. 1959. *The Vegetation of Wisconsin : An ordination of plant communities.* The University of Wisconsin Press, Madison, Wisconsin. 657 pp.

DeFries, R., M. Hansen, J.R.G.Townshen, A.C. Janetos, & T.R. Loveland.2000. A new global 1km data set of percent tree cover derived from remote sensing. *Global Change Biology **6:** 247-254*.

Dixon, R. K., S. Brown, R.A. Houghton, A.M. Solomon, M.C.Trexler& J. Wisniewski.1994. Carbon Pool and flux of Global Forest Ecosystem. *Science **263:**185-190.*

ForestryNepal.2013. *Forest Types of Nepal* [Online]. ForestryNepal. Available: http://www.forestrynepal.org/notes/silviculture/forest-types.[Accessed September 22, 2013]

Geider, R. J.,E.H. Delucia, P.G. Falkowski, A.C. Finzi, J.P. Grime, J. Grace, T.M. Kana, J. La Roche, S.P. Long, B.A. Osborne, T. Platt, I.C. Prentice, J.A. Raven, W.H. Schlesinger, V. Smetacek, V. Stuart, S. Sathyendranath, R.B. Thomas, T.C. Vogelmann, P. Williams & F.I. Woodward. 2001. Primary productivity of planet earth: biological determinants and physical constraints in terrestrial and aquatic habitats. *Global Change Biology **7**: 849-882.*

Ghimire, S. K., I.B. Sapkota, B.R. Oli, & R.R. Parajuli. 2008. *Non-Timber Forest Products of Nepal Himalaya: Database of Some Important Species Found in the Mountain Protected Areas and Surrounding Regions.*Kathmandu, Nepal, WWF Nepal.186 pp.

Gibbs, H. K., S. Brown, J.O. Niles& J.A. Foley. 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters* ***2:*** *1-13.*

Gibbs, H K & S. Brown. 2007a. Geographical distribution of woody biomass carbon stocks in tropical Africa: an updated database for 2000. Available at http://cdiac.ornl.gov/epubs/ndp/ndp0555/ndp05b.html

Hanson, H. C. & E.D. Churchill. 1961. *The plant community*, Reinhold Publishing Corporation,New York, U.S.A. 218 pp.

Hunt, C. A. G.2009.*Carbon Sinks and Climate Change: Forest in the Fight against Global Warming.* Edward Elger Publishing Limited, U.K. 236 pp.

IPCC, 2006.*IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme*ed H S Eggleston, L Buendia, K Miwa, T Ngara and K Tanabe (Japan: Institute For Global Environmental Strategies)

IPCC, 2007.*Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B.M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IUCN. (2012, September 2, 2012). "Protected Areas Category VI." from http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories/gpap_category6/.

Jana, B. K., S. Biswas, M. Majumder, P.K. Roy & A. Mazumdar.2009. Comparative Assessment Of Carbon Sequestration Rate And Biomass Carbon Potential Of Young

Shorearobusta and Albizzialebbek. International Journal of Hydro-Climatic Engineering ***1:****1-15.*

Jati, R.2012.*Comparative Study of Carbon Assessment: A Study on Carbon Stock in Kumvakarna Conservation Community Forest*. Department of Environmental Science, Khwopa College,Tribhuwan University.

Jina, B. S., P. Sah, M.D. Bhatt, & Y.S. Rawat.2008.Estimating Carbon Sequestration Rates and Total Carbon Stockpile in Degraded and Non-Degraded Sites of Oak and Pine Forest of Kumaun Central Himalaya. *Ecoprint****15:****75-81.*

Jobbagy, E. B. & R.B. Jackson. 2000. The vertical distribution of Soil Organic carbon and its relation to climate and vegetation. *Ecological Applications* ***10:*** *423-436.*

Johnson, I. & R. Coburn. 2010.*Trees for carbon sequestration*. NSW Government, Australia. 6 pp.

Joppa, L. N., S.R. Loarie, & S.L. Pimm .2008.On the protection of "protected areas".*In: Proceedings of the National Academy of Sciences of the USA*, pp. 6673-6678.

