"A Comparative Study on Carbon Pool in Disturbed and Undisturbed Stands of Oak (*Quercus leucotrichophora*)"

Thesis

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By

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CERTIFICATE

This is to certify that the thesis entitled **"A Comparative Study on Carbon Pool in Disturbed and Undisturbed Stands of Oak (*Quercus leucotrichophora*)"**, submitted in partial fulfillment of the requirements for the degree of **Master of Science** with major in **Environmental Science** of the College of Post Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona-fide* research carried out by **Mr. Pankaj Bhatt, Id. No. 30660**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and sources of literature have been duly acknowledged.

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We, the undersigned, members of the Advisory Committee of Mr**. Pankaj Bhatt, Id. No. 30660**, a candidate for the degree of **Master of Science** with major in **Environmental Science**s agree that the thesis entitled **"A Comparative Study on Carbon Pool in Disturbed and Undisturbed Stands of Oak (*Quercus leucotrichophora*)** may be submitted in partial fulfillment of the requirements for the degree.

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CONTENTS

List of Tables

4.3.2.	Carbon content in different components of trees, shrubs, herbs and litter in site II	
4.4.1	Quantification of CO_2 released from forest land conversion into other land use classes	
4.4.2.	Valuation of carbon lost due to human interferences in site II.	
4.4.3.	CO_2 released in different land use change scenarios in site I (Kailakhan Cantt. Reserve forest)	
4.4.4.	CO_2 released in different land use change scenarios in site II (Manora Peak forest)	

List of Figures

List of Plates

List of Abbreviations

AMSL	Above Mean Sea Level
ARIES	Aryabhatta Research Institute of Observational Sciences
CBH	Circumference at Breast Height (1.37 m)
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CFC	Chloro Fluoro Carbons
FSI	Forest Survey of India
Gt/ Gg	Giga tonnes/ Giga grams (10^{12})
GHG	Green House Gases
IPCC	Inter Governmental Panel on Climate Change
IVI	Importance Value Index
M g/Mt	Mega grams/ Mega tonnes (10^{6})
µ L	Micro liters (10^{-6})
Pg / Pt	Pega grams/ Pega tonnes (10^{15})
ppm	Parts Per Million
SOC	Soil Organic Carbon
t	Tonnes (10^{3} kg)
Tg/ Tt	Terra grams/ Terra tonnes (10^{12})
TERI	The Energy Research Institute
UNFCCC	United Nations Frame Work Convention on Climate Change

INTRODUCTION

The forest is a fundamental natural resource that represents values for many aspects of human development. Traditionally, forests have been a provider of energy for heating and cooking, building materials, protection and cooling and a habitat for huntable and harvestable species.

In addition to these tangible benefits, there has been a growing recognition of the more intangible services provided by forests. These range from the aesthetical and recreational values of a living forest to the role of forests in the question of bio-diversity, general life-support functions and mitigating the effect of green house gases, i.e., CO_2, H_2O, CH_4, N_2O, NO, stratospheric O_3, CO and CFC's. Out of these, CO_2 alone contributes about 60% to Green House Effect **(Houghton, 1991)** and has a potential to cause a global warming of 1°-3.5°C by 2100 **(IPCC, 1996)**.

On a grand scale, forests cover more than 1/3rd of the earth's land surface and are the most important carbon pool in terrestrial ecosystems, containing some 80% of all global above-ground carbon stored in biomass **(Waring and Running, 1998)**.

The tropical forests are considered to be the "hot-spots" of bio-diversity. These "hot spots" cover only 0.2% of the earth's total area, but have 27% of all tropical forest species or 13% of the total plant species found on earth (**Myers, 1988)**. The biodiversity is of vital importance to biosphere's health, stability and proper functioning, and thus has more economic value.

Since the beginning of the 20th century the atmospheric concentrations of Green House Gases (GHG), mainly CO_2 has increased from 300-370 ppm. The two main causes for this have been identified as:

i. Burning of fossil fuels such as oils, coal and natural gas

ii. Land-use changes, particularly deforestation.

There is a growing consensus among scientists that these two together contribute 9.1 Pg C/yr towards the atmosphere as CO_2. The CO_2 gas is fundamental to sustaining life on earth for two reasons:

i. It is a source of carbon for photosynthesis, and

ii. It acts like a blanket in atmosphere that keeps the earth warm.

An atmospheric concentration of 300 ppm is adequate to support life on earth. But its concentration has now reached 370 ppm and is increasing at a rate of 1.5 μL/yr **(Lee and Dodson, 1996).** This unregulated increase in CO_2 levels leads to global warming. A strong correlation exists between increase in atmospheric CO_2 levels and the climate change resulting from global warming. The resulting climatic and atmospheric change will affect not only where species grow, but is also likely to affect how well they grow. A sustained increase of 1°C in mean annual temperature can be sufficient to cause significant changes in the growth and regeneration capacity of many species **(Davis and Botkin, 1985)**.

Growing global concern on increasing levels of GHG in the atmosphere has led to the search for various mitigation options. CO_2 is one of the major GHG which has increased in the atmosphere in the recent years. Concentrations of CO_2

can be lowered either by reducing emissions or by taking CO_2 out from the atmosphere and storing it in the terrestrial, aquatic or oceanic ecosystems.

Forestry has been proposed as a means to reduce net GHG emissions by either reducing sources or enhancing sinks. Forests play an important role in global carbon cycle. About 60 G t C is exchanged between terrestrial ecosystems and the atmosphere each year, of which, forests account for around 80% **(Schimel, 1995)**.

Dixon *et al.* (1994) has reported that globally forest vegetation and soils contain about 1146 Pg of carbon with approximately 37% of this carbon in low-latitude forests, 14% in mid-latitudes and 49% high-latitude forests.

If the mitigation policies are not translated in robust actions on ground, the rate of warming will increase. The developing countries, with their vast reserves of forests, can serve to offset the carbon released by developed countries and help mitigate global warming.

India has a forest cover of 20.55% of its geographical area **(FSI, 2001)** of which 86% of the forested area is under tropical forests **(Kaul and Sharma, 1971)** having an actively growing biomass of 93 t/ha **(Anon. 1999).** An economic cost analysis of carbon stored in above ground biomass using replacement cost method, amounted to an annual flow of 433.12 US $/ha **(Lal *et al.* 2003).**

In Uttaranchal, the 27th state amongst the 28 states of the Republic of India, the maximum area falls under forests, i.e., 62% **(Statistical Bulletin, Uttaranchal, 2001).** Agricultural production, the main occupation in hilly areas, leads to a massive consumption of forest energy (1 unit of energy produced in the crop field entails about 10-20 units of energy from the surrounding forests in the form of fodder, manuring, leaves, firewood and other non-timber forest products), and yet the level of agricultural production is insufficient to meet the human needs **(Singh and Singh, 1992).**

The agricultural system of the state is thus intimately associated with forest resource base and hence any increase in pressure on the agricultural system has a corresponding impact on the forests. Owing to ever increasing human and livestock population most of the uncultivated lands have been deforested and the grasses and shrubs that remain are subjected to various gradients of multiple utilization. **Valdiya (1985)** has reported that the grazing intensity was 2.5 to 4.5 times higher than the carrying capacity of the forests in the Central Himalayas. This may have led to the over lopping of trees for top feed, which has been observed frequently in the areas rich in mixed oak forests. Trees sequester CO_2 from the atmosphere and lock away carbon. This is a comparatively cost-effective option for reducing net emissions that has additional social, economic and ecological benefits **(Pandey, 2002).**

As a fallout of the 1992 Earth Summit held at Rio de Janeiro, the Kyoto Protocol was initiated in 1997, which commits Developed Country Parties to return their emission of GHG to an average of approximately 5.2% below 1990 level over the period 2008-2012.

India acceded to this protocol on August 2002 and one of the objectives of acceding was to fulfill pre-requisites for implementation of CDM projects in accordance with National sustainable priorities, where-under-a developed country would take up GHG reduction project activities in developing countries.

The Kyoto protocol was ratified by 141 countries and came into force as an International Law on Feb 16 2005. As per this law, reducing 1 tonne of carbon is called Certified Emission Reduction (CER). Every CER can be brought and sold on global exchange rates, i.e., 1 CER can fetch between US $ 3- 7 **(Prasad, 2005).**

Uttaranchal with its vast reserves of forests can benefit from this protocol. For this there is a need to preserve the existing forests and plant and manage new forests, with a view to earn more carbon credits, and socio-economic upliftment of the people.

Objectives

In view of the above stated issues, the present study was undertaken to compare the pre-locked stocks of carbon in disturbed and undisturbed oak forests with the following objectives:

1. Characterization of the disturbed and undisturbed mixed oak forest community with reference to ecological, economic and anthropogenic influences.
2. To valuate the storage and loss of carbon through anthropogenic influences.
3. To suggest ways for conservation of carbon pool for better sequestration with a view to earn more carbon credits.

REVIEW OF LITERAURE

This chapter is devoted to a brief review of important research studies pertaining to the theme of the study. Studies have been presented in five sections to give a systematic representation of literature. The section 2.1 deals with climate change, its evidences, causes and impacts. Section 2.2 deals with the effects of elevated CO_2. Section 2.3 gives an overview of the mitigation options of elevated CO_2. The carbon cycle is described in section 2.4, while section 2.5 deals with the quantification and valuation of the carbon pool.

2.1. Climate Change

The **United Nations Frame Work Convention on Climate Change** [UNFCCC] was adopted in 1992 as a consequence of the world wide concern over global warming. UNFCCC calls for stabilizing green house gases (GHG) in the atmosphere at a level that would prevent dangerous interference with climate system. The UNFCCC defines climate change as *"a change in climate which is attributed directly or indirectly to human activity that alter the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".*

Climate change is a natural phenomenon completing over a time scale of hundred, thousands and millions of years. It was only because of this change that the earth became suitable for human beings, after the snow receded to Polar regions from the equator. But in the recent past this rate of change has been accelerated and it is well established that the global climate is changing day by day as a result of natural variability and anthropogenic causes.

2.1.1. Evidences of climate change

Evidence for global climate change is accumulating, and there is a growing consensus that the most important cause is humankind's interference in the natural cycle of green house grasses namely CO_2.

Houghton *et al.* (2001) reported the estimates of the IPCC that the emissions of CO_2 and other GHG have begun to affect the world's climate. Anthropogenic increases in GHG in the atmosphere are likely to bring about a global temperature rise of 1.4-5.8^{0}C during the next century.

As reported by **Hansen *et al.* (2002)** the global surface air warming in the past century was approximately 0.75^{0}C which has increased to 0.5^{0}C over the past 25 years. Year 2001 recorded the 2nd warmest global surface temperature.

A 410 year old (A.D. 1590-1999) ring width chronology of Himalayan Pine near Chirbara, Gangotri, was developed by **Singh and Yadav (2000).** An abrupt surge in the growth was recorded during the late 20th century, with the 1990's recording the highest growth indices. Strong correlation was noted between the growth and warmer winters during the 20th century. The growth surge is closely associated with the area vacated by the Gangotri glacier.

As reported by **McCarthy *et al.* (2001)** the average air temperature of the earth's surface increased by 0.06^{0}C/decade during the 20th century and rose to 0.19^{0}C/decade during the years 1979-1998.

2.1.2. Causes of climate change

Since the beginning of the 20^{th} century the atmospheric concentration of CO_2 has increased roughly from 300 ppm to well over 368 ppm and the two main causes have been identified as:

Land use/Land cover changes

Land use/land cover change is significant to a range of themes and issues central to the study of global environmental change. The land use transformation has been observed to cause tremendous loss of carbon to the atmosphere, which has both national and global concerns in terms of climate change.

Wang *et al.* (2002) used Landsat TM time series data for the years of 1991/1992, 1995/96 and 1999/2000, to assess the potential effect of land cover change on the vegetation and soil-carbon in north eastern China. A decrease of 2.76×10^4 km^2 in forest area and an increase of 2.32×10^4 km^2 in urban area was reported. The conversion of forests into other land cover types resulted in a loss of 256.4 Tg of carbon for the study period, accounting for 68.8% of the total potential carbon loss in north eastern China.

Paired forest-field sampling and a chronosequence approach was used to study the effect of conversion of boreal forest to agriculture. Chronosequence showed large soil carbon losses during the first two decades following deforestation, with mean carbon stocks in agricultural soils being 8.3 kg/m^2 or 44%

lower than the carbon stocks in original forest soils **Grunzweig *et al.* (2004).**

The losses of biomass and structure arising from the conversion of tropical dry forest to pasture land in Mexico were described by **Kauffman *et al.* (2003).** Total above ground biomass (TAGB) was sampled at five distinct periods during the process of conversion of forest to pasture. Two treatments i.e., *Baja and Alta*, based on degree of biomass consumed were established to capture the variability in biomass burning. It was reported that mean TAGB of slashed primary forest was 118 Mg/ha and 135 Mg/ha in *Baje* and *Alta* treatments respectively. It was concluded that the total biomass lost *via*. fire and decomposition was 113 Mg/ha and 132 Mg/ha in *Baje* and *Alta* plots respectively, of which fire accounted for 89-92% of the loss and decomposition comprised of 2-11% of the total biomass lost.

Biomass burning

Forests act as carbon sinks, they absorb CO_2 from the atmosphere, retain carbon and release oxygen. When wood/biomass is burnt, the process is reversed i.e. CO_2 is emitted, resulting in global warming and consequent climate change.

Suman *et al.* (1996) assessed the effect of biomass burning in North Africa on the heat budget of the Mediterranean region. The principal biomass burning activities were forest and marquis fires, burning of agricultural wastes, and domestic use of fire wood. The forest fires, burning of agricultural wastes and burning of fuel wood emitted 1.33 Gg/yr, 7.27 Gg/yr and 5.16 Gg/yr of black carbon into the atmosphere respectively. The atmospheric loading from the above activities ranged between 0.01-0.05g black carbon/m^3. From estimates of the Saharan dust, black carbon and biomass burning aerosols transported to the north over the Mediterranean Sea, it was concluded that North African biomass burning particulates had an impact on the Mediterranean climate and heat budget.

Zhang *et al.* (2003) has reported the forest fire carbon emission estimates for Russian Federation using SPOT-VGT data. It was estimated that in 2001, the total burned area was 51, 546 km^2 with 38,512 km^2 occurring in forest area and 13,034 km^2 in other land use classes. The direct carbon emission from these Russian fires ranged between 39.3-55.4 Mt carbon, five to eight times more than that from North American boreal forest fires.

