STUDY OF REDD: SPECIAL EMPHASIS ON FOREST CARBON STOCK ACCOUNTING

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A STUDY OF REDD: SPECIAL EMPHASIS ON FOREST CARBON STOCK ACCOUNTING

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(Energy Systems)

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Certificate

This is to certify that the work contained in this thesis titled "**A STUDY OF REDD: SPECIAL EMPHASIS ON FOREST CARBON STOCK ACCOUNTING**" has been carried out by Ms. Shivya Singhal under my supervision and has not been submitted elsewhere for a degree.

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Declaration

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text."

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Abstract

India's forests have long been an important part of its culture and a defining feature of landscape. India recognizes that conserving, expanding and improving the quality of our forests is a major national priority. This has enormous domestic and transnational mitigating benefits. Not only is it a cost-effective and efficient way to mitigate the effects of climate change but it also improves India's water security, safeguards rich biodiversity and provides livelihood security for millions of Indians.

Because of the crucial role that forests play in lowering the effects of climate change and because their destruction leads to more emissions it has become clear that we need to slow deforestation and forest degradation and maintain healthy old growth forest systems. This has led to the idea of "**R**educing **E**missions from **D**eforestation and Forest **D**egradation"

Based on the figures for biomass carbon and SOC in forests, the estimates of total forest carbon stocks comprising components of biomass carbon and SOC for 1995, 2005 and 2008 are computed in my report. The analysis showed that there is improvement in forest carbon stocks on temporal basis from 1995 to 2005. The difference of 376.772 Mt between figures of 1995 and 2005 shows the incremental carbon accumulation in India's forests during the period but the total carbon difference between 2005 and 2008 is 111.578 Mt shows the decrement due to the decrement of growing stock of country.

In this study, I have used a dynamic model of carbon storage in forests, CO2FIX v. 3.1 (Masera et al. 2003; Schelhaas et al. 2004) to investigate the full carbon cycle of Sal (Shorea robusta Gaertn. F.) as representative of natural forests, and poplar (Populus deltoides Marsh) as exotic plantation species.

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A journey is easier when you travel together. Interdependence is more valuable than independence. This thesis work is the result of one year whereby I have been supported by many people. It is a pleasant aspect that I have now the opportunity to express my gratitude for all of them.

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Nomenclature

AR	Afforestation and reforestation
C	Carbon pool
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CFM	Community forest management
CFUG	Community forest user group
CL	Clarification Request
CO	Carbon Monoxide
COP	Conference of Parties
CO2	Carbon dioxide
CO2e	Expressed as carbon dioxide equivalent
dbh	Diameter at breast height
DNA	Designated National Authority
DOE	Designated Operational Entity
FAO	Food and Agriculture Organization of the United Nations
FRA	Forest Resources Assessment
GHG	Green House Gas/es
Gt C	Gigaton carbon or billion tonnes carbon or petagram carbon (1 Gt = 1 billion tonnes = 1 Petagram = 1 x 1015 g)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KP	Kyoto Protocol
LULUCF	Land use, land use change and forestry
SBSTA	Subsidiary Body for Scientific and Technological Advice
SOC	Soil Organic Carbon
UNFCCC	United Nations Framework Convention for Climate Change

1 Introduction

1.1 Background

India's forests have long been an important part of its culture and a defining feature of landscape. India has more than **70 million hectares** under Forest Cover, which is more than twice the entire geographical area of Finland. While most developing countries lost forest cover, **India added around 3mn hectares of forest** and tree cover over the last decade. Forests neutralize ~11% of India's GHG emissions. **200 million people are dependent on forests** for livelihood in India. Concerted programs are making them partners in conservation. India enacted a Forest Rights Act, 2006 to vest forest rights and titles on traditional forest dwelling communities. India has one of the most **advanced forest mapping** programs in the world, with the Forest Survey of India conducting a biennial cycle of forest and tree cover assessment.

India recognizes that conserving, expanding and improving the quality of our forests is a major national priority. This has enormous domestic and transnational mitigating benefits. Not only it is a cost-effective and efficient way to mitigate the effects of climate change but it also improves India's water security, safeguards rich biodiversity and provides livelihood security for millions of Indian.