Karki, K. B. 2008.Atmospheric Carbon and Foood Security in Nepal.*The Journal of Agriculture and Environment* ***9:****54-61.*

Keeeling, C.D., S.C. Piper & M. Heimann. 1989. A three-dimensional model of atmospheric CO2 transport based on observed winds: *4. Mean annual gradients and interannual variations.*American Geophysical Union, USA, Pp.305-363.

Kumar, S., M. Kumar & M.A. Sheikh. 2013. Carbon Stock Variation of *Pinusroxburghii*Sarg. Forest along Altitudes of Garhwal Himalaya, India.*Russian Journal of Ecology* ***44:****131-136.*

MacDicken, K. 1997.A Guide to Monitoring carbon Storage in Forestry and Agroforestry Projects.Winrock International Institute for Agricultural Development, Arlington, USA.87 pp.

Nepstad, D., S. Schwartzman, B. Bamberger, M. Santilli, D. Ray, P. Schlesinger, P. Lefebvre, A. Alencar, E. Prinz, G. Fiske & A. Rolla. 2006. Inhibition of Amazon Deforestation and Fire by Parks and Indigenous Lands. *Conservation Biology* ***20:*** *65-73.*

Nizami, S. M. 2010.*Estimation of Carbon Stocks in Subtropical Managed and Unmanaged Forests of Pakistan*.Ph.D. dissertation.PirMehr Ali Shah Arid Agriculture University, Pakistan.

NTNC.2009. *Profile of NTNC*, National Trust for Nature Conservation.

Odum, E. P.1967. *Fundamentals of Ecolgy.*W.B. Saunders Company, Philadelphia, USA.574 pp.

Oli, B. N. & K. Shrestha.2009. Carbon Status in Forests of Nepal: An Overview. *Journal of Forest and Livelihood 8****:*** *62-67.*

Pan, Y., R.A. Birdsey, J. Fang, R. Houghton, P.E. Kauppi, W.A. Kurz, O.L. Phillips, A. Shvidenko, S.L. Lewis, J.G. Canadell, P. Ciais, R.B. Jackson, S.W. Pacala, A. D. Mcguire, S.Piao, A. Rautiainen, S. Sitch&D. Hayes. 2011. A Large and Persistent Carbon Sink in the World's Forests. *Science* ***333:*** *988-993.*

Pearson, T., S. Brown & R. Birdsey.2007.*Measurement Guidelines for the Sequestration of Forest Carbon.*General Technical Report NRS-18.Northern Research Station, Department of Agriculture, USA, 47 pp.

Ramachandran, A., S. Jayakumar, R.M. Haroon, A. Bhaskaran& D.I. Arockiasamy.2007. Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. *Current Science* ***92:****323-331*.

Rana, E. B., H. L. Shrestha& R. Silwal.2008. Participatory Carbon Estimation in Community Forest: Methodologies and Learnings. *The Initiation,* 2**,** 91-98.

Scharlemann, J.,V. Kapos, A. Campbell, I. Lysenko, N.D. Burgess, M.C. Hansen, H.K. Gibbs, B. Dickson & L. Miles. 2010. Securing tropical forest carbon: the contribution of protected areas to REDD. *Oryx* ***44:****352-357.*

Shannon, C. E. 1948. A Mathematical Theory of Communication.*The Bell System Technical Journal* ***27:*** *379-423*.

Sharma, C., S. Gairola, N. Baduni, S. Ghildiyal& S. Suyal. 2011. Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya, India. *Journal of Bioscience* ***36:*** *701-708.*

Sharma, E. R. & T. Pukkala. 1990. *Volume Equations and Biomass Prediction of Forest Trees of Nepal*. Forest Survey and Statistics Division,MFSC. 85 pp.