Forest biomass burning estimates in India during 1985-1987 show that more than 151×10^6 tonnes (by dry wt) was burned annually. Maximum contribution was found to be from tree biomass i.e., > 88% followed by litter i.e., >8% and grasses i.e., > 3.5%, resulting into total 6.0×10^6 tonnes of GHG release **(Kaul *et al.*, 1993).**

Using DMSP-OLS derived aerial estimates of active fires, the trace gas emissions released from biomass burning in tropical dry deciduous forests of India in the Eastern Ghats region of northern Andhra Pradesh, were quantified. It was reported that during March 1987, the emissions were 8.2×10^{10} g of CO_2, 1.8×10^8 g of CO, 6×10^6 g N_2O, 3×10^6 g NO_x and 1.2×10^8 g CH_4; which increased to 1×10^{11} g CO_2, 2.3×10^{8} g of CO, 7.8×10^{6} g N_2O, 3.9×10^{7} g NO_x and 1.6×10^{8} g CH_4 over the period of 10 years **Prasad *et al.* (2002).**

2.1.3. Effects of climate change

Climate change is likely to have considerable impacts on most or all ecosystems. Climate change is an additional stress on ecosystems and species that are often already under stress, may altogether become extinct.

Iverson *et al.* (2001) studied the potential changes in tree species richness and forest community types in Eastern USA following a climate change resulting from doubling of atmospheric CO_2. Using the empirical model DISTRIB, for potential future distributions of 80 common tree species, it was concluded that there would be an extirpation of spruce fir from New England, and a large reduction in Aspen-birch and Maple-beech forests.

The extinction risks for sample regions that cover 20% of earth's terrestrial surface were assessed using projections of species distribution for future climate scenarios. On the basis of mid-range climate warming scenarios for 2050, it was concluded that 15-37% of species in sample regions would be committed to extinction **Thomas, (2004).**

The possible responses of north eastern North American forests to a warmer and generally drier climate, by combining a forest productivity/soil process model with climate model predictions corresponding to doubling of CO_2 were reported by **Pastor *et al.* (1988).** It was observed that the greatest changes occurred at the current boreal/cool temperate forest border. Simulated productivity and biomass increased on soils that retained adequate water and decreased on soils with inadequate water.

The increased risks of great floods following a climate change using both stream flow measurements and numerical stimulations of anthropogenic climate change were studied. It was concluded that the frequency of floods increased substantially **Milly *et al.* (2002).**

2.2. Effects of Elevated CO_2

Beneficial effects of elevated CO_2

Initial increase in CO_2 concentration shows many beneficial effects as an increase in photosynthetic activity of C_3 plants as reported by **Woodward *et al.* (1991).** A general decrease in leaf protein and an increase in C/N ratio, thus reducing the rates of leaf decomposition were observed.

Hymus *et al.* (2003) conducted a two year study to observe the effects of elevated atmospheric CO_2 concentration on net ecosystem CO_2 exchange of a scrub oak ecosystem. Throughout the study, elevated CO_2 concentrations increased maximum net ecosystem CO_2 exchange and apparent quantum yield, thus greater carbon sequestration rate was achieved.

An increased growth efficiency of *Quercus alba* trees in CO_2 enriched atmosphere was observed when *Quercus alba* seedlings were grown for 4 complete growing reasons with different partial pressures of atmospheric CO_2. The production of dry mass increased by 58% and 135% at 50 pa and 65 Pa of CO_2 respectively compared to plants growing in ambient i.e. 35 Pa CO_2. The annual stem wood production was 37% greater under elevated CO_2 **Norby *et al.* (1995).**

Schafer *et al.* (2003) studied the carbon assimilation and allocation in a pine forest ecosystem following an exposure to enriched CO_2 atmosphere. The canopy CO_2 uptake was estimated at the Duke forest, free air enrichment (FACE) study. It was observed that the net ecosystem production increased by 272 g C/m^3/yr under elevated CO_2.

Harmful effects of elevated CO_2

The yield response of rice to elevated CO_2 and temperature was studied in Sri Lanka **de Costa (2000)** using a process based mechanistic simulation model. It was reported that on doubling the concentration of CO_2 from 350 ppm to 700 ppm, the rice yields increased by 50%, but it would decrease by 39-47% following an associated temperature rice of 4^{0}C.

Stiling *et al.* (2003) reported the results of a study on the effects elevated CO_2 on herbivore (i.e., insect) density across all species of scrub-oak forests. The unabated rise in global atmospheric CO_2 induces physiological changes in plants, including changes in foliar N_2. On the basis of enrichment field-based experiments done at Kennedy Space Center, Florida a decrease in herbivore density per 100 leaves was reported, across all species of oak studied.

2.3. Mitigation Options

Under the Kyoto Protocol the industrialized countries are expected to reduce the GHG emission by an average of 5.2% below 1990 levels by 2008-2012. To offset the carbon (as CO_2) released into the atmosphere mitigation through forestry activities and land/soil management appear to be the most practical, potential and natural means.

Forestry Options

The forest sector is an interesting microcosm of the overall climate change issue, in that it suffers impacts from climate change, and has particular opportunities in the mitigation of climate change. The forests act as a natural scrubber of CO_2, hence they can act as a sink for CO_2.

As reported by **Lal *et al.* (2000)** an increase in annual productivity from 0.7 m^3/ha in 1985 to 1.37 m^3/ha in 1995, indicated an increase in forest biomass and hence higher carbon sequestration. Analysis of annual carbon intake increment showed that Indian forests and plantation removed 0.125 G t of carbon from the atmosphere in 1995.

The carbon sequestration of an old pasture and two young forest stands of Ash and pine-oak, planted on former pasture lands 27 and 30 years ago, were compared by **Lust *et al.* (1995).** The carbon content all the compartments was studied using Hohenland's model trees and it was reported that the total carbon content of pasture lands amounted to 128 t C/ha compared to 173 t C/ha and 118 t C/ha in Ash and pine-oak stands respectively.

Nabuurs *et al.* (1993) quantified the present stock of carbon in living biomass, litter and humus, and carbon accumulations in stem/bole of 15 forest types in Netherlands using inventory data. It was reported that the total forest (of area 330,000 ha and average age 50 yrs), sequestered 0.66 Mt C/yr and 67.3 Mt of carbon was stored in the entire forest.

Using the record of forest planting since 1990, and a model that calculated the flow of carbon from the atmosphere to trees, litter, soil, wood products and back to atmosphere, the rate of accumulation of carbon in forests and woodlands of Northern Ireland was estimated. In 1990, the coniferous forests were sequestering 0.15-0.20 Mt C/yr and the broad leaved wood lands 0.025 Mt C/yr **Cannell *et al.* (1996).**

Chuan *et al.* (2003) determined the carbon storage in two 20 yr and 27 yr old plantation of Liukuei Experimental Forest using allometric equations. It was observed that of 36-41% of carbon storage in tress, 80% was stored in boles.

The carbon storage in different stages of stand development in a New Zealand, Northofagus forest was determined by **Davis *et al.* (2003).** Carbon storage was estimated in stem wood, coarse woody debris, forest litter+fermentation/humus layers and 0-10 cm of soil. The maximum carbon storage was in 125 yr old stand i.e., 219 Mg C/ha, followed by 150 yr old stand, i.e., 192 Mg C/ha, and 10yr old stand, i.e., 152 Mg C/yr, and minimum in 25 yr old stand i.e. 114 Mg C/ha.

Saxena *et al.* (2003) integrated the remote sensing data with the field inventory data to assess the carbon sinks in Indian forests between 1984-1994. The growing stock in 1994 was estimated as 4340.0×10^6 m^3, while the above-ground biomass and carbon content were recorded as 2395.4 and 1083.8×10^6 tonnes respectively.

Using LUCS model, carbon sequestration estimates for forestry options for different land use scenarios in India were made by **Bhadwal and Singh (2002).** Out of the 3 scenarios i.e., maximum land under forests – **LUCS I**; 'Business as Usual' scenario – **LUCS II**; and maximum land under plantation forestry, **LUCS III**, generated for 50 years from 2000 A.D.; the maximum amount of carbon was sequestered in **LUCS-III** scenarios i.e., 6.937×10^8 t of carbon.

Storage in soils

GHG (especially CO_2) are widely accepted by the international scientific community as one of the potential threats to existence of human kind. The concentrations of atmospheric CO_2 can be lowered by taking CO_2 out of the atmosphere and storing it in terrestrial, oceanic or aquatic ecosystems. The increasing net fixation of atmospheric CO_2 through soil carbon sequestration is one such option.

Sperow *et al.* (2003) studied the soil carbon stock changes in U.S. agricultural soils, using a modified version of the 'IPCC' soil organic carbon [SOC] inventory method together with the 'National Resources inventory' data. Potential SOC storage was analyzed from increased adoption of no-till, decreased fallow operations, conversion of highly erodible land to grasslands, and increased use of cover crops in annual cropping systems. It was reported that the U.S cropland soils have potential to increase SOC by an additional 60-70 Tg C/yr over the present rates of 177 g C/yr. The total sequestration potential for a 15 yr projection period was estimated as 83 Tg C/yr, representing 5% of 1999 total US CO_2 emissions.

A study on the size and distribution of organic carbon and Nitrogen pools in Danish forest soils by examining 140 soil profiles was done by **Vejre *et al.* (2003)**.Total carbon and Nitrogen pools in organic layers and mineral soils were calculated up to a depth of 1 m. The average total organic carbon and N_2 contents were estimated as 12.5 and 0.61 kg/m^2 respectively, of which the Spodosols had the highest carbon content i.e. 14.6 kg/m^2, and the Alfisols had the least, i.e. 8.8 Kg/m^2.

Forest SOC densities for 2 depth classes, i.e., 50 cm and 1 m were estimated using a database of published measurements. The mean SOC density estimates for top 50 cm based on 175 observations ranged from 37.5 t/ha in tropical dry deciduous forests to 92.1 t/ha in littoral and swamp forests; whereas that for 1m depth class varied from 70 t/ha in tropical dry deciduous forests to 162 t/ha in montane temperate forests. The estimated SOC densities were combined with remote sensing based forest area inventory to estimate the SOC pool in major forest types of India. The total SOC pool in India forests in top 50 and 1 m depth class was estimated as 4.13 and 6.81 Pg C **Chhabra *et al.* (2003).**

The SOC store in total forest soils of India as per 1994 forest stands under 19 species spread over 27 states and U.T of India was studied by **Jha *et al.* (2003).** A total of 9815.95 × 10^6 t of SOC was estimated with the Spruce forest soils having the maximum i.e., 386.0 t/ha, and the Khair forest soils having the minimum i.e., 51.93 t/ha.

2.4. Cycling of Carbon

The biogeochemical cycle of carbon contributes the basic mechanism for the storage and loss of carbon. The measurement of system carbon within present ecosystems has assumed particular importance because the carbon lost contributes significantly to global climate change.

Edwards *et al.* (1977) studied the carbon cycling within the floor of a mixed deciduous forest, including estimates of litter fall, litter standing crop and measurements of gaseous carbon losses from the various components. The annual carbon inputs to the system were reported as 161 gm C/m^2 as litter fall and 733 gm C as small roots. The mean annual standing pools were 126gm in litter, 340 gm in small roots, 395 gm in large roots and 12,850 gm C/m^2 in soil detritus. The annual total C efflux was reported as 1665 g C/m^2.

Trees

The carbon pools and sequestration in British vegetation were studied by **Cannell *et al.* (1995).** The carbon pool in the British vegetation was reported to be

113.8 × 10^6 t of carbon, of which 80% i.e. 91.9 × 10^6 tonnes was present in forests and woodlands, currently sequestering 2.5 × 10^6 t C/yr equivalent to 1.5% of the carbon emitted by burning of fossil fuels in UK.

Negi *et al.* (2003) estimated the carbon content and its allocation in 54 plant species, firstly by Ash method and secondly by Regression equation derived between carbon and calcium content. It was concluded that in comparison to leaves and bark, wood/bole stores the maximum amount of carbon.

Litter

Raizada *et al.* (2003) estimated the carbon flux through litter fall in forest plantations of India occurring in 4 major forest groups using published studies covering 82 stands. The carbon flux rates (Mt/C/yr) from total litter fall were reported as 2.17, 1.18, 1.66 and 2.30 in tropical moist deciduous forests, tropical dry deciduous forests, montane sub-tropical forests and montane temperate forests respectively.

Soils

The carbon storage in Oak/Beech and an Ash stand in Belgium were studied by **Vande *et al.* (2001).** The total carbon stocks amounted to 324.8 t/ha and 321.4 t/ha in Oak/Beech and Ash stands respectively. The soil organic matter was reported as 43.5% and 53.0% in Oak/Beech and Ash stand respectively.

2.5. Potential and Valuation of Sequestered Carbon

Forests provide a vast range of values including a wide range of ecological, economic, social and cultural values. These values need to be expressed in terms of money. One of the important ecological roles of forests that has a great potential to realize an economic return is carbon sequestration.

Potential

The Kyoto protocol allows countries to credit their GHG inventory with the emissions captured from afforestation or reforestation, providing the potential for carbon polluters to pay the tree planters to store carbon **Willman *et al.* (2002).**

The developmental trends of Russian forests and their impacts on global carbon budget were studied at national level by **Anatoly *et al.* (2002),** using long term forest inventory data (1961-1998). During this period, the Russian forest lands acted as carbon rinks and the annual average level of carbon sequestration was reported as 210 ±30 Tg C/yr in vegetation and organic matter, of which the living biomass contained 153 Tg C/yr and dead wood 57 Tg C/yr.

The carbon budget and future carbon sequestration potential of the natural forests of Madhya Pradesh, India, was studied by **Pande, (2003).** The forests were classified as Open i.e. less than 40% cover, and Dense canopy i.e. greater than 40% cover. The Net Ecosystem Productivity (NEP) values for carbon assimilation rate (t/ha/yr) were 0.531 and 0.172 for dense and open canopy forests respectively. The average rate of carbon accumulation for the past 17 years till 1999 was 1.058

t/ha/yr. It was concluded that the open canopy forests had a potential for sequestering more carbon, as they were sequestering 53% less carbon than the dense canopy forests.

Economic valuation

Reduction and cost requirements to achieve the Kyoto target were estimated by **Chen *et al.* (2003)** using the emission projections and Marginal Abatement Cost curves. On the basis of this it was concluded that for the Annexure I parties, i.e., developed countries, the total reduction requirements range from 503-1304 Mt C with US participation and decreased to 140-612 Mt/C with its withdrawal. The total cost varied from 21-77 billion US $ (with US participation) and 5-36 billion US $ (without participation), if only domestic reduction actions were considered.

Jong *et al.* (2000) made an economic analysis of the carbon sequestration potential of forests in Southern Mexico. The current vegetation type, land use and carbon stocks were assessed and the carbon sequestration potential was estimated. The most effective method for carbon sequestration was the improved management of natural forests on community lands, and it was reported that 38×10^6 Mg of carbon could be sequestered at a rate of US $ 15/Mg of carbon.