If forests are ruined or degraded, large amounts of gases that cause global warming are released into the atmosphere. The most important of these gases is carbon dioxide (CO_2), a gas that is present in high level in trees, forests, animals and nature. When trees grow, they absorb CO_2 from the atmosphere and bind it into themselves and their root systems. When trees die, the gas is released back into the atmosphere. In an old forest, gases are constantly being absorbed and released, and overall, a balance is maintained. However when large-scale logging happens or these old-growth forests are converted into plantations or lighter forest cover, large amounts of CO_2 are released without enough being absorbed again. It has been estimated that 18% of the global CO_2 emissions are a result of this sort of destruction and degradation of forests. This means that deforestation and forest degradation are major causes of climate change, although not as large as industrial production and energy generation.

Forests are also victims of climate change. Climate change can damage the health of forests due to less rain and increase in temperature. Climate change can also lead to more forest fires as weather becomes less predictable and more violent. This means that changing climate can actually make forest destruction worse.

1.2 Forest degradation

"Degraded forest" refers to an unhealthy, damaged forest with reduced tree cover. Forests might be degraded because of some logging or because they have been converted to plantations or agriculture. An unhealthy and damaged forest cannot provide the many ecosystem services on which so many people all over the world, and above all those living in and near the forests depend such as:

- Controlling soil erosion,
- Providing clean water,
- Providing a habitat of wildlife and plants which above all for indigenous peoples are an important basis of our livelihoods,
- Many other important services and roles in our lives, including cultural and spiritual roles.

Forest degradation is considered as the quantitative and qualitative loss of vegetation cover over a long period of time within the forests and thus gradually reduced productivity (FAO, 1993). It is not one time process, but ongoing process due to continuous anthropogenic pressures for exploitation of forest products. Degradation is a critical environmental problem which has significant impact on depletion of biomass, loss of economic opportunities and increase in social problem in addition to the global warming. Forest degradation is critically reducing the potential of land for C-sequestration in the long run and therefore, considered a serious hazard to the environment. Degradation processes can be assessed in terms of crown cover, tree density, biomass density, biodiversity loss, soil quality and erosion. It causes land degradation and ultimately leads to loss of productivity because of poor soil conditions, loss of nutrients and soil organic matters.

Forests degradation, as a result of unsustainable human activities, affects an even large area of forests per annum than deforestation (De Gier, 1996). The forests are largely degraded by mining, overgrazing, lopping, over-harvesting of wood and non-wood forest produces, linked with underlying causes of demographic, socio-economic, population growth, agriculture, urban development and political factors of the region. The natural forests once exposed to such overexploitation of the resources develop physiological stress in vegetation and become more susceptible to the natural hazards such as fire, pests, diseases and climatic factors. Such impacts of human activities aggravate forest degradation. The degradations reduce the potential of forest to function as regulator of the environment, natural regeneration, soil and water conservation, and lastly serious impacts on C- dynamics. The magnitude of forest degradation with respect to C-dynamics is still not well understood. The estimation of changes in forest C pool is useful for understanding C storage associated with various level of degradation in various forest types.