Sheikh, M. A., M. Kumar & R.W. Bussman. 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and Management****4*** *(6).*

Sheikh, M. A., M. Kumar, R.W. Bussman& N. Todaria. 2011. Forest carbon stocks and fluxes in physiographic zones of India. *Carbon Balance and Management* ***6:*** *1-10.*

Shrestha, B. P. 2009.Carbon sequestration in *Schima- Castanopsis*Forest: A case study from Palpa district. *The Greenery (A Journal of Environment and Biodiversity)* ***7:*** *34-40.*

Simpson, E. H. 1949. Measurement of Diversity. *Nature **163:** 688-688.*

Subedi, B. P., S.S. Pandey, A. Pandey,E.B. Rana, S. Bhattarai, T.R. Banskota, S. Charmakar& R Tamrakar. 2010. *Guidelines for measuring carbon stocks in community-managed forests*. ANSAB, ICIMOD, FECOFUN, NORAD. 79 pp.

Tamrakar, P. 2000.*Biomass and Volume Tables with Species Description for Community Forest Management.Kathmandu*.TISC Technical paper series no.101 MoFSC.90 pp.

Task Force on Economic Benefits of Protected Areas of the World Commission on Protected Areas (WCPA) Of IUCN, in collaboration with the Economics Service Unit of IUCN.1998.*Economic Values of Protected Areas: Guidelines for Protected Area Managers*. IUCN, Gland, Switzerland and Cambridge, U.K.

USDA-NRCS. 2013. *Soil Bulk Density/ Moisture/ Aeration* [Online]. United States Department of Agriculture, natural resource Conservation Centre. Available: http://soils.usda.gov/sqi/assessment/files/bulk_density_guide.pdf [Accessed: 22 September 2013].

Walkley, A. J. & I.A. Black.1934. An examination of Degtjareffmethod for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science **37:***29-38.

Zhu, B., X. Wang, J. Fang, S. Piao, H. Shen, S. Zhao &C.Peng. 2010. Altitudinal changes in carbon storage of temperate forests on Mt Changbai, Northeast China. *Journal of Plant Research **123:** 439-452*

Zobel, D., P. Jha, M. Behan & U. Yadav. 1987. *A practical manual for Ecology*.RatnaBook Distributors, Kathmandu, Nepal.149 pp.

ANNEXES

Annex 1. Vegetation Parameters

1.1 Northern aspect

Species	Relative Basal Area (RBA)	Relative Frequency (RF)	Relative Density (RD)	I.V.I.
*Castanopsis*sp	11.4	9.43	7.4	28.23
Cedrusdeodara	14.96	13.2	16.67	44.83
*Celtus*sp	3.61	1.89	1.85	7.35
Garam	0.74	1.89	0.92	3.55
Piceasmithiana	0.26	5.66	2.78	8.7
Pinuswallichiana	66.5	32.07	55.09	153.66
Rhododendron arboreum	1.06	16.98	6.02	24.06
Thamali	0.054	1.89	1.39	3.334
Toksang	0.45	5.66	4.17	10.28
Unknown	0.06	3.77	0.93	4.76
Unknown 1	0.88	7.55	2.78	11.21

1.2 Southern aspect

Species name	Relative Basal Area (RBA)	Relative Frequency (RF)	Relative Density (RD)	I.V.I.
*Celtis*sp	2.68	18.18	3.7	24.56
Pinuswallichiana	97.32	81.82	96.3	275.44

Annex 2. Biomass Carbon Estimation

2.1 Northern aspect

S.N.	Plot No.	AGTB+BGB(tC/ha)	AGSB(tC/ha)	LHG(tC/ha)	SOC(upto 10 cm)(tC/ha)	Total (tC/ha)
1	T1N1	18.82	0.2	0.587	36.058	55.665
2	T1N2	32.55		0.314	35.976	68.84
3	T1N3	60.83		0.47	33.524	94.824
4	T1N4	77.37	0.08	0.914	34.75	113.114
5	T1N5	35.4	0.054	0.388	32.992	68.834
6	T2N1	92.19		0.357	35.036	127.583
7	T2N2	139.5		0.623	36.794	176.917
8	T2N3	33.45		1.175	35.568	70.193
9	T2N4	29.22	0.02	0.621	37.162	67.023
10	T2N5	176.36	0.017	0.1175	40.065	216.5595
11	T3N1	137.3		0.382	36.341	174.023
12	T3N2	206.87	0.037	0.607	41.656	249.17
13	T3N3	78.8	0.023	0.823	40.533	120.179
14	T3N4	20.62		0.912	40.942	62.474
15	T3N5	47.48	0.01	0.587	40.712	88.789
16	T4N1	34.39	0.014	0.705	32.863	67.972
17	T4N2	15.31	0.1	0.614	35.888	51.912
18	T4N3	106.26	0.037	0.705	41.065	148.07
Mean		74.6	0.054	0.6	37.1	112.34
Standard Deviation		57.63	0.056	0.25	2.96	58.87
Standard Error		13.58	0.0167	0.06	0.7	13.88