Using replacement cost method an economic worth analysis of carbon stored in above ground biomass of Indian forests was done. The total above ground stocks amounted to an annual flow of 4.33.12 US $/ha, as reported by **Lal *et al.* (2003).**

2.6. Green House Gases and Policy Prescriptions

The Kyoto protocol on climate change was a follow up of the Earth summit of 1992. The protocol commits Annexure I countries, i.e., developed countries, to return their emissions of GHG to on average of 5.2% below 1990 levels by 2008-2012. The carbon absorbing countries can earn pollution credits or reducing emission for reducing emissions by afforestation and reforestation (A/R) programme under the clean development mechanism (CDM).

India is a party to UNFCCC and acceded to the protocol in Aug. 2002. The protocol was satisfied by 141 countries and become an International Law on Feb 16, 2005. As per this law reduction of 1 tonne of carbon is termed as Certified Emission Reduction (CER), and it can be brought and sold on global exchange rates of US $ 3-US $ 7 **Prasad, (2005).**

MATERIALS AND METHODS

This chapter describes the details of materials, instruments used, experimental techniques and methodology adopted during the course of the present study.

3.1. Chemicals and Glasswares.

Source of chemicals

All the chemicals used during the course of this study were of A.R. grade and were supplied by E. Merck (India), Himedia (India), BDH (India), S.D. Fine chemicals (India) and Sigma (USA).

Glasswares and plastic wares

The glasswares used were of Corning grade manufactured by Borosil, India Ltd., Reviera (India) and Agassi (India).

The plastic wares used were of Poly Lab, India, O.P. Sarpual & Company, New Delhi and Tarson, India.

Equipments

The following equipments were used:

1.	Hot air oven	(Indian Equipment, Bombay)
2.	pH meter	(Systronics, India)
3.	Digital electronic balance	(Elico, India)
4.	Muffle furnace	(Ambassador)
5.	Desiccator	(Borosil, India)
6.	Flame Photometer [Model-321]	(Systronics, Ahemdabad,India)
7.	Spectronic-20	(Baush and Lomb, USA)
8.	Top pan balance	
9.	Polyethylene bags and paper bags	

3.2 Profile of Study Area

3.2.1. Location of the study area

The study area falls under the purview of Nainital district (Uttaranchal), situated in the Himalayan and sub-Himalayan regions between latitudes 28°-30°N, and longitudes 78°-81°E, and covering an area of 3860 km^2. It is surrounded by Champawat on the east, Pauri Garwhal on west, Almora on the North and Udham Singh Nagar on the South, (Fig 3.2.1).

The maximum area of the district is covered by hills. The region is manifested with wide agro-climatic variability ranging from sub-tropical to alpine zone. Consequently, the climate of the region varies from place to place in accordance with altitudinal variation, shape, aspect, density and kind of vegetation.

3.2.2. Land use pattern

Table 3.2.1. shows the total reported area of Nainital district was 411073 ha, of which 73.01% area was under forests and 6.5% fell under uncultivated land. Horticultural crops occupied 3.96% of the total reported area. The gross sown area and the net sown area were 82461 ha and 49486 ha respectively. The cropping intensity was 166.63%.

3.2.3 Climate

The average minimum and maximum temperature, humidity and rainfall data for 1994-2003 were obtained from **ARIES** (Aryabhatta Research Institute of Observational Sciences), Manora Peak, Nainital. Climatically the region differs from the plains, and the climate is exceedingly diverse. Winters are very severe at higher elevations. In the summer months (May-June) the lower valleys are warm.

Fig.3.2.1 Map of Uttaranchal

Table 3.2.1. Land use pattern in Nainital district.

S.No	Particulars	Area (ha)	% of total reported area
1	Total reported area	411073.0	100.0
3	Area under forests	300153.0	73.01
3	Uncultivated barren land	26792.0	6.51
4	Current fallow	991.0	0.24
5	Other fallow	4390.0	1.06
6	Land use other than cultivation	3025	0.735
7	Cultivable waste	8719	2.12
8	Pasture land	1211	0.29
9	Area under horticultural crops	16306	3.96
10	Net area under crops	49486	12.03
11	Area sown more than once	32975	-
12	Gross cropped area	82461	-
13	Cropping intensity (%)	166.3	-

Source: Statistical Bulletin Nainital, Uttaranchal, 2001

Temperature varies markedly within a year. The mean maximum temperature was highest and lowest during May and January, whereas the mean minimum temperature was highest and lowest during June and January.

The average climatic data for the period of 1994-2003 is shown in Table. 3.2.2. Depending upon the climatic variations, the year can be divided into following:

i. Rainy season (June – September)
ii. Winter season (October – February)
iii. Summer season (March - May)

Table.3.2.2. Average climatic data of Nainital for 1994-2003.

Years	Temperature (°C)		Humidity (%)		Rainfall (cm)
	Max.	Min.	Max.	Min.	
1994	16.75	9.1	64.6	35.6	145.01
1995	21.3	12.3	77.9	41.7	337.4
1996	20.5	11.6	75.1	41.6	194.8
1997	18.3	10.45	84.6	46.9	177.7
1998	20.1	13.3	84.9	45.9	224.1
1999	20.1	12.7	77.3	45.5	208.2
2000	18.7	11.6	84.6	51.4	263.65
2001	20.3	11.3	85.1	49.3	217.8
2002	23.1	7.6	97.6	20.6	179.9
2003	23.5	7.5	96.5	22.5	221.3

Source: ARIES, Manora Peak, Nainital, 2004

Table.3.2.3. Demographic Statistics for Nainital and Uttaranchal, 2000-2001.

Particulars	**Unit**	**Nainital**	**% of Uttaranchal**	**Uttaranchal**
Total area	Sq.km.	3860.4	7.23	53483
Total population	Lakh Nos.	7.6	8.96	84.8
Male	Lakh Nos.	4.2 (52.6)	9.26	43.2 (50.9)
Female	Lakh Nos.	3.6 (47.5)	8.65	41.6 (49.1)
Rural	Nos.	510720 (67.2)	6.0	-
Urban	Nos.	249280 (32.8)	2.93	-
SC	Nos.	148960 (19.6)	1.75	-
ST	Nos.	4408 (0.58)	0.05	-
Literacy	%	79.6	-	72.3
Male	%	87.4	-	84.0
Female	%	71.0	-	60.0
Population density	Per Sq. km.	112.3	-	-

Source: Monthly review of Uttaranchal and economy, Center for Monitoring Indian Economy, 2001

Note: Figures in parentheses show the % to total population in the district

3.2.4. Demographic features

The Nainital district of Uttaranchal has an area of 3860 km^2 and a population of 7.6 lakh, with the rural and urban population being 510,720 and 249,280 respectively. The sex ratio is 1.41:1, as shown in Table. 3.2.3.

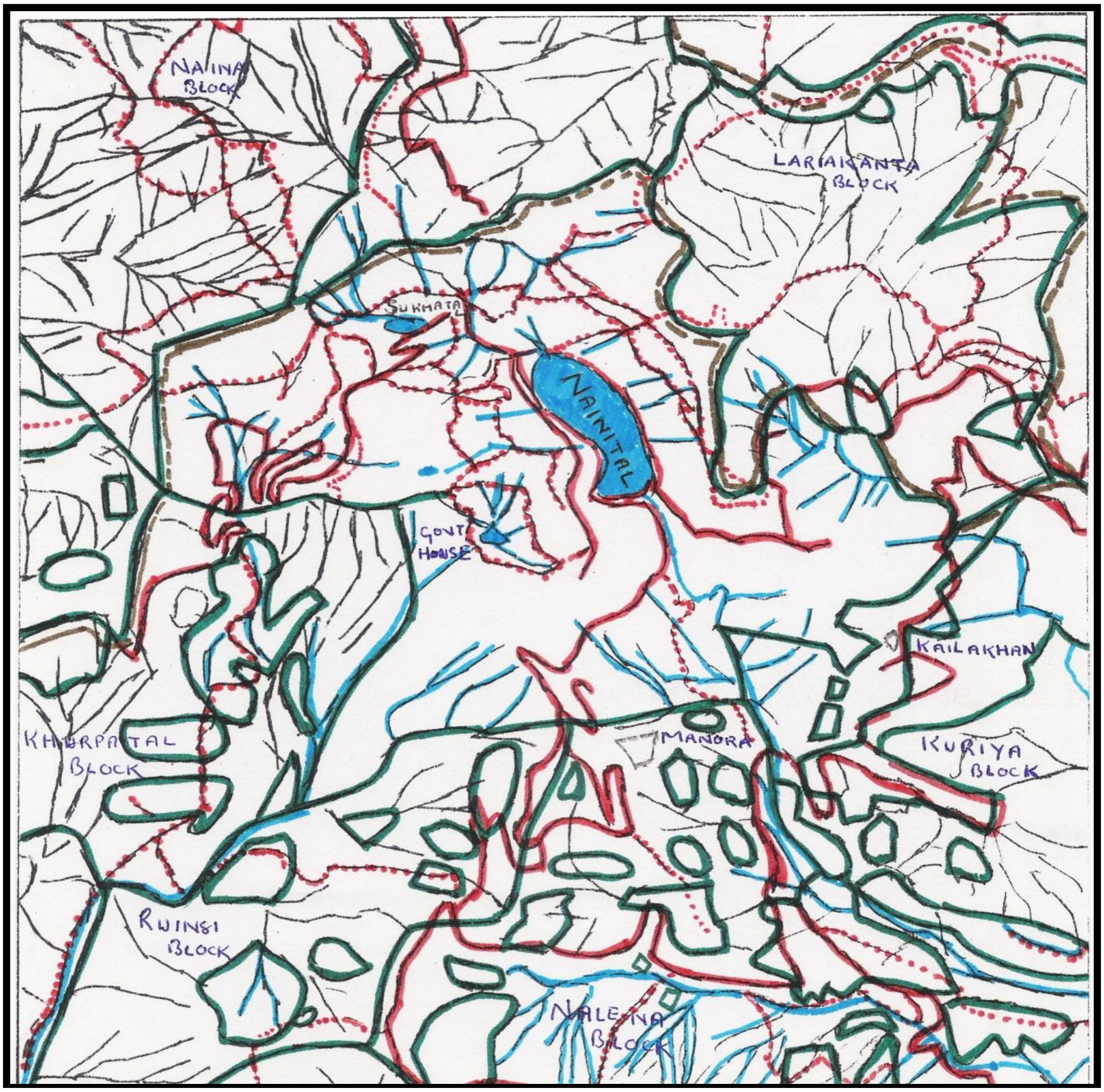


Fig.3.3.2 Toposheet of Nainital showing the location of study sites.

Legend

	Range forest Block
	Metalled Road
	Cart track/Foot path
	Stream/ Water body
	Range Boundary
I	Study Site I
II	Study Site II

3.3. Location of the Study Sites

Two forest sites of varying condition were selected for the analysis of forest vegetation in Nainital, district Nainital. The selection of the sites was done after a reconnaissance of the entire area. (Fig. 3.3.1)

3.3.1 Study site I

The site is located at Kailakhan, 2 Km from Nainital, at an altitude of 1950m AMSL. The site comprises of a pure, undisturbed, reserve forest of *Quercus leucotrichophora* and the slope angle is 20°, (Plate I).

The site falls under Compartment 6 of the Kuriya Block of Manora Forest Range, Nainital Division. The site was proclaimed as Cantonment by the Govt. of N.W. provinces and Oudh **(Notification no-224 XII-651-B, dated Feb 8, 1889)** and subsequent amendments. The provisions of the Forest Act were applied to the area under **G.O. No. 462/XIV-63, dated Nov. 2, 1909.**

Study site II

The site is located at Manora, 5 km from Nainital, having an altitude of 1930 m AMSL, with a disturbed forest of *Quercus leucotrichophora* and a slope angle of 38° (Plate II). The site falls under Compartment 21 of Nalena Block under Manora Forest Range of Nainital Division.

Survey of the study site II.

A survey was conducted in the study site II, to study the villages present within a 3 km radius of the study site. The villages were surveyed and the relevant primary data were collected on pre-structural schedule by personal interview

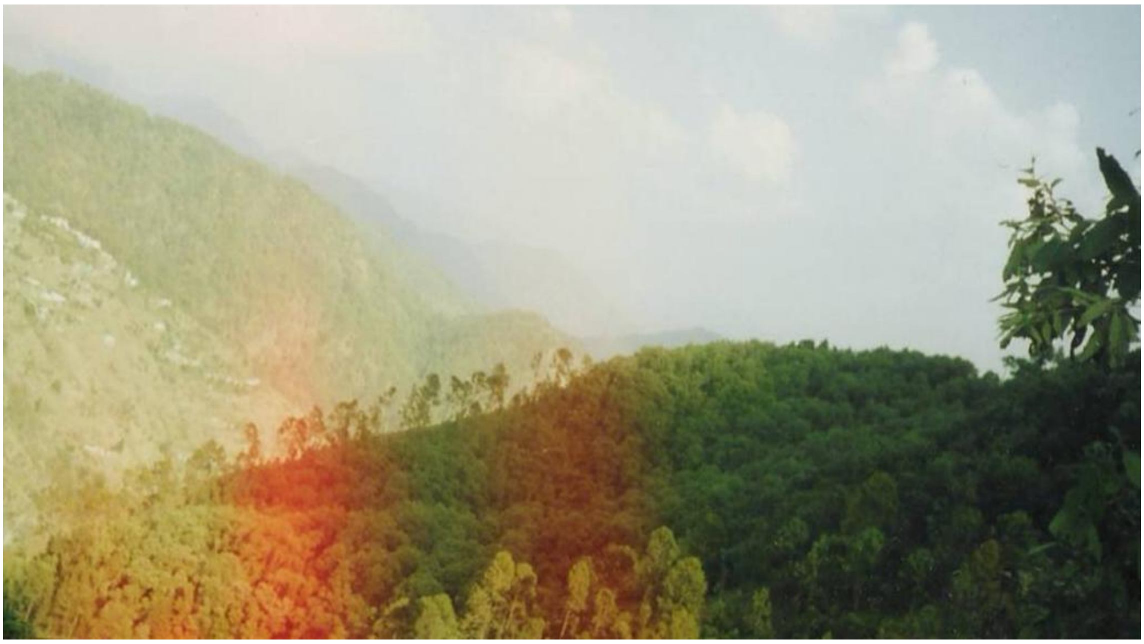


Plate I. Undisturbed site, Kailakhan cantonment reserve forest, Nainital

Plate II. Disturbed site, Manora peak forest, Nainital

method. The data collected included the number of individuals, literacy, main occupation, number and type of livestock, and family income from all sources.