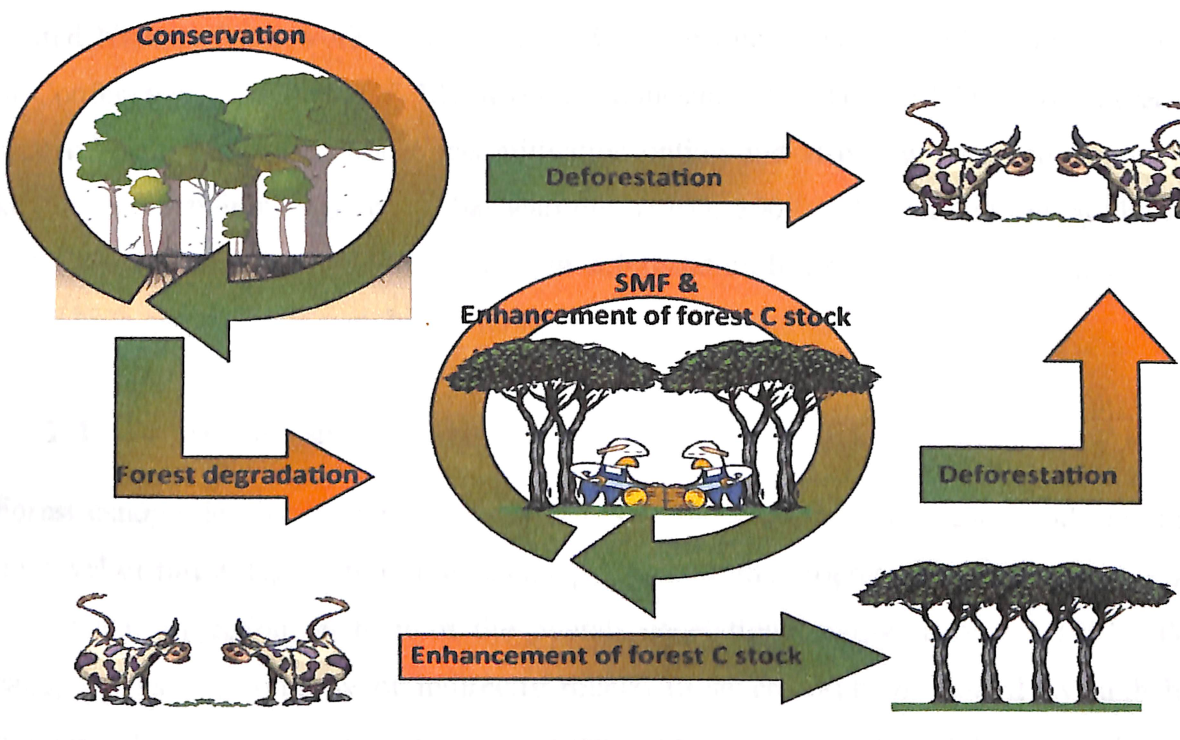

Figure 1: Deforestation & Forest Degradation

1.3 Deforestation

Deforestation is considered as "the removal of forest stand where land is put to a non forest land-use" (Helm, 1998). Good Practice Guidance for Land Use, Land-Use Change and Forestry (LULUCF), (IPCC, 2003) defined deforestation as the direct human- induced conversion of forested land to non-forested land. The conversion of forests for other land use is broadly for agriculture, pastures, shifting cultivation, plantations etc. Most of these changes affect the vegetation and soil and thus change the amount of C held in forest land. Deforestation is one of the single biggest threats to the terrestrial C sink and climate change along with soil management practices influence sink capacity of the soils (Reay, 2007). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the forestry sector, mainly through deforestation, accounts for about 17% of the global greenhouse gas emissions which is the second source after energy sector. Recognizing this, the support to reduce emissions from forest deforestation and forest degradation (REDD) has been adopted in Bali Action Plan of United Nations Framework Convention on Climate Change (UNFCCC) at the 13th session of Conference of Parties(COP 13) in Bali, Indonesia, 2007. The REDD is considered as a relatively low cost green house gas mitigation option and also now emerged as one of the key areas for fighting against global warming (FAO, 2009). As pointed out by the IPCC (1996) global estimate of C emission from deforestation has remained highly uncertain and show high geographical variability, needs to be further studied.

1.4 Forest canopy density

Forest canopy density is one of the indicators of the status of forest and good measure of the level of forest degradation. Forest canopy refers to the proportion of the ground covered by vertical projection on to it of the overall vegetation canopy (Howard, 1991). Forest canopy density is directly or indirectly related to severe problem caused by high biotic pressure, degradation, soil erosion and encroachment on forest land for agriculture and settlement. Canopy density is a dynamic process, usually opened by removal of trees or vegetation. The created gaps are generally filled up by new vegetation or co-dominant vegetation, depending upon the climate, disturbances, factors etc. The anthropogenic interventions like fire, illegal felling, fuel wood collection, lopping, grazing etc. in the natural forests adversely affect canopy closure and continuous disturbances may not allow recovering canopy closure to its original potential. Canopy disturbances are not a random process because certain areas are more persistently and more frequently disturbed than other areas. Bharti (1999) has also reported the loss of canopy closure in Sal forests of Dehradun, adjacent to human habitation due to high biotic pressure for lopping, grazing, firewood and timber collection which is the indicator of forest degradation.

Because of the crucial role that forests play in lowering the effects of climate change and because their destruction leads to more emissions it has become clear that we need to slow deforestation and forest degradation and maintain healthy old growth forest systems. This has led to the idea of "reducing emissions from deforestation and forest degradation".