2.2 Southern aspect

S.N.	Plot No.	AGTB+BGB (tC/ha)	AGSB (tC/ha)	LHG (tC/ha)	SOC(upto 10 cm) (tC/ha)	Total (tC/ha)
1	T1S1	56.86	0.014	0.319	43.817	101.01
2	T2S1	9.79		0.235	44.364	54.389
3	T2S2	4.49	0.06	0.324	41.234	46.108
4	T3S1	9.68	0.014	0.235	43.718	53.647
5	T4S1	32.09	0.044	0.352	41.73	74.216
6	T4S2	15.76		0.336	41.73	57.826
7	T4S3	0.4	0.17	0.47	41.73	42.77
8	T4S4	4.48	0.048	0.485	38.25	43.263
9	T4S5	1.64	0.07	0.235	47.195	49.14
Mean		**15.02**	**0.06**	**0.33**	**42.64**	**58.041**
Standard Deviation		**18.42**	**0.053**	**0.094**	**2.5**	**18.75**
Standard Error		**6.14**	**0.02**	**0.03**	**0.83**	**6.25**

Annex 3. Soil Organic Carbon

3.1 Northern aspect

Plot no.	Bulk density (gm/cc)			Carbon stock density (tC/ha)			Total carbon stock (tC/ha)
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	
T1N1	0.882	NA	NA	36.058	NA	NA	NA
T1N2	0.88	NA	NA	35.976	NA	NA	NA
T1N3	0.82	NA	NA	33.524	NA	NA	NA
T1N4	0.85	NA	NA	34.75	NA	NA	NA
T1N5	0.807	NA	NA	32.992	NA	NA	NA
T2N1	0.857	NA	NA	35.036	NA	NA	NA
T2N2	0.9	NA	NA	36.794	NA	NA	NA
T2N3	0.87	NA	NA	35.568	NA	NA	NA
T2N4	0.909	NA	NA	37.162	NA	NA	NA
T2N5	0.98	NA	NA	40.065	NA	NA	NA
T3N1	0.84	0.859	0.923	36.341	34.369	28.897	99.608
T3N2	0.97	0.9713	0.986	41.656	37.601	21.768	101.025
T3N3	0.967	0.94	0.932	40.533	37.421	30.481	108.437
T3N4	0.977	0.983	0.996	40.942	38.042	32.449	111.434
T3N5	0.898	0.991	1.002	40.712	38.343	30.645	109.702
T4N1	0.706	0.875	0.759	32.863	32.972	24.769	90.61
T4N2	0.78	0.821	0.822	35.888	31.937	25.670	93.5
T4N3	0.98	0.98	0.98	41.065	39.929	31.338	112.332
Mean				37.1	**36.33**	**28.25**	**103.33**
Standard Deviation				2.96	**2.857**	**3.762**	**8.375**
Standard Error				0.698	**1.010**	**1.33**	**2.96**

3.2 Southern aspect

Plot no.	Bulk density (gm/cc)			Carbon stock density (tC/ha)			Total carbon stock (tC/ha)
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	
T1S1	0.882	0.89	0.943	43.817	40.045	32.786	116.649
T2S1	0.893	0.932	0.985	44.364	36.981	26.786	108.132
T2S2	0.83	0.89	0.884	41.234	35.314	22.9	99.449
T3S1	0.88	0.897	0.868	43.718	35.592	29.076	108.387
T4S1	0.84	0.879	0.897	41.730	40.465	27.915	110.112
T4S2	0.84	0.902	0.9023	41.730	35.791	28.080	105.602
T4S3	0.84	0.879	0.8567	41.730	33.897	26.661	102.289
T4S4	0.77	0.784	0.8021	38.25	31.108	24.962	94.324
T4S5	0.95	0.992	1.1067	47.195	40.797	28.671	116.663
Mean				**42.64**	**36.66**	**27.53**	**106.84**
Standard Deviation				**2.5**	**3.26**	**2.76**	**7.42**
Standard Error				**0.83**	**1.08**	**0.92**	**2.47**