3.4 Sampling

The Quadrat Method of sampling was used. The quadrat is a square sample plot or unit for a detailed analysis of vegetation. In vegetational analysis, quadrats of any size, number and arrangement may be used depending upon the Species Area Curve. For the study of forest community quadrats of 100 m^2 were used to include maximum number of trees, while for studying shrubs and grass covers quadrats of 9 m^2 and 1 m^2 respectively were used. The shape of quadrat is usually a square but rectangular or circular quadrats are also used.

Count Quadrat or List – Count Quadrat

When the species name and number of individuals of each species found in the sample plot are recorded, the sample plot is called count or list count quadrat. It is usually used in forest survey work **(Chandel and Shukla, 2001).**

3.5. Vegetational Analysis

The field study was conducted during the months of June and December 2004, at various locations in the study sites. To study the forest community 10 quadrats of size 10m x 10m were laid out inside the forest in both forests. Data on all trees above 30 cm girth were collected. The observation recorded were name of species, CBH, and number of individuals of the species.

For studying the shrub species, 10 quadrats of size 3m x 3m were laid within the 10m x 10m quadrats, one in each quadrat, and data on all shrubs, regarding their name and number was noted.

The herbaceous layer was studied by laying 10 quadrats of size 1m x 1m within the 10m x 10m quadrats, one in each quadrat and data on all herbs was recorded. The observations recorded were name of species and individuals of each species **(Gera *et al*. 2003).** The numerical data obtained were used to find out, density, frequency, abundance, A/F, and IVI of the species.

The following parameters were studied for analyzing the vegetation of the study area.

Frequency

Frequency as introduced by **Raunkiaer (1934)** indicates the number of sampling units in which a given species occurs, and thus expresses the distribution or dispersion of various species in a community. From there, % frequency is calculated as follows:

$$\% \text{ Frequency} = \frac{\text{Number of sampling units in which the species occurred}}{\text{Total number of units studied}} \text{ x } 100$$

Procedure

Lay the required number of quadrat of appropriate size in the vegetation to be studied, and note presence or absence of each species by + or – respectively in each of the quadrats, **Mishra, (1968).**

Density

The term density represents the numerical strength of species in the community. The density and frequency taken together are of prime importance in determining community structure **(Oosting, 1958).**

Procedure

Lay a number of quadrat of desired size and count the individuals of each species in each quadrate. Record the total number of quadrat studied. From this density is calculated as follows:

$$\textbf{Density} = \frac{\text{Total number of individuals}}{\text{Total number of quadrat studied}}$$

Abundance

Abundance is described as the number of individuals per quadrat of occurrence. The abundance was calculated as per the following formula:

$$\textbf{Abundance} = \frac{\text{Total number of individuals}}{\text{Total number of quadrat of occurrence}}$$

Importance Value Index (IVI)

IVI of a species is the relative contribution of the species to the whole community. IVI is defined as the “sum of relative density, relative frequency and relative dominance” as:

$$\text{IVI} = R_o + R_f + R_{Do}$$

3.6. Determination of Plant Biomass

The biomass of thus was calculated using the regression equations developed by **Rawat, (1983)** (Table.3.6.1.). Based on field measurements, different CBH (circumference at breast height, i.e., 1.37 m) classes of trees were recognized i.e., 30-40, 40-50, 50-60 cm etc. Mean CBH for each species for a girth class was used in the regression equation to get an estimate of mean biomass (dry wt.) component wise, for the girth class.

This value was multiplied by the density of the trees in that girth class. Stand biomass was calculated by adding the biomass values across the girth classes.

Table 3.6.1. Allometric relationship between the biomass (dry wt.) of tree components (Y, Kg /tree) and CBH (X cm) for different species **(Ln Y = a+b Ln X) (Rawat, 1983)**

Quercus leucotrichophora

Plant part	**Intercept (a)**	**Slope (b)**	r^2
Bole	-0.523	1.367	0.994
Branch	-0.718	1.302	0.973
Twig	0.065	0.895	0.897
Foliage	-0.976	0.954	0.299
Stump root	0.982	0.904	0.612
Lateral root	-0.312	0.809	0.569
Fine root	-1.326	0.504	0.487

Rhododendron arboreum

Plant part	Intercept (a)	Slope (b)	r^2
Bole	10120	0.704	0.873
Branch	1.113	0.609	0.605
Twig	1.155	0.373	0.327
Foliage	1.194	0.170	0.101
Stump root	-0.119	0.867	0.612
Lateral root	-1.752	0.984	0.601
Fine root	-1.009	0.407	0.568

Inter species

Plant part	Intercept (a)	Slope (b)	r^2
Bole	-0.861	1.425	0.915
Branch	-0.908	1.327	0.907
Twig	-.0506	1.028	0.796
Foliage	-1.106	1.042	0.755
Stump root	0.098	0.948	0.789
Lateral root	-2.346	0.997	0.724
Fine root	-2.874	0.529	0.722

3.7. Carbon Content

Samples of above ground, litter components, and below ground parts of dominant trees and shrubs of the present study forests were collected. The samples were brought to the laboratory, oven dried at 80^0C for 48 hrs and finely ground in an electric grinder. Composite mixtures, in triplicate, were made and analyzed for carbon content.

For carbon estimation, weighed amount (2 gm) of plant material in triplicates was transferred to silica crucibles having constant weight. Combustion process of the material was carried out in a muffle furnace at 550^0C for $3^{1/2}$ hrs. Ash free dry weight was determined by subtracting final weight of the crucible from the initial weight (Crucible + plant material). **(Rana *et. al* 1989)**

Organic carbon was assumed 50% of ash free dry weight following **Mc Brayer and Cromack, (1980).** Total carbon estimates for the stand were obtained by multiplying these values with biomass.

3.8. Soil Analysis

Soil Sampling

Soil samples were collected after removing the surface upper layer, and collecting samples at two depths of 0-10 cm and 10-20 cm respectively. The samples were collected from the four corners and 1 sample from the centre of the quadrat. The samples were bulked and mixed thoroughly for laboratory analysis.

Laboratory Analysis

The soil samples (about 500 gm) in triplicates were collected from the selected forest sites and brought to the laboratory in sealed polyethylene bags. The soils were shade dried and passed through a 2 mm sieve to remove any large stones and debris.

The samples were analyzed for soil pH, moisture content, soil texture, organic carbon, N, P, and K.

Soil pH

The pH of the soil was determined by electrometric method using pH meter with confined glass electrode (ELICO Digital). The instrument was calibrated with the help of buffers (4.7 and 9.2) before using the soil samples in the ratio of 1:2.0 Soil: Water mixtures.

Soil moisture

Soil moisture is determined by 'Gravimetric and Volumetric method'. Weighed soil, prior to shade drying, is placed in an oven at 105^{0}C for 24 hrs. The difference in weight is the 'moisture content' of the soil.

$$\textbf{\% moisture} = \frac{\text{Loss in weight}}{\text{Oven dry weight of soil}} \times 100$$

Soil texture

The soil texture was determined by 'Feel method' as given by **Jackson, (1973).**

Organic carbon

The organic carbon is measured by **Walkely and Black's method (1934).** Weigh a suitable amount of shade dried soil (not exceeding 1.0 gm) into a 500 ml conical flask. Add 10 ml of 1 N $K_2Cr_2O_7$ solution and 20 ml of conc. H_2SO_4. Mix thoroughly and allow it to stand for 30 minutes. Dilute the contents with 200 ml distilled water and add 10 ml phosphoric acid, 1 ml diphenylamine indicator. Titrate the solution with standard 0.5 N $FeSO_4$ solution to a brilliant green colour.

$$\textbf{\% Organic carbon} = \frac{V_1 - V_2}{W} \times 0.003 \times 100$$

Where,

V1= Volume of $FeSO_4$ used with sample

V2= Volume of $FeSO_4$ used with blank

W= Weight of soil sample

Available Nitrogen

Available N was determined by alkaline $KMnO_4$ method **(Subbiah and Asija, 1956).** 20 gm soil was taken in a distillation flask and 20 ml water was added. Then 100 ml of 0.32% $KMnO_4$ and 100 ml of 2.5% NaOH solutions were added and the distillation flask was immediately fitted into distillation apparatus. Then 25 ml of 4% boric acid containing mixed indicator, adjusted to pH 4.5, was taken in a conical flask and the delivery tube of distillation apparatus was dipped in it. Distilled NH_3 gas from the distillation flask, collected in boric acid, was back titrated with 0.02 N standard H_2SO_4. Available N was calculated by using following formula:

Available N (kg/ha) = (S-B) × 31.36

Where,

S = sample titration (ml standard H_2SO_4 acid)

B = blank titration (ml standard H_2SO_4 acid)

Available Phosphorus

Available P was extracted by a mixture of HCl and NH_4F as per method of **Bray and Kurtz No. 1 (1945)** using 2.5 gm soil sample. The solution was shaken well for 5 minutes on a mechanical shaker, and then the contents were filtered using a Whatman No. 42 filter paper. 5 ml of the filtered aliquot was taken in a 25 ml volumetric flask and 20 ml distilled water and 4 ml of mixed reagent were added. The colour was allowed to develop and the intensity was read at 882 nm or 720 nm on Spectronic-20 spectrophotometer. The concentration of P was worked out with the help of a standard curve.

Available Potassium

Available K was extracted by 1 N ammonium acetate solution as outlined by **Hanway and Heidal (1952).** The concentration of K in the filtrate was measured by using a Flame Photometer. The concentration of K was worked out with the help of standard curve.

3.9. Valuation of Carbon Pool

The methodology used to evaluate the economic worth and carbon stored in the above ground biomass of the forests is that of Replacement Cost (RC) **(Lal *et al.,* 2003).** In the Replacement Cost methodology, the value of an environmental service is evaluated by cost required to restore the environment to the original state by a ‘shadow’ or ‘compensating’ projects after it has been damaged **(Winpenny, 1994).**

The economic worth of carbon stored in the above ground biomass of the forests is evaluated by equating it to the cost that would be incurred in offsetting by alternative projects, the CO_2 released if the forests land were converted to alternate land use. A monetary value required to offset the additional carbon stored in the forests as compared to other land uses such as pasture or cropland is calculated. This monetary value is then converted into annual flows.

First the fresh biomass of the growing stock is calculated and it is converted to mass of dry matter multiplying it by conversion ratio (CR) of 0.5 t dry matter **(IPCC, 1996).**

The carbon content of the dry matter is calculated taking into account that the carbon fraction (CF) in live biomass is 0.5. The carbon content so obtained is multiplied by 44/12 to obtain tonnes of CO_2 liberated **(IPCC, 1996).**

The average cost (US $ per tonne of CO_2) of various other mitigation options (Table.3.9.1.), is used to calculate the cost required to offset the CO_2 released by forests land conversion **(TERI, 2001).** The monetary value obtained is converted into annual flows.

3.10. Statistical Analysis

The collected primary data was analyzed using different statistical methods, and on the basis of the analysis different graphs, tables and pie charts were prepared.

Table.3.9.1. Cost of various CO_2 mitigation options for India

Technology	**Cost (US $/t CO_2)**
Transport sector	12.00
Renewable energy for power	88.00
Agriculture sector	115.00
Power generation	10.00
Average Cost	**56.25**

Source: TERI, 2001

RESULTS AND DISCUSSION

This chapter is devoted to the presentation of the findings of the study regarding different objectives as stated in Chapter I. The chapter is divided into four sections. The Ist section deals with the status of forest ecosystem in the study sites. In the 2nd section the environmental conditions of the study sites are described. Quantification of the biomass and stock carbon is done in the 3rd section, while the 4th section deals with the valuation and the loss of carbon stored.

4.1. Study of Forest Ecosystem

4.1.1. Vegetational analysis of Site I (Kailakhan Cantt. Reserve forest)

The forest of the study area is close canopied and has a dense under storey of mainly *Arundinaria falcata*. The site comprises of pure, undisturbed stand of *Quercus leucotrichophora.*

Trees

In the trees, *Quercus* was the dominant species, having an IVI of 196.84. The density per 100 m^2 of *Quercus* was 5.9, followed by *Rhododendron* and *Cupressus*. *Rhododendron* was the co-dominant species having an IVI of 43.52. As the IVI of *Quercus* is maximum, it is the Keystone species of the ecosystem, consequently requiring care and protection for its continued existence (Table. 4.1.1).

Table 4.1.1. Vegetational analysis of trees of Site I

Species	**Density** (Per 100m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**	**IVI**
Quercus leucotrichophora	5.9	100	5.9	0.059	196.84
Rhododendron arboreum	1.0	50	2.0	0.04	43.62
Cupressus torulosa	0.6	50	1.2	0.024	31.63
Myrica esculenta	0.4	40	10	0.025	23.17
Cedrus deodara	0.3	20	1.5	0.075	14.97
Aesculus indica	0.1	10	1.0	0.10	6.16

Table 4.1.2. Vegetational analysis of saplings and seedlings of Site I

Species	**Density** (Per 100m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**
Quercus leucotrichophora	1.7 (7.7)	80 (100)	2.125 (7.7)	0.026 (0.077)
Myrica esculenta	0.4 (4.4)	20 (50)	2.0 (8.8)	0.10 (0.176)
Rhododendron arboreum	0.3 (0.4)	20 (20)	1.5 (2.0)	0.075 (0.1)
Cedrus deodara	0.2 (0.1)	10 (10)	2.0 (10)	0.20 (0.1)

Note: Figures in parentheses are the values for seedlings

Saplings and Seedlings

Quercus has the highest sapling and seedling density of 1.7 per 100 m^2 and 7.7 per 100 m^2 respectively. Thus it can be concluded that the regeneration potential of *Quercus* is good and the forest will maintain itself (Table 4.1.2.).

The sapling density of *Myrica* i.e., 0.4 per 100 m^2 is less compared to the reported sapling density of 4.17 per100 m^2 **(Rawal *et.al.* 2003).** The low sapling and high seedling density may be due to dense canopy cover of the forest, which hinders light penetration thus affecting the growth of saplings.

Shrubs

The dominant position was occupied by *Arundinaria falcata*, having on density of 266.67 per 100$m^{2.}$ (Table 4.1.3.). *Arundinaria* is a close associate of *Quercus* and develops well in close canopied forests. It is fast spreading and develops a thick under storey, thus hindering the penetration of light. This may be the reason for the low shrub diversity of the region. Individuals of *Berberis aristata, Rubus lanatus and Argemone mexicana*, were found scattered near the road side. This indicates some minor disturbance due to vehicular movement and the persons living in the Cantonment.