1.5 Climate Change, Trees and Carbon

Strong scientific evidence shows that, since the industrial revolution, the burning of fossil fuels and the destruction of forests have caused the concentrations of heat-trapping greenhouse gases to increase significantly in our atmosphere, at a speed and magnitude much greater than natural fluctuations would dictate (IPCC, 2007c). If concentrations of greenhouse gases in the atmosphere continue to increase, the average temperature at the Earth's surface could grow from 1.8 to 4°C (3 to 7°F) above 2000 levels by the end of this century (IPCC, 2007c). Impacts of climate change, many of which are already being seen, include temperature increase, sea level rise, melting of glaciers and sea ice, increased coral bleaching, changes in the location of suitable habitat for plants and animals, more intense droughts, hurricanes and other extreme weather events, increased wildfire risk, and increased damage from floods and storms. The rural poor are often most at risk for being severely and negatively impacted by climate change, as their livelihoods are closely tied to ecosystems which provide water for drinking, wildlife for hunting and fishing, and medicinal plants. Deforestation and degradation also have detrimental effects on soils, reducing the amount of carbon stored in soils over time, as well as increasing erosion and polluting rivers.

1.6 The Role of Forests in the Carbon Cycle

Trees absorb carbon dioxide gas from the atmosphere during photosynthesis and, in the process of growing, transform the gas into the solid carbon that makes up their bark, wood, leaves and roots. When trees are cut down and burned or left to decompose, the solid carbon chemically changes back to carbon dioxide gas and returns to the atmosphere. Even if the trees are harvested, only a fraction of harvested trees makes it into long-term wood products such as houses and furniture. For example, one study estimates that for every tree harvested using conventional logging techniques in Amazonia, 35.8 additional trees were damaged (Gerwing, et al., 1996). As much as 20 percent of usable timber volume that was extracted from a typical hectare was never removed and instead left to rot in the forest. Furthermore, less than 35 percent of the timber that made it to the saw mill was actually converted into usable boards. Hence, the majority of the harvested forest vegetation ends up as waste and, whether burned or left to decay, emits carbon dioxide gas as it breaks down.