Annex 4: Geographical position of the sample plots

4.1 Northern aspect

S.N.	Plot No.	Elevation (m)	Longitude	Latitude	Slope (°)
1	T1N1	2700	84°51'11"E	28°30'23"N	45°
2	T1N2	2700	84°51'09"E	28°30'21"N	43°
3	T1N3	2700	84°51'12"E	28°30'15"N	40°
4	T1N4	2700	84°51'00"E	28°30'36"N	40°
5	T1N5	2700	84°50'50"E	28°30'38"N	45°
6	T2N1	2500	84°51'18"E	28°30'19"N	40°
7	T2N2	2500	84°51'15"E	28°30'24"N	30°
8	T2N3	2500	84°51'10"E	28°30'28"N	30°
9	T2N4	2500	84°51'02"E	28°30'35"N	30°
10	T2N5	2500	84°50'55"E	28°30'29"N	43°
11	T3N1	2300	84°51'25"E	28°30'21"N	25°
12	T3N2	2300	84°51'22"E	28°30'27"N	45°
13	T3N3	2300	84°51'16"E	28°30'32"N	45°
14	T3N4	2300	84°51'05"E	28°30'37"N	35°
15	T3N5	2300	84°51'00"E	28°30'43"N	30°
16	T4N1	2100	84°51'05"E	28°30'49"N	45°
17	T4N2	2100	84°51'09"E	28°30'45"N	40°
18	T4N3	2100	84°51'18"E	28°30'40"N	40°

4.2 Southern aspect

S.N.	Plot No.	Elevation (m)	Longitude	Latitude	Slope (°)
1	T1S1	2700	84°50'09"E	28°32'18"N	40°
2	T2S1	2500	84°50'05"E	28°32'08"N	42°
3	T2S2	2500	84°49'57"E	28°32'06"N	40°
4	T3S1	2300	84°49'47"E	28°31'59"N	15°
5	T4S1	2100	84°50'18"E	28°31'43"N	25°
6	T4S2	2100	84°50'13"E	28°31'44"N	30°
7	T4S3	2100	84°50'06"E	28°31'47"N	38°
8	T4S4	2100	84°50'00"E	28°31'50"N	30°
9	T4S5	2100	84°49'48"E	28°31'54"N	20°

Annex 5: Picture Plates

Plate 1: Prok V.D.C.

Plate 2: Forest on northern aspect (F_{NA})

Plate 3: Forest on southern aspect (F_{SA})

Plate 4: layout of sampling plots

Plate 5: measuring dbhPlate 6: Measurement of tree height

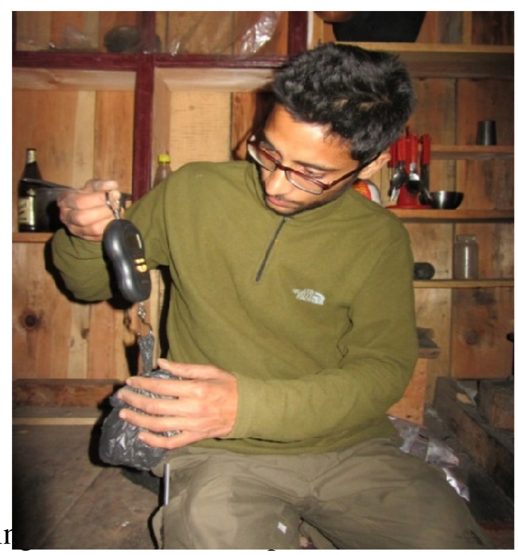

Plate 7 : Weighin