Table 4.1.3. Vegetational analysis of shrubs of Site I

Species	**Density** (Per 100 m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**
Arundinaria falcata	266.64	100	24	0.240
Rubus lanatus	37.78	60	5.66	0.094
Pyracantha crenulata	23.33	50	4.2	0.084
Daphne cannabina	22.22	40	5.0	0.125
Berberis aristata	4.44	20	2.0	0.1
Argemone mexicana	4.44	40	1.0	0.025
Ranidia tetrasperma	4.44	20	2.0	0.1
Coriaria nepalense	2.22	10	2.0	0.2

Herbaceous layer

The species present in the site are mainly shade and moisture loving. As the habitat is moist, *Selaginella chrysocaulos* has the maximum density of 37.5 per $m^{2.}$ Due to dense cover of *Quercus* and *Arundinaria*, few herbaceous species are able to develop. Thus the herbaceous diversity is less (Table 4.1.4.).

Table 4.1.4. Vegetational analysis of herbaceous layer in Site I

Species	**Density** (Per m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**
Selaginella chrysocaulos	37.5	60	62.5	1.04
Athyrium pectinatum	12.6	100	12.6	0.126
Microsorum membranaceum	9.1	80	11.375	0.142
Carex crucianth	9.0	60	15	0.25
Themeda anthera	8.0	50	16.0	0.32
Carex nubigena	6.5	30	21.66	0.722
Carex gryllus	4.1	30	13.66	0.455
Asparagus racemosus	3.9	80	4.875	0.0609
Geranium nepalense	3.6	40	9.0	0.225
Apluda mutica	3.3	40	8.25	0.206
Oxalis corniculata	2.6	30	8.66	0.288
Anthraxon prionodes	1.8	20	9.0	0.45
Micromeria biflora	0.8	20	4.0	0.2
Ophiopogon intermedius	0.8	10	8.0	0.80

4.1.2.Vegetational Analysis of Site II (Manora Peak)

The forest in the study area is fairly open and mainly consists of *Quercus* and *Cupressus*. The under storey is open and the site has a disturbed forest of Quercus *leucotrichophora.*

Trees

Quercus had the dominant position, having a density of 3.7 per 100 m^2 and IVI of 76.79 (approximately 60% less than Site I). The majority of the trees observed were stunted and there were evidences of lopping. *Cupressus* occupied the co-dominant position, replacing the natural associates *Rhododendron* and *Myrica.* This is because the area has been marked for soil and water conservation by the Forest Department of Nainital. Thus plantations of *Cupressus* and the species have been carried out from time to time. This accounts for the unusually high density of *Cupressus,* i.e., 2.9 per 100 m^2 and 52.71 respectively (Table 4.1.5.)

The species diversity is more in this forest as compared to Site I, due to regular plantations carried out by Forest Department, Nainital, (Appendix-XI)

Saplings and Seedling

Quercus had the highest sapling density of 5.6 per 100 m^2 followed by *Myrica* i.e. 3.9 per 100 $m^{2.}$ This is because the canopy is open and there is easy light penetration, therefore, the seedlings can grow easily. *Cupressus* being artificially propagated had a low sapling density of 0.4per 100 $m^{2.}$ (Table.4.1.6.)

Table 4.1.5. Vegetational analysis of trees of Site II

Species	**Density** (Per 100m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**	**IVI**
Quercus leucotrichophora	3.7	70	5.28	0.075	76.79
Cupressus torulosa	2.9	60	4.83	0.080	52.71
Rhododendron arboreum	1.5	50	3.0	0.06	48.20
Myrica esculenta	0.9	50	1.8	0.036	28.95
Cedrus deodara	0.3	20	1.5	0.075	24.82
Prunus cerasoides	0.2	10	2.0	0.20	13.45
Ficus numeralis	0.2	10	2.0	0.20	12.11
Pyrus pashia	0.2	10	2.0	0.20	11.98
Pinus roxburghi	0.1	10	1.0	0.10	11.35
Lyonia ovalifolia	0.1	10	1.0	0.10	9.52

Table 4.1.6. Vegetational analysis of saplings of Site II

Species	**Density** (Per 100m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**
Quercus leucotrichophora	5.6	100	5.6	0.056
Myrica esculenta	3.9	70	5.57	0.0795
Pyrus pashia	1.9	70	3.33	0.0476
Lyonia ovalifolia	1.2	40	4.0	1.0
Prunus cerasoides	0.8	40	2.33	0.058
Ficus numeralis	0.7	40	2.33	0.058
Rhododendron arboreum	0.5	40	1.25	0.031
Fraximus micrantha	0.5	30	2.50	0.083
Cupressus torulosa	0.4	40	1.33	0.0332
Acer oblungum	0.3	30	1.5	0.05
Aesculus indica	0.3	30	1.5	0.05

The site experiences disturbances in the form of lopping, regular scrapping for fodder, and grazing by cattles. This may be the reason for the absence of seedlings in the site. Thus the site requires immediate protection for the survival of the forest.

Shrubs

The shrub diversity is more due to open habitat. *Berberis* had a frequency of 100%, this increased presence can be attributed to the ever increasing human interference. *Rubus lanatus* too was present profusely (Table 4.1.7.)

Herbaceous Layer

The site is dominated by grasses. This may be due to the vegetative propagation and the easy dispersal of seeds by animals. The grasses present are mainly coarse grasses and sedges. *Selaginella chrysocaulos* is found mainly under the canopy of *Quercus.* In the site, *Themeda anthera* had the highest density of 75.4 per m^2, while *Asparagus racemosus* and *Arundinaria falcata* had the least density of 0.4 and 0.9 per m^2 respectively (Table 4.1.8.)

4.1. Study of Environmental Conditions

4.2.1. Study of climatic conditions

The data on climatic change during the period of 1994-2002 as given in (Fig.4.2.1) shows that the mean maximum temperature varies from 16˚C – 23˚C, showing an increasing trend. The mean minimum temperature ranges from 7˚C -12˚C and shows a decreasing trend.

The rainfall pattern showed a remarkable difference. The maximum rainfall was recorded in 1995 i.e. 337.4cm. In the recent years (i.e. 1999-2003), the average

Table 4.1.7. Vegetational analysis of shrubs of Site II

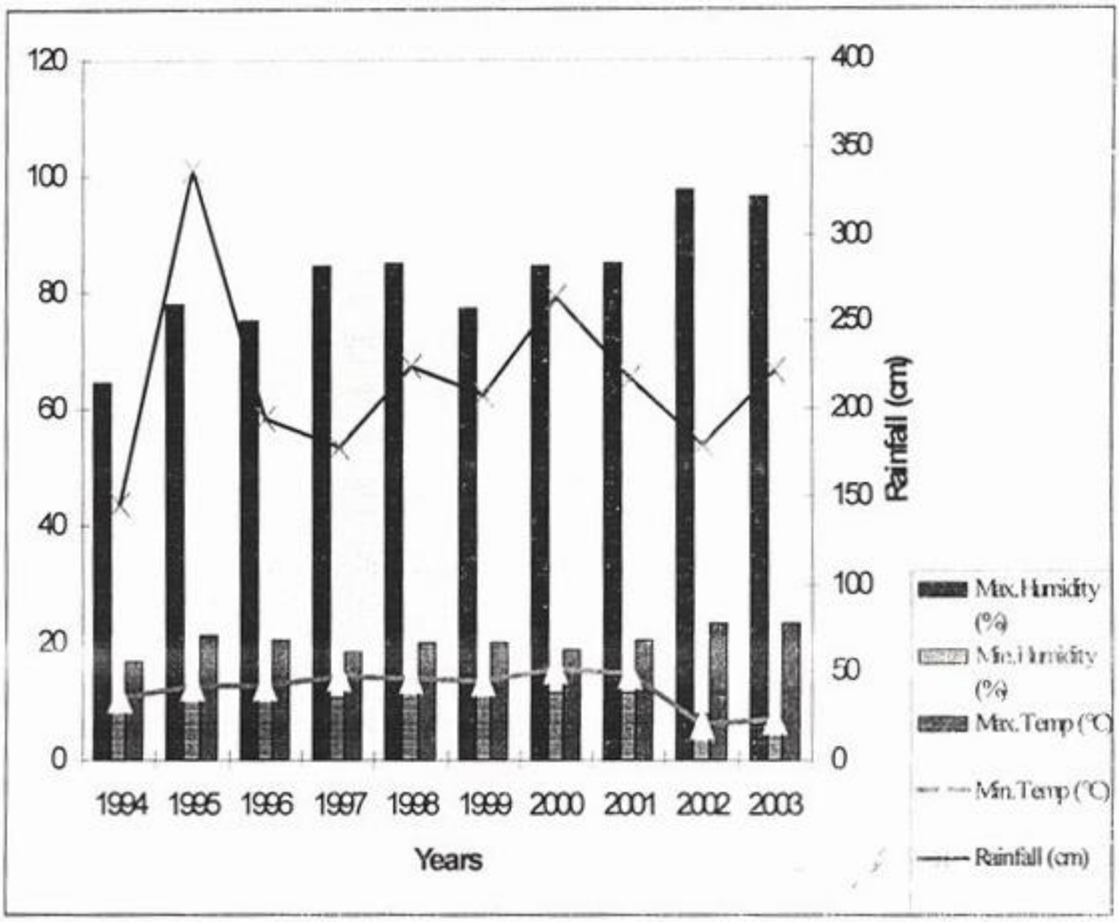
Species	**Density** (Per 100 m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**
Utrica diocea	1188.87	30	5.66	0.188
Pilea scripta	1188.87	30	5.66	0.188
Hedychium spicatum	88.88	40	20	0.50
Indigofera heterantha	55.55	30	16.66	0.55
Berberis aristata	47.77	100	4.3	0.043
Reinwardalia indica	35.55	30	10.66	0.355
Sarcococcoa saligna	32.22	30	9.66	0.322
Daphne cannabina	32.22	50	4.8	0.096
Spirea canesdcens	28.88	30	8.66	0.288
Rubus lanatus	25.55	70	3.285	0.0469
Coteneaster microphyllus	23.33	30	7.0	0.233
Leptodermis lanceolata	22.22	50	4.0	0.08
Phyllanthes parviflora	17.77	20	8.0	0.4
Mrysine africana	16.66	30	5.0	0.166
Pyracanthus crenulata	12.22	30	3.66	0.122
Ranidia tetrasperma	9.99	40	2.25	0.056
Viburinum cotinifolium	8.88	30	2.66	0.088
Coriaria nepalensis	8.88	40	2.0	0.05
Indigofera dosua	5.55	20	2.50	0.125
Eupatorium adenophorum	2.22	10	2.0	0.2

Table 4.1.8. Vegetational analysis of herbaceous layer in Site II

Species	**Density** (Per m^2)	**Frequency (F) (%)**	**Abundance (A)**	**A/F**
Themeda anthera	75.4	60	125.67	2.09
Selaginella chrysocaulos	52.3	80	65.375	0.82
Ophiopogon imtermedius	26.3	30	67.66	2.255
Anthraxon prionodes	25.8	80	32.25	0.403
Athyrium pectinatum	22.2	70	31.71	0.45
Carex nubigena	20.0	50	40	0.80
Scutellaria angulosa	17.8	50	35.6	0.172
Apluda mutica	16.5	30	55	1.83
Heteropogon contortus	15.6	30	52	1.73
Pogonotherum paniceum	13.5	20	67.5	3.37
Origanum vulgare	10.7	30	35.66	1.188
Carex crucianth	9.7	50	19.4	0.386
Gallium aparine	9.0	40	22.5	0.56
Artemesia nilagerica	8.4	60	14	0.23
Bupuleurum falcatum	8.0	20	40	2.0
Agrimonia pilosa	7.3	60	12.2	0.202
Micromeria biflora	6.5	20	32.5	1.62
Pouzolia hirta	6.3	40	15.7	0.39
Cyanotis barbata	5.5	30	18.33	0.011
Carex gryllus	5.1	20	25.5	1.27

Strobilanthes dalhousiana	4.4	30	14.66	0.488
Roscea procera	4.1	50	8.2	0.164
Erigeron bellidoides	3.8	40	9.5	0.24
Calamintha umbrosum	3.5	30	11.66	0.388
Chrysopogon gryllus	3.0	20	15	0.75
Lepisorus sesquipedalis	3.0	30	10.0	0.33
Valeriana wallichii	3.0	20	15	0.75
Prunella vulgaris	2.9	20	14.5	0.725
Geranium nepalense	2.7	60	4.5	0.075
Wikstroemia canescens	2.6	30	8.66	0.288
Desmodium gangeticum	2.4	30	8.0	0.266
Smilax parviflora	2.2	30	7.33	0.244
Boenninghousenia albiflora	2.0	30	6.66	0.22
Microsorum membranaceum	1.9	30	6.33	0.211
Gerbera gossypiana	1.5	20	7.5	0.375
Plectranthus japonicus	1.3	30	4.33	0.144
Voila canescens	0.9	30	3.0	0.10
Asparagus racemosus	0.4	30	1.33	0.443
Arundinaria falcata	0.3	20	1.5	0.075

Fig 4.2.1. Climatic change during the period of 1994-2003.



Source: ARIES, Manora Peak, Nainital,(2004) annual rainfall varied around 218 cm, with the highest i.e. 263 cm in yr 2000 and the least in 2002 i.e. 179.9 cm.

4.2.2. Study of soil conditions

The soil pH was near neutral in the Kailakhan site. The presence of dense forest cover insured a high moisture content of 52%. Due to more litter accumulation the organic carbon and consequently the available nitrogen were more.

In the site II, (Manora Peak) due to the presence of conifers, *Cupressus,* the soil was acidic. Also the carbon % and nitrogen was less compared to site I. Due to open canopy, less moisture was present.

Table.4.2.1. Soil characteristics of the study sites.

Soil parameters	Kailakhan site		Manora site	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Soil pH	6.3	6.0	5.5	5.4
Soil moisture (%)	52	35.8	32.8	25.90
Soil texture	Silt clay	Silt clay	Silt clay	Silt clay
Organic carbon (%)	2.30	1.85	2.01	1.625
Available nitrogen (N) (ppm)	259.78	242.85	238.39	231.69
Available potassium (K) (ppm)	93.0	87.58	89.35	82.57
Available phosphorus (P) (ppm)	11.16	9.4	10.26	8.48

4.3. Plant Biomass and Carbon Determination

4.3.1 Plant biomass determination

Plant biomass in study Site I (Kailakhan Cantt. Reserve forest)

In the undisturbed site, the *Quercus* contained the maximum biomass, followed by interspecies and *Rhododendron* respectively. The biomass of *Quercus* on per hectare basis, i.e. 459.6 t is in agreement with the values given by **Rana *et al.* (1989**).

In the stand *Quercus* contributed 84% of the total forest biomass, while the interspecies contributed only 12%. This shows that *Quercus* was predominant in the region (Fig. 4.3.2.).