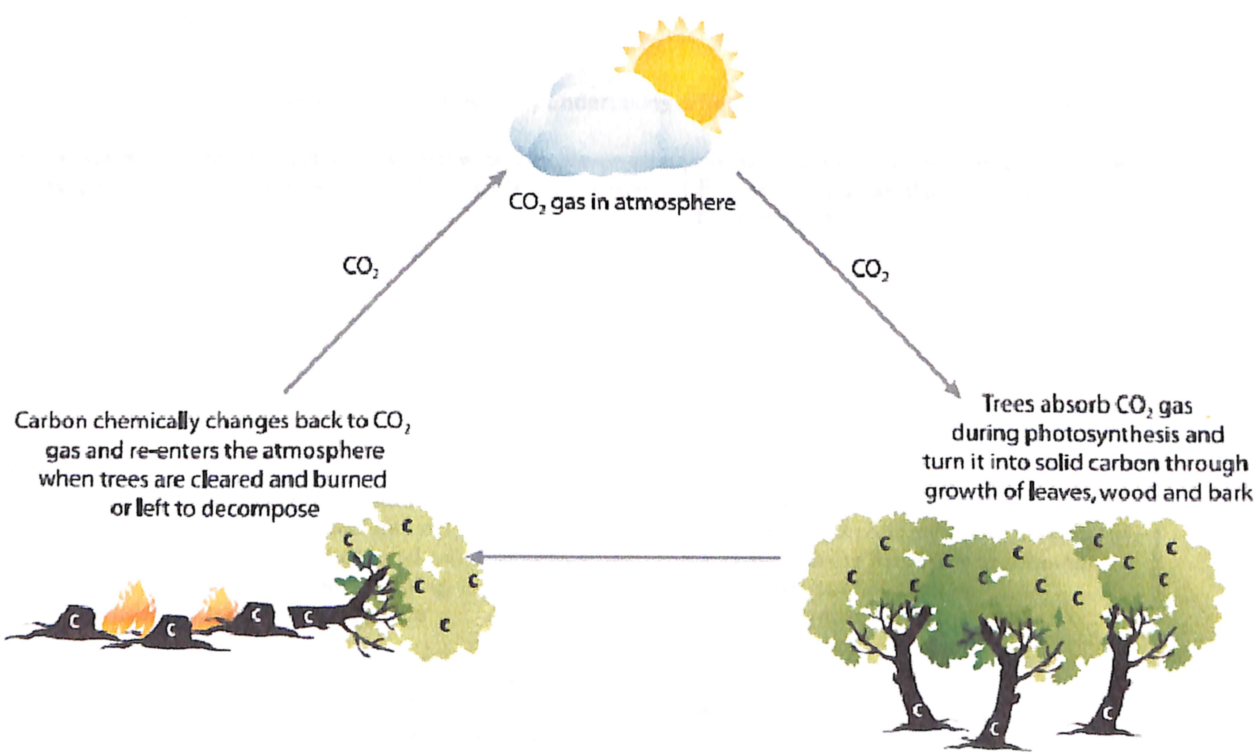

Figure 2: CO_2 Cycle

Forests therefore play an important role in the global carbon cycle as both a "sink" (absorbing carbon dioxide) and a "source" (emitting carbon dioxide). According to the most recent Intergovernmental Panel on Climate Change (IPCC) report, the 5.87 $GtCO_2e$ emitted by deforestation and degradation of forests accounts for 17.4 percent of total emissions from all sectors, more than the emissions of the entire global transportation sector (see Figure) (IPCC, 2007b). More recent estimates put this percentage at about 15 percent, due mainly to increases in fossil fuel emissions and the use of updated data (van der Werf, et al., 2009; Canadell, et al., 2007).

1.7 Forestry Activities for Carbon Management

As forests play a critical role for both reducing and releasing CO2 depending on its management, forest management is a key strategy for managing atmospheric concentration of CO2. Bass *et al.,* (2000) have classifi ed various forest management activities into three carbon management strategies namely carbon sequestration, carbon conservation and carbon substitution, as illustrated in Table.

Table 1: Carbon Management Strategies by undertaking different forest management activities

Strategy	Land use type and forestry activity	Forestry/rural development project type
Carbon sequestration	• Silviculture in increased growth rates • Agroforestry • Afforestation, reforestation and restoration of degraded lands • Soil carbon enhancement (e.g. alternative tillage practices)	• Community/farm/outgrower plantations • Forest rehabilitation or restoration • Agroforestry
Carbon conservation	• Conservation of biomass and soil carbon in protected areas • Change forest management practices (e.g., reduced impact logging) • Fire protection and more effective use of prescribed burning in both forest and agricultural systems	• 'People and Protected Areas' projects • Agriculture intensification • Rotational shifting cultivation • Community fire control schemes • Home gardens • NTFP production • Eco-tourism
Carbon substitution	• Increased movement of forest biomass into durable wood products, used in place of energy-intensive materials • Increased use of biofuels (e.g., introduction of bioenergy plantations) • Enhanced utilization of harvesting waste as a biofuel feedstock (e.g., sawdust)	• Community fuelwood • Community farm fuelwood
Source: Bass et al., 2000 :6 and 17.		

This table is important in that it shows the different activities in forest management that lead to reductions in emissions. Initially under the CDM, only the strategy of carbon sequestration was regarded for recognition and consequently it limited forestry related activities to afforestation and reforestation (AR) in developing countries. However, now this deficiency has been recognized and the proposed REDD include the strategy of carbon conservation by recognizing carbon saved from avoiding deforestation and conservation of existing forests.

1.8 Objective

The project will include the following steps:

(i) Mapping and displaying of forest gains or losses,

(ii) Study of REDD,

(iii) Calculation and elaboration of a Carbon stock model.

1.9 Structure of thesis

The thesis comprises of 6 chapters starting with the present one which throws light on background, and objectives. The chapter 2 deals with review of literature explaining the basic concepts on related issues of research and the previous works. Chapter 3 gives a description of REDD, Its Phases, mechanism and challenges. Chapter 4 explains research approach to methodology and materials needed in order to calculate forest carbon and achieve objectives. Chapter 5 summarizes the results obtained by CO2FIX tool for investigate the full carbon cycle of Sal (Shorea robusta Gaertn. F.) as representative of natural forests, and poplar (Populus deltoides Marsh) as exotic plantation species. Chapter 6 includes references.

2 Literature Review

The area of work is chosen mainly because of the research scope prevailing in this area.

2.1 What are REDD and REDD+

With the reference of the report retrieved from "**http://moef.nic.in/** ***India's forests and REDD+ Ministry Of Environment and Forests, Government Of India.***" The basic theory of REDD can be easily explained.

Forests have a critical role to play in addressing climate change. About 15 percent of annual global carbon dioxide emissions are caused by deforestation and forest degradation and it will be extremely difficult to solve the climate change problem without reducing these emissions. Recognizing the importance of and providing incentives for conserving (as well as restoring and better managing) forests provides an effective way to mitigate climate change while offering a cost effective and near-term option to ease the transition to low carbon economies. Within the current policy context, there is interest in including the full scope of forest carbon activities in an overall REDD framework— Reducing Emissions from Deforestation and Forest Degradation, Forest Conservation, Sustainable Management of Forests and Carbon Stock Enhancement.

REDD (Reducing Emissions from Deforestation and Forest Degradation) is the global Endeavour to create an incentive for developing countries to protect, better manage and save their forest resources, thus contributing to the global fight against climate change.

REDD+ goes beyond merely checking deforestation and forest degradation, and includes incentives for positive elements of conservation, sustainable management of forests and enhancement of forest carbon stocks. REDD+ conceptualizes flow of positive incentives for demonstrated reduction in deforestation or for enhancing quality and expanse of forest cover.

- It works on the basis of creating a financial value for the carbon stored and enhanced in biomass and soil of standing forests. Countries that reduce emissions and undertake sustainable management of forests will be entitled to receive funds and resources as incentives.

- REDD+ approach incorporates important benefits of livelihoods improvement, biodiversity conservation and food security services.

2.2 Forest Carbon Accounting

With the reference of ***"Charlene Watson, Forest Carbon Accounting: Overview & Principles, London School of Economics and Political Science"*** *The basic theory of Forest Carbon Accounting can be explained.*

Carbon accounting is the practice of making scientifically robust and verifiable measurements of GHG emissions. Although characteristics of forests have been recorded for numerous historical purposes, accounting for carbon is a more recent addition to forest inventories. This follows the growing need to quantify the stocks, sources and sinks of carbon and other GHGs in the context of anthropogenic impacts on the global climate.

The forestry sector plays a vital role in the global balance of GHGs. Deforestation alone accounts for approximately 20% of anthropogenic emissions (FAO 2006; Stern, 2006) and the forestry sector represents upwards of 50% of global greenhouse gas mitigation potential (IPCC, 2007). As forests rise up the climate change agenda, three types of forest carbon accounting have developed: stock accounting, emissions accounting and project emission reductions accounting.

2.2.1 Stock accounting

Forest carbon stock accounting often forms a starting point for emissions and project-level accounting. Establishing the terrestrial carbon stock of a territory and average carbon stocks for particular land uses, stock accounting allows carbon-dense areas to be prioritised in regional land use planning. An early form of forest carbon accounting, emissions and emission reductions accounting have evolved from the principles established for stock accounting.

2.2.2 Emissions accounting

Emissions accounting is necessary to assess the scale of emissions from the forestry sector relative to other sectors. It also aids realistic goal-setting for GHG emissions targets. Under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, countries are mandated to undertake some land use, land use change and forestry (LULUCF) carbon accounting. With a significant portion of developing country emissions arising from the LULUCF sector, the forestry sector is likely to play a prominent role in climate change strategies in these countries.

2.2.3 Project emission reductions accounting

Carbon accounting for forestry project emission reductions is required for both projects undertaken under the flexible mechanisms of the Kyoto Protocol and the voluntary carbon markets. Both necessitate good carbon accounting to ensure that emissions reductions are *real, permanent* and *verifiable.* For projects to generate tradable emission reductions, accounting methods between countries, regions and projects must be standardised in both developed and developing countries.

2.3 Measuring and Monitoring

With the reference of ***"Reducing Emissions from Deforestation and Degradation (REDD): A Casebook of On-the-Ground Experience. 2010. The Nature Conservancy, Conservation International and Wildlife Conservation Society. Arlington, Virginia."*** The basics of Measuring and Monitoring can be explained.

Measuring and monitoring are the processes by which the amount of carbon stored in forests ("carbon stocks"), as well as changes in these amounts, are calculated and tracked, using both **satellite technology and field measurements** (complimented by laboratory testing). Measuring and monitoring fall under the larger category of "carbon accounting," this refers to the calculation of carbon benefits over time as a result of forest carbon activities. Carbon stocks are not isolated to the trees themselves, but instead are made up of several "carbon pools", as shown in Figure 3. Soil and above-ground live biomass generally constitute the largest carbon pools.