The girth class of 90-100 cm contained 25% of the biomass of *Quercus* followed by girth class of 80-90 cm and 110-120 cm respectively (Fig. 4.3.1.)

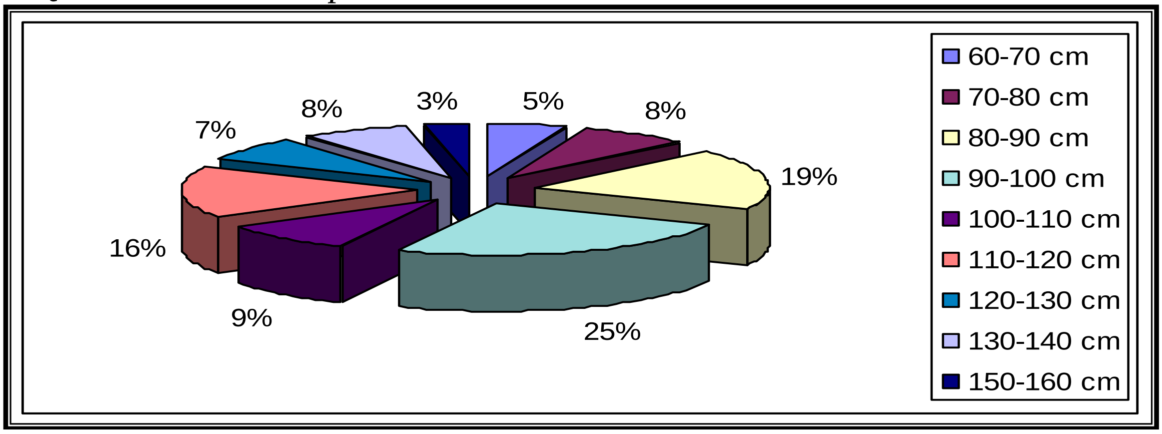
In the *Rhododendron* stand, the girth class of 80-90 cm contained the maximum biomass, i.e., 37% followed by 100-110 cm, i.e., 32%. *Rhododendron* contributed only 4.1% to the total forest biomass.

Whereas, in the interspecies, the maximum contribution was by girth class of 110-120cm. i.e., 35% while 24% and 21% biomass was stored in girth class of 80-90 cm and 70-80 cm respectively. The interspecies contributed 12% to the total forest biomass.

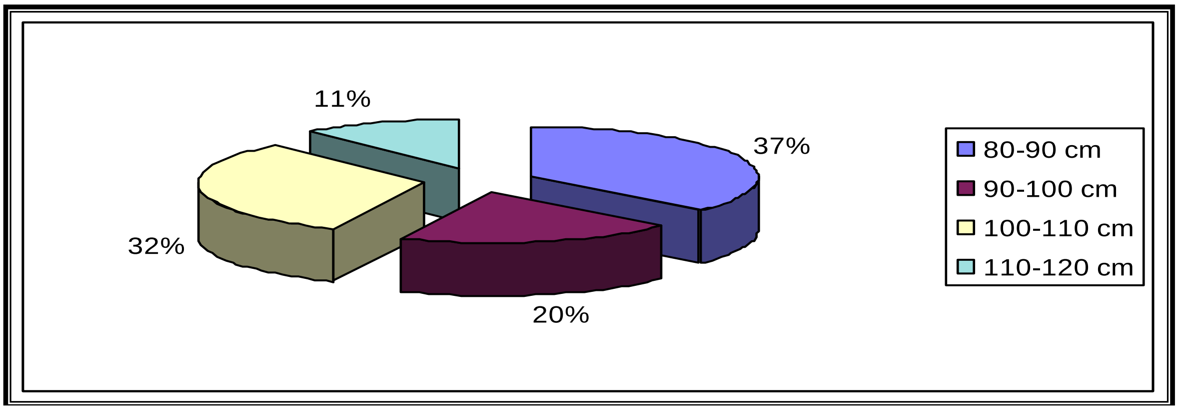
An overall analysis shows that the more biomass was present in trees falling within the girth class of 90-120 cm, and less in girth class of 40-50 or 50-60 cm.

Fig 4.3.1. % biomass in different CBH classes at Site I (Kailakhan cantt. reserve forest)

1. *Quercus leucotrichophora*



2. *Rhododendron arboreum*



3. Inter species

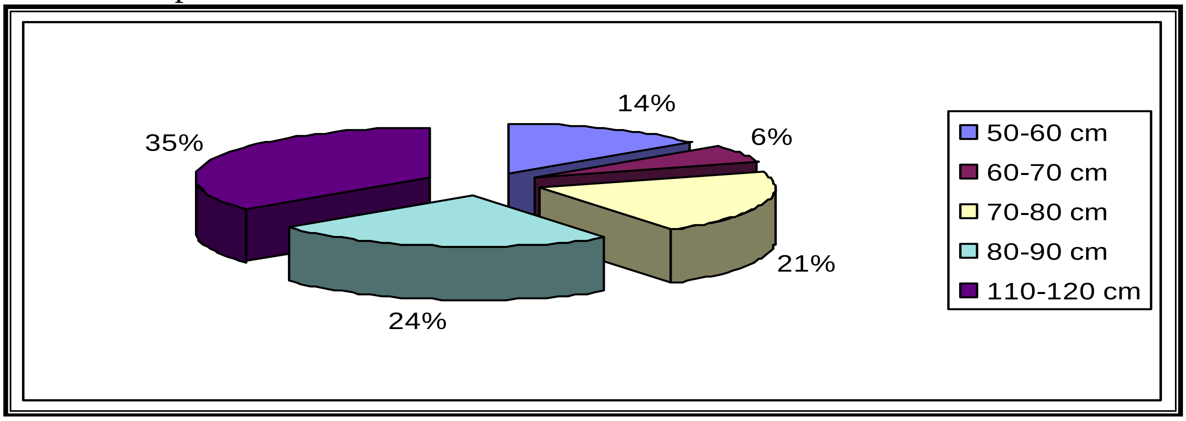
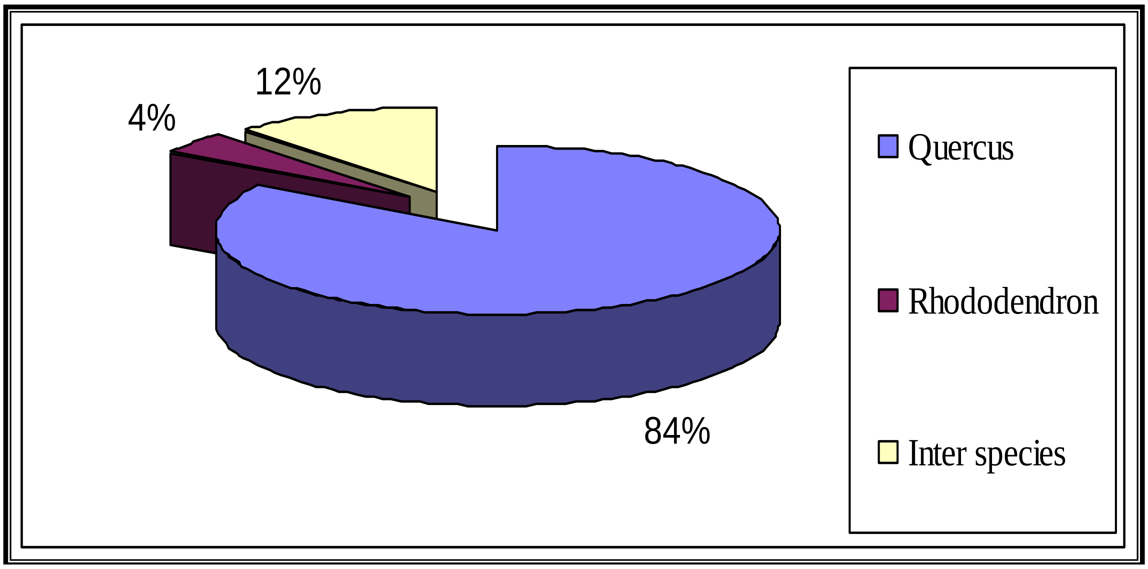
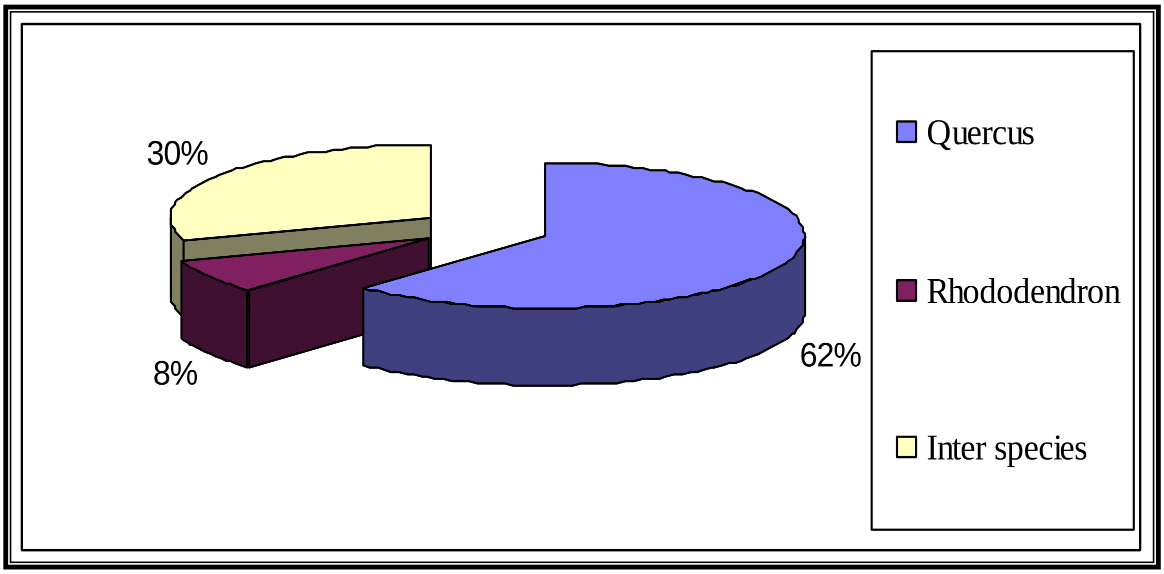


Fig 4.3.2. Relative contribution of biomass of individual species to total biomass.

1. Site I (Kailakhan cantt. reserve forest**)**



2. Site II (Manora peak forest)



Plant biomass in study Site II (Manora Peak forest)

In this site too, the maximum biomass was present in the *Quercus* stands. The biomass of *Quercus* on per hectare basis i.e. 282.1 t is less than the reported value of 426.2 t/ha by **Rana *et al*. (1989).** Moreover the contribution of *Quercus* to total forest biomass was only 62% compared to 84% in Site I (Fig. 4.3.2.)

There is a significant increase in the relative contribution of inter species to the total forest biomass, i.e., 30%. The decrease in the biomass stored in *Quercus* may be due to incidences of lopping for fodder and firewood.

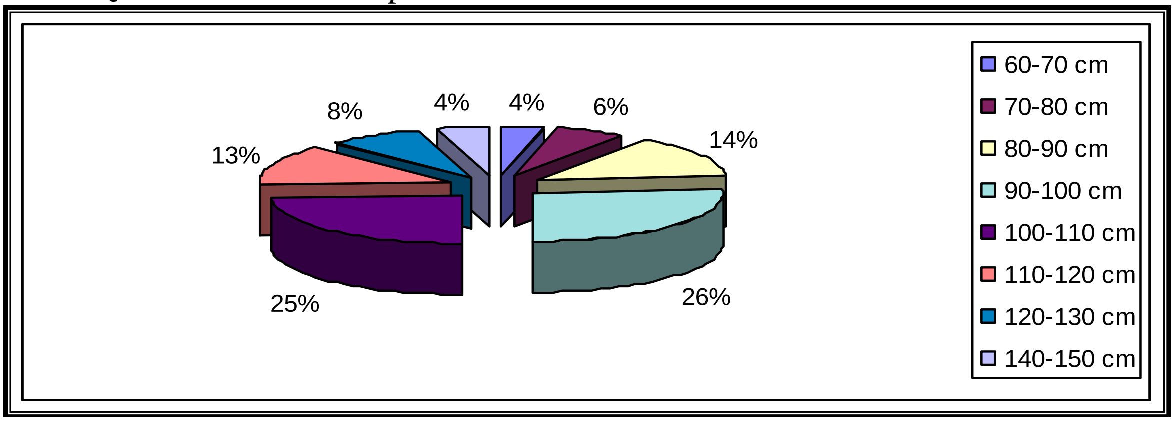
In the *Quercus* stand, the maximum biomass was contained in girth class of 90-100 cm, i.e., 26% followed by 25% accumulation in 100-110 cm girth class. The trees of smaller girth contain less amount of biomass. This may be due to their improper growth as a result of lopping for fodder (Fig. 4.3.3).

In the *Rhododendron* stand the maximum biomass was present in girth class of 110-120 cm, i.e., 36% followed by girth class of 90-100 cm i.e. 18%. *Rhododendron* contributed 8.0 % to the total forest biomass.

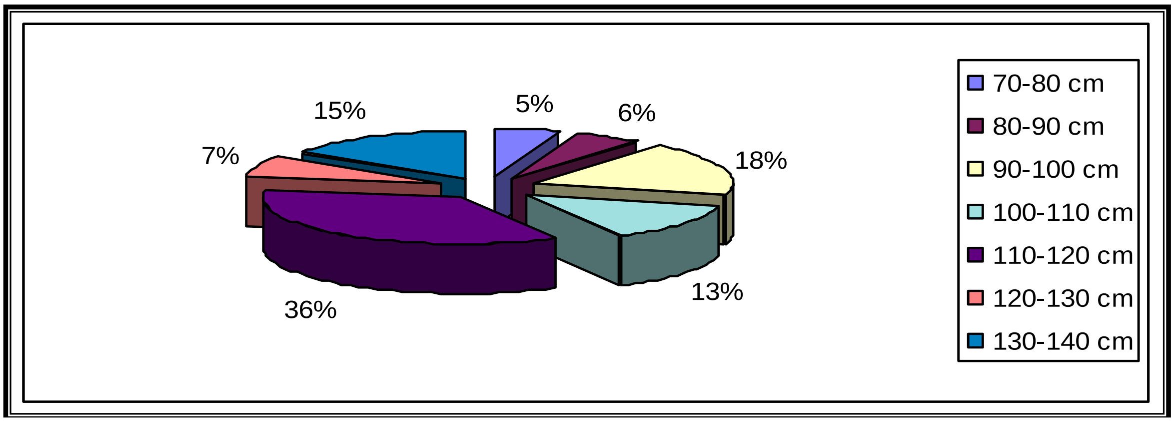
The contribution of inter species, to the total forest biomass was 30%. This is because of the time to time plantations (namely *Cupressus*) being done in the site by the Forest Department, Nainital. On studying the percentage distribution in different girth classes, it was observed that girth class of 50-60 cm had the maximum biomass i.e., 27%, followed by 23% in 60-70 cm girth class. This can be attributed to the regular plantation done in the area.

Fig. 4.3.3. % biomass in different CBH classes at Site II (Manora peak)

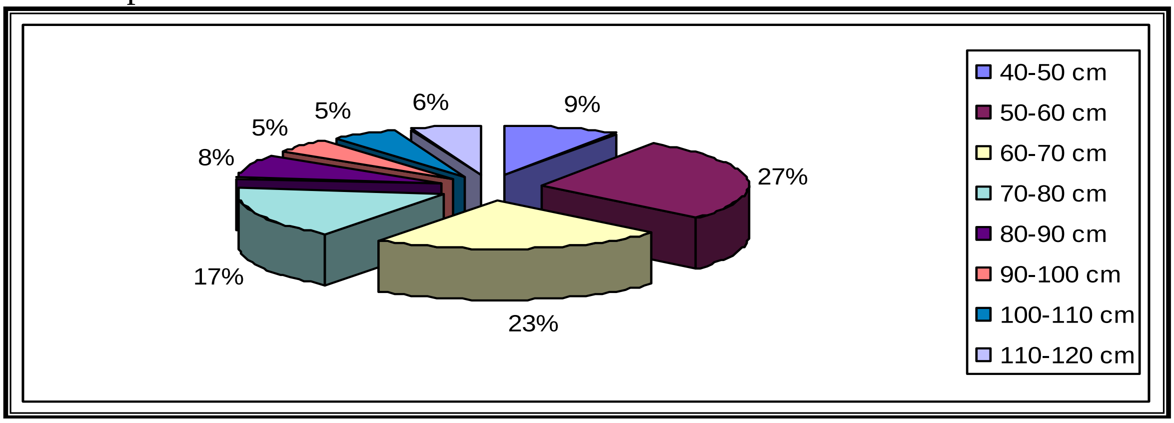
1. *Quercus leucotrichophora*



2. *Rhododendron arboreum*



3. Inter species



4.3.2. Carbon determination

Carbon storage in site I (Kailakhan Cantt. Reserve forest)

The carbon storage of wood/stem showed a limited range, 47.48% to 47.68%, in all the trees studied. These values are in agreement with the values reported by ***Rana et al. (1989).*** The carbon content of leaves varied from 40.24 - 42.11% in all the age class studied. The roots had almost the same values as leaves (Table 4.3.1.)

In the case of shrubs, i.e., Arundinaria *falcata*, the maximum carbon content was in the stem, i.e. 48.68%. The total carbon storage in these forests was 273.6 t /ha.

Carbon storage in site II (Manora Peak forest)

The carbon content in stems and branches varied from 45.53 to 46.59%. In the case of shrubs, i.e. *Berberis aristata* and *Rubus lanatus,* the stem stored the maximum carbon i.e. 48%, while the carbon % of leaves and roots was approximately 47% (Table.4.3.2.)

The total carbon storage in there forest was 226.6 t/ha, less than in Site I forest. This is due to the removal of wood and twigs for firewood by the neighboring villages.

4.4 Carbon Valuation

On per ton carbon basis, the value of US $ 15.3 calculated by the replacement cost method is in agreement with the figures cited in literature. Using this value, the carbon stocks in Kailakhan site amount to US $ 112,961.25, whereas those of Manora amount to US $93,547.70.

Table.4.3.1. Carbon content in different components of trees, shrubs and litter in Site I

Young tree of *Quercus leucotrichophora* (70-80cm girth class)

Plant part	Mean +	% carbon
Stem	0.9503	47.52
Branches	0.9411	47.29
Leaves	0.8436	42.10
Roots	0.8299	41.53

Medium tree of *Quercus leucotrichophora* (90-100cm girth class)

Plant part	Mean	% carbon
Stem	0.9496	47.48
Branches	0.9460	48.30
Leaves	0.8423	42.11
Roots	0.8303	41.51

Old tree of *Quercus leucotrichophora*(120-130cm girth class)

Plant part	Mean	% carbon
Stem	0.9537	47.68
Branches	0.9283	46.41
Leaves	0.8048	40.24
Roots	0.8202	41.01

Shrub of *Arundinaria falcata* **Site I**

Plant part	**Mean**	**% carbon**
Stem	0.9736	48.68
Leaves	0.9045	45.23
Root	0.8419	42.10

Litter layer of Site I

Component	**Mean**	**% carbon**
Litter	0.8950	44.75

Table.4.3.2. Carbon content in different components of trees, shrubs and litter in Site II

Young tree of *Quercus leucotrichophora* (70-80cm girth class**)**

Plant part	**Mean**	**% carbon**
Stem	0.9318	46.59
Branches	0.9288	46.44
Leaves	0.8726	43.63
Roots	0.8842	44.21

Medium tree of *Quercus leucotrichophora* (90-100cm girth class)

Plant part	**Mean**	**% carbon**
Stem	0.9275	46.37
Branches	0.9268	46.34
Leaves	0.8251	41.25
Roots	0.8293	41.46

Old tree of *Quercus leucotrichophora* (120-130cm girth class)

Plant part	**Mean**	**% carbon**
Stem	0.9292	46.46
Branches	0.9105	45.53
Leaves	0.8595	42.96
Roots	0.8681	43.40

Shrub I *(Berberis aristata)*

Plant part	**Mean**	**% carbon**
Stem	0.9735	48.68
Leaves	0.9203	46.02
Root	0.9501	47.50

Shrub II *(Rubus lanatus)*

Plant part	**Mean**	**% carbon**
Stem	0.9677	48.38
Leaves	0.9495	47.47
Root	0.9434	47.17

Litter layer of Site II

Component	**Mean**	**% carbon**
Litter	0.8516	42.58

If only the monetary value of *Quercus* trees is considered then the *Quercus* trees of Kailakhan amounted to an annual flow of US $ 94,876.9/ha/yr, whereas that of Manora amount to an flow of US $ 58,236.2/ ha/yr (Table.4.4.1.)

The above estimate gives an idea of the immense economic and ecological value that the forests provide by storing carbon.

Valuation of loss due to anthropogenic influences

The Manora forest site experiences disturbances from the neighboring villages of Charta and Manora, mainly Charta. The majority of the people in Charta own cattles and are milkmen. Thus these people depend heavily on the forest for their daily needs of firewood and fodder.

An average house hold removes 15-20 kg of firewood, mainly for burning, 5-7 times a week. Considering the lower value, the calculations can be summed up as:

Table. 4.2.2. Valuation of loss due to anthropogenic influences on Manora forest site

Net removal of firewood (per yr)	(15× 5× 52) ×15	58.5 t
Net emission of CO_2 from burning	58.5×0.5×3.67	107.35 t
Estimated loss	**107.35 × 56.25**	**60, 38.44US $ /yr**

Table.4.4. Quantification of CO_2 released from forestland conversion into other land use.

Site I (Kailakhan Cantt. Reserve forest)

Species	**Dry Biomass t/ha**	**Conversion factor***	**Tonnes of CO_2 liberated/ha**
Quercus leucotrichophora	459.6	3.67	1686.7
Rhododendron arboreum	21.5	3.67	78.90
Inter species	66.1	3.67	242.6
Total	**547.2**		**2008.2**

*** IPCC, 1996**

Site II (Manora peak forest)

Species	**Dry Biomass t/ha**	**Conversion factor***	**Tonnes of CO_2 liberated/ha**
Quercus leucotrichophora	282.1	3.67	1035.31
Rhododendron arboreum	34.7	3.67	127.35
Inter species	136.35	3.67	500.41
Total	**453.15**		**1663.07**

*** IPCC, 1996**

Quantification of CO_2 lost in different land use scenarios.

Site I (Kailakhan Cantt. Reserve forest)

Assuming that due to land use change, 10% of the biomass stored in the forest in lost. This will release an equivalent of 100.4t of CO_2 to the atmosphere. If the level of disturbance increases and 50% of the biomass stored is lost then it releases 502t of CO_2 to the atmosphere. An amount of 5647.5 US $ and 28237.5 US $ is needed to offset the CO_2 released by land use change of 10% and 50% respectively ,Table .4.4.3.

Site II (Manora peak forest)

A land use change resulting in a loss of 10% of biomass release 83.15 t of CO_2 which increases to 415.76 t CO_2 with the level of disturbance increasing to 50%. For offsetting this CO_2 released money amounting to US $ 4677.2 and 23, 386 are needed respectively Table 4.4.4.

In the above calculations only the removal of firewood has been accounted for, the removal of leaves for fodder is not considered. In the valuation of carbon stocks, only the above ground carbon stocks have been accounted for. The shrubs and herbaceous layer have not been considered.

Further it is assumed that the biomass harvested from the forest does not result in long term storage of carbon. The fate of soil carbon, below ground biomass is ignored in this calculation, as little information is available on this.

Nevertheless, the above factors, if accounted for would increase the economic worth of the forest.

Table 4.4.3. CO_2 released in different land use change scenarios in Site I (Kailakhan Cantt. Reserve forest)

10% land use change

Species	**Dry biomass (t)**	**Conversion factor***	**Tonnes of CO_2 liberated/ha**
Quercus leucotrichophora	45.96	3.67	168.67
Rhododendron arboreum	2.153	3.67	7.89
Inter species	6.61	3.67	24.26
Total	**54.72**		**200.82**

*** IPCC, 1996**

50% land use change

Species	**Dry biomass (t)**	**Conversion factor***	**Tonnes of CO_2 liberated/ha**
Quercus leucotrichophora	229.8	3.67	843.37
Rhododendron arboreum	10.75	3.67	39.45
Inter species	33.05	3.67	121.3
Total	**273.6**		**1004.12**

*** IPCC, 1996**

Table 4.4.4. CO_2 released in different land use change scenarios in Site II (Manora Peak forest)

10% land use change

Species	**Dry biomass (t)**	**Conversion factor***	**Tonnes of CO_2 liberated/ha**
Quercus leucotrichophora	28.21	3.67	105.53
Rhododendron arboreum	3.47	3.67	12.73
Inter species	13.635	3.67	50.04
Total	**45.3**		**168.3**

*** IPCC, 1996**

50% land use change

Species	**Dry biomass (t)**	**Conversion factor***	**Tonnes of CO_2 liberated/ha**
Quercus leucotrichophora	141.05	3.67	517.65
Rhododendron arboreum	17.35	3.67	63.67
Inter species	68.20	3.67	250.3
Total	**226.6**		**831.62**

*** IPCC, 1996**

4.5. Limitations of the Study

Currently the sink projects under the CDM are restricted only to "afforestation" and "reforestation". The Kyoto protocol does not consider forest conservation as an eligible activity. However, the previous calculations broadly indicate the value of benefits the forests are providing by sequestering CO_2 from the atmosphere.

During the course of this study it has been assumed that forest management, i.e., slowing deforestation and promoting regeneration, qualifies as an eligible activity under the CDM.

If, however, the decision regarding the eligibility of forest management were to be reversed in the near future, it would help promote protection of forests and help slowing deforestation, which in itself is a major environmental problem.

In spite of all the above short comings, valuing carbon stored in forest in done to facilitate capital inflows under Clean Development Mechanism of the Kyoto Protocol.

SUMMARY AND CONCLUSION

The forest is a fundamental natural resource providing many tangible and intangible benefits. The intangible services provided by forest are being increasingly recognized. These ranged from the aesthetical and recreational values of a forest to mitigating the effect of green house gases. Under the CDM, forestry has been proposed as a means to reduce net GHG emissions.

The present study was done to compare the pre-locked stocks of carbon in disturbed and undisturbed oak forest in Nainital with respect to anthropogenic influences. There was minimum disturbance in the site I forest as compare to site II forest.

The carbon pools valued by Replacement Cost methodology amounted to a flow of 117, 961 US $ in the undisturbed site. The stock changes were observed in both the forest at 10% and 50% biomass destruction levels. These disturbances are linked to the livelihood of the people dependent on these forests.

The salient features of the present study are summarized as follows:

5.1. Site I Kailakhan Cantonment Reserve forest

- In the stocked forest (Site I) the maximum portion of the biomass was stored in *Quercus*.
- The regeneration potential of the forest is good.
- There is minimum interference by the humans and cattles.

5.2. Site II Manora Peak forest

- In disturbed forest (Site II), the maximum biomass was stored in *Quercus*.

- In this ecosystem, the inter species, namely *Cupressus*, play an important role, due to regular plantations done by the Forest department Nainital.
- There is more diversity in trees, shrubs and herbaceous layer as a result of plantations done by the Forest department Nainital
- Lopping for top feed and grazing by cattles in evident and causes immense ecological damage.
- There is a monetary loss due to removal of fire wood from the forest.
- Due to trampling, grazing & browsing, and browsing no seedlings were present which not a good sign for the future of the forest.

5.3. Steps for better management of forest.

- Protection is to be given to stop reduction is tree cover due to lopping and fire wood needs by providing alternate sources for fuel and fodder.
- The fuel wood needs can be substituted with alternate sources like LPG, biogas and solar energy.
- Rotational grazing should be practiced and stall feeding encouraged, to arrest the loss of tree cover.
- Regular plantation of species like a *Quercus*, *Alnus*, *Grewia* and other broad leaved varieties should be done rather than planting *Cupressus* only.
- Lopping of trees and grazing by cattles should be discouraged.

- To improve regeneration, the forest area should be managed in small blocks of 1 ha. Protection should be provided until the crop/seedling escapes the damaging stage by grazing, browsing and adverse climatic conditions.
- The natural regeneration should be supplemented with plantations.

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Appendix I Climate data for 1994

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	14.5	4.7	81.2	36.0	87.0
February	13.5	4.3	83.3	22.7	55.5
March	22.0	12.2	69.0	25.9	6.0
April	21.9	13.1	57.5	30.4	45.5
May	26.0	16.5	71.1	33.9	15.5
June	23.8	12.2	81.2	57.6	295.0
July	22.1	15.8	92.8	74.7	640.5
August	21.9	15.5	93.6	78.0	303.0
September	-	-	-	-	-
October	-	-	-	-	-
November	19.1	9.6	74.5	35.3	-
December	16.1	5.6	70.9	33.3	1.5

Appendix II Climate data for 1995

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	12.6	2.8	87.5	28.7	122.5
February	13.6	4.0	82.0	33.3	90.0
March	20.0	11.0	65.3	28.6	21.5
April	22.7	14.8	43.5	20.9	-
May	28.9	21.4	51.0	301	14.0
June	29.4	19.7	72.5	44.5	415.5
July	238	16.6	91.8	71.9	690.5
August	23.5	15.8	93.7	78.3	692.5
September	22.8	15.1	93.3	66.5	221.5
October	23.1	12.4	78.2	37.2	-
November	20.0	8.6	90.8	30.1	-
December	15.3	5.0	85.3	302	3.5

Appendix III Climate data for 1996

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	13.0	3.9	47.6	31.6	90.0
February	15.5	6.3	81.9	27.1	83.5
March	201	10.5	71.9	25.6	17.0
April	24.5	13.8	51.3	28.2	1.5
May	28.3	17.8	46.5	23.5	9.5
June	22.9	153	90.1	61.5	631.5
July	22.5	159	92.5	763	322.0
August	21.9	15.4	95.4	76.3	548.5
September	22.2	14.8	94.0	62.0	164.5
October	21.2	12.0	83.2	33.5	80.0
November	18.5	8.5	73.2	29.5	-
December	16.0	5.6	73.5	24.5	-

Appendix IV Climate data for 1997

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	12.5	3.3	79.1	27.0	10.0
February	13.4	3.5	75.6	28.3	46.5
March	180	8.8	76.4	29.4	52.5
April	220	11.5	72.2	37.3	67.5
May	24.0	13.8	64.7	31.4	51.0
June	22.1	14.8	87.5	55.5	256.0
July	19.2	15.9	94.0	79.0	616.5
August	21.5	15.9	93.4	73.4	215.0
September	20.9	15.5	96.1	70.0	115.5
October	17.5	10.2	96.2	48.2	166.5
November	15.9	8.0	86.9	41.8	91.0
December	12.4	4.3	93.0	425	89.0

Appendix V Climate data for 1998

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	13.1	5.1	82.4	25.9	10.0
February	15.5	6.4	93.3	37.9	36.5
March	15.7	8.1	88.8	36.3	67.5
April	225	15.5	67.4	31.4	55.5
May	27.0	19.6	74.8	32.4	94.5
June	25.3	19.8	78.4	49.8	331.5
July	23.4	18.8	95.5	77.8	495.5
August	22.3	17.8	95.3	81.1	737.0
September	22.2	15.6	95.7	69.0	175.5
October	20.8	13.6	89.0	46.8	224.0
November	18.5	10.3	82.4	33.4	13.5
December	15.5	7.0	75.4	29.0	-

Appendix VI Climate data for 1999

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	12.8	3.6	73.9	33.3	25.5
February	17.0	9.2	72.7	26.9	-
March	20.5	12.2	55.0	21.0	1.0
April	26.9	17.9	37.1	22.2	-
May	22.5	15.9	80.7	40.8	181.0
June	22.1	15.7	86.3	60.8	502.5
July	21.0	16.4	92.7	77.0	663.5
August	21.4	15.9	93.2	74.7	263.5
September	20.5	16.5	93.5	74.7	361.0
October	20.8	12.9	79.0	41.5	67.5
November	19.1	10.6	73.5	36.0	-
December	15.5	6.3	90.2	37.7	16.5

Appendix VII Climate data for 2000

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	13.4	4.6	75.3	36.7	30.5
February	11.4	2.9	79.0	41.0	109.5
March	18.1	8.9	68.8	27.8	34.5
April	24.1	15.4	58.3	31.5	15.0
May	22.9	16.6	88.7	51.9	157.0
June	20.7	16.1	95.5	75.2	596.0
July	20.3	15.7	97.0	89.0	586.5
August	20.2	15.7	98.1	86.0	753.0
September	19.9	14.4	95.4	68.8	344.5
October	20.5	13.8	87.9	36.3	-
November	17.5	8.9	88.1	42.3	10.1
December	15.5	6.4	83.0	30.0	-

Appendix VIII Climate data for 2001

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	14.3	6.0	67.1	24.5	18.0
February	16.4	6.9	80.1	25.2	35.0
March	18.5	9.5	73.5	31.3	10.0
April	23.3	14.7	58.7	33.7	67.5
May	22.6	14.5	93.2	51.6	96.5
June	21.6	16.2	99.3	77.0	648.0
July	22.8	17.4	99.9	84.9	754.5
August	22.8	17.2	99.8	80.6	471.5
September	23.1	-	98.4	64.2	64.5
October	21.7	14.1	86.0	48.2	20.5
November	18.9	9.4	84.1	39.9	-
December	18.1	6.2	80.9	30.3	-

Appendix IX Climate data for 2002

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	16.5	-1.0	1000	12.0	52.8
February	18.0	1.0	1000	7.0	147.4
March	22.0	3.5	92	15.0	59.2
April	27.0	7.5	8	18.0	38.4
May	29.0	11.0	95	7.0	62.9
June	25.5	13.0	98	28.0	198.5
July	25.0	16.0	96	30.0	411.5
August	23.5	15.0	1000	59.0	333.6
September	25.0	11.0	97	24.0	354.0
October	26.5	9.5	96	21.0	1114.4
November	21.0	6.5	99	19.0	-
December	18.0	-1.0	100	7.0	26.8

Appendix X Climate data for 2003

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	Max	Min.	
January	18.0	2.0	97	9.0	67.7
February	17.5	0.5	100	9.0	239.1
March	22.0	3.0	90	7.0	3.3
April	28.0	9.0	84	12.0	14.0
May	28.5	10.0	84	13.0	17.8
June	29.5	12.0	100	19.0	325.5
July	25.0	11.5	100	65.0	514.0
August	24.5	15.0	100	74.0	541.5
September	23.0	13.0	100	20.0	427.9
October	24.0	9.0	93	21.0	-
November	21.5	5.0	100	10.0	3.5
December	20.0	0.5	100	11.0	30.1

Appendix XI Details of plantation at Site II (Manora peak)

Years	Area planted (ha)	Species planted	Purpose
1951-1952	32	*Cedrus deodara, Cupressus torulosa.*	Soil conservation
1977-1978	15	*Aesculus indica, Cupressus torulosa.*	Soil conservation
1982-1983	33.6	*Acer oblungum, Cedrus deodara, Cupressus torulosa,*	Soil conservation
1983-1984	15	*Cupressus torulosa.*	Soil conservation
1984-1985	14.6	*Cupressus torulosa, Pinus roxburghi.*	Soil conservation
1985-1986	13	*Cedrus deodara, Cupressus torulosa, Grewia optiva, Prunus cornuta.*	Soil conservation
1992-1993	25	*Aesculus indica, Acacia - pseudoburnea, Acer oblongum, Alnus nepalenses, Cedrus deodara, Cupressus torulosa, Fraximus micrantha, Grewia optiva, Olea glandufolia, Prunus cornuta, Quercus leucotrichophora, Salix babylonica, Sapindus mukurossi, Syzygium cumini, Toona cilliata.*	Soil conservation

Source: Working Plan, Nainital Division, 1997-98 - 2007-08, Forest Department, Uttaranchal.

Appendix XII Biomass of *Quercus leucotrichophora* at Site I (Kailakhan Cantt. Reserve forest)

CBH classes (cm) Biomass (Kg/tree	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	150-160
Bole	180.80	214.16	254.41	294.22	338.96	376.24	445.41	480.92	584.85
Branch	113.34	133.18	156.92	180.22	206.23	227.78	267.50	287.78	346.73
Twig	45.16	50.46	56.48	62.12	68.15	72.97	81.49	85.69	97.40
Leaf	20.41	22.97	25.91	28.67	31.65	34.04	38.29	40.40	46.31
Stump root	117.32	131.22	147.05	161.89	177.78	190.48	212.97	224.05	255.0
Lateral root	21.61	23.89	26.46	28.83	31.35	33.35	36.85	38.56	43.30
Fine root	2.19	2.33	2.48	2.62	2.76	2.87	3.05	3.14	3.37
Total	**500.83**	**578.21**	**669.71**	**758.04**	**856.88**	**937.73**	**1085.56**	**1160.54**	**1376.96**
Total x density	**25041.5**	**34692.6**	**87062.3**	**113707.5**	**42844.0**	**75018.4**	**32566.8**	**34816.2**	**13769.6**

Appendix XIII Biomass of *Rhododendron arboreum* at Site I (Kailakhan Cantt. Reserve forest)

CBH Classes (cm) / Biomass (Kg/tree)	80-90	90-100	100-110	110-120
Bole	69.79	77.31	80.88	88.11
Branch	45.46	49.66	51.64	55.61
Twig	16.63	17.55	17.98	18.81
Leaf	7.02	7.20	7.27	7.43
Stump root	41.68	47.28	50.00	55.54
Lateral root	13.69	15.79	16.82	18.96
Fine root	2.22	2.36	2.42	2.54
Total	**196.49**	**217.15**	**227.01**	**247.0**
Total x Density	**7859.6**	**4343.0**	**6810.3**	**2470**

Appendix XIV Biomass of Inter species at Site I (Kailakhan Cantt. Reserve forest)

CBH classes (cm) / Biomass (Kg/tree)	50-60	60-70	70-80	80-90	110-120
Bole	127.67	154.93	193.63	266.73	356.21
Branch	82.25	98.49	121.21	140.41	213.84
Twig	37.10	42.65	50.10	56.14	77.77
Leaf	21.53	24.81	29.20	32.77	45.60
Stump root	40.49	46.05	53.41	59.33	80.12
Lateral root	5.20	5.96	6.96	7.78	10.67
Fine root	0.470	0.51	0.55	0.58	0.69
Total	**314.71**	**373.40**	**455.06**	**523.74**	**784.88**
Total x Density	**9441.3**	**3734.0**	**13651.8**	**15712.20**	**23546.4**

Appendix XV Biomass of *Quercus leucotrichophora* at Site II (Manora peak)

CBH classes (cm) Biomass (Kg/tree)	**60-70**	**70-80**	**80-90**	**90-100**	**100-110**	**110-120**	**120-130**	**140-150**
Bole	183.93	212.86	251.59	286.23	346.64	379.68	421.62	528.86
Branch	115.21	132.41	155.26	175.56	210.68	229.76	253.87	315.04
Twig	45.67	50.26	56.07	61.00	61.16	73.41	78.62	91.19
Leaf	20.66	22.87	25.706	28.13	32.15	34.25	36.85	43.17
Stump root	118.66	130.70	145.97	158.97	180.43	191.63	205.37	238.58
Lateral root	21.84	23.81	26.28	28.36	31.77	33.53	35.67	40.79
Fine root	2.20	2.32	2.47	2.59	2.78	2.87	2.98	3.25
Total	**508.17**	**555.23**	**663.35**	**740.84**	**865.55**	**745.12**	**1113.59**	**1260.88**
Total x density	**10163.4**	**16656.9**	**39801**	**74084.0**	**69244**	**37256**	**22271.8**	**12608.8**

Appendix XVI Biomass of *Rhododendron arboreum* at Site II (Manora peak)

CBH classes (cm) / Biomass (Kg/tree)	70-80	80-90	90-100	100-110	110-120	120-130	130-140
Bole	66.43	68.77	75.25	80.88	86.99	91.76	95.85
Branch	43.55	44.88	48.51	51.64	54.45	57.59	59.81
Twig	16.19	16.49	17.30	17.98	18.57	19.22	19.67
Leaf	6.94	6.99	7.15	7.27	7.38	7.49	7.58
Stump root	39.22	40.94	45.73	49.99	53.91	58.39	61.62
Lateral root	12.77	13.41	15.21	16.82	18.33	20.06	21.33
Fine root	2.16	2.20	2.32	2.42	2.50	20.60	2.67
Total	**187.26**	**193.68**	**211.47**	**227.0**	**242.13**	**257.11**	**268.53**
Total x density	**1872.6**	**1936.8**	**6344.1**	**4540**	**12106.5**	**2571.1**	**5370.6**

Appendix XVII Biomass of Inter species at Site II (Manora peak)

CBH classes (cm) / Biomass (Kg/tree)	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120
Bole	96.16	120.56	158.89	191.12	226.85	282.36	307.84	365.23
Branch	63.17	77.97	100.83	119.75	140.48	172.24	186.67	218.88
Twig	30.24	39.59	43.44	49.63	56.16	65.77	69.99	29.18
Leaf	17.50	20.65	25.27	28.92	32.78	38.48	40.98	46.44
Stump root	40.79	47.41	56.97	64.41	72.19	83.15	88.45	99.11
Lateral root	4.27	4.99	6.06	6.90	7.78	9.07	9.63	10.86
Fine root	0.42	0.46	0.51	0.55	0.58	0.63	0.65	0.69
Total	**252.55**	**311.63**	**391.97**	**461.28**	**536.82**	**651.7**	**704.21**	**761.39**
Total x density	**12627.5**	**37395.6**	**31357.6**	**23064.0**	**10736.4**	**6517.0**	**7042.1**	**7613.9**

Appendix XVIII   Household Survey Scheme

Date of Survey: **Name:**
Village: **District:**
Block: **Gram Panchayat:**

1. **Family composition and occupation.**

S.No.	Particulars	No. of family members available for work	Literate/ illiterate	Occupation
	Men adult Children			
	Women adult Children			

2. **Livestock**

Kind of livestock	Breed	No.	Milk/meat products	Self consumed	Amount sold	Net income
Milch cow						
Milch buffaloes						
Goat						
Sheep						
Pigs						
Poultry birds						
Others						

3. **Family income from different sources**

Source **Income**

1) Crop
2) Livestock
    - Dairy
    - Animal husbandry
3) Service
4) Others

VITA

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ABSTRACT

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The forest is a fundamental natural resource that represents value for many aspects of human development. Forests provide a lot of goods and environmental services, which must be properlyaccounted to evaluate the total dconomic value of the forest. Theree has been a growing recognition of the intangible benefits desived ftom the forest, like the role of forest in meetigating the effect of green house gases by carbon sequestration. During the course of this study, carbon sequestration, one of the major intangible benefits is valued by using replacement cost method. The value of the carbon stored in forest is evaluated by the cost that would be in curd in offsetting by alternatives means the CO_2 realised by forest plant conversion. The present study was undertaken in the Oak forest of Nainital, to assesss the prelocked stocek of carbon in two oak forest of varying degree of distrubencee. The present status pf the forest was studied by standard ecological methods. The biomass stored was determine byt using the allometric equations. Results showed that in case of stock forest , the contribution of querces to the total forest biomasss was 84% ehich decreased to 62% in disturbed forest site> The carbon content was determinewd by Ash method and by regrewsssion methods. The bioles stem had the maximum carbon percentage followed by twigs and leaves. Acconting for the above grown carbon stocks only in the forest yield and annual flow of U$ 1179621 – IS $ 93544.7. This reflects the immense economic and ecological value of the forest.

(R.S. Chauhan)	**(Pankaj Bhatt)**
Advisor	Author