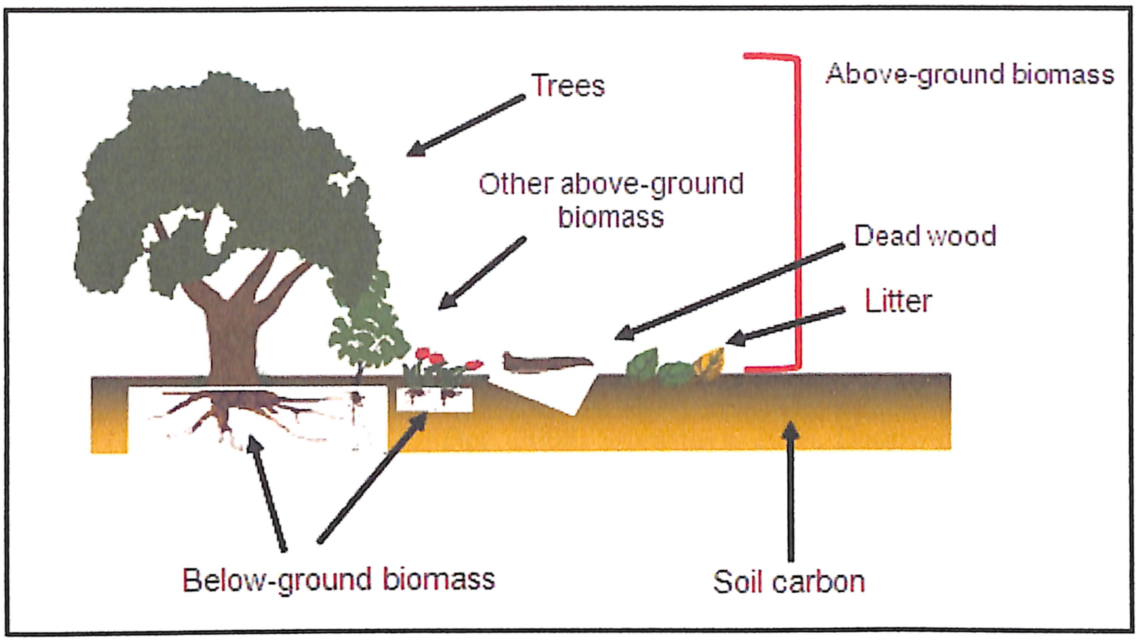

Figure 3: Carbon Pools

Using information on area, density and rate, it is then possible to calculate the project baseline; the business-as-usual emissions scenario. Methods of calculation vary depending on the form deforestation takes and associated drivers; however, several standards such as the Voluntary Carbon Standard (VCS) and Climate Action Registry (CAR) provide detailed guidance on developing baselines. Calculation of the baseline emissions scenario for REDD projects might involve running spatial land use change models. Along with the baseline emissions scenario, it is also necessary to estimate the with-project emission scenario, since the difference between the two yields the carbon benefits from project activities.

2.4 Biomass estimation

FAO (2005) has defined biomass as "the organic material both above and below the ground, and both living and dead, trees, crops, grasses, dried litter, root etc." Aboveground biomass include all living biomass above the soil, while belowground biomass includes all biomass of live roots, exceeding fine roots (<2mm dia).

2.4.1 Above ground biomass (AGB) estimation

Literature survey revealed that different approaches, based on field measurement and Remote Sensing (RS) and Geographic Information System (GIS) are available for AGB estimation.

RS does not measure biomass directly, but rather it measures other parameter of forest characteristic like spectral reflectance and therefore, ground data is necessary to develop the biomass predictive models and its validation. A sufficient number of field measurements are a prerequisite for evaluating AGB estimation results. Biomass assessment is usually carried out by collecting field inventory data from sample design. The existing species specific volume/ biomass regression equations, specific gravity and biomass expansion factors are used to calculate biomass of the sample design, followed by the extrapolation to the entire area for total biomass (e.g. Zianis, *et al.*, 2005; Deo, 2008; Srivastava, 2009, Dadhwal, *et.al.*, 2009).

2.4.1.1 Allometric regression equations

The allometric regression equations and expansion factors (EF) for a range of tree species and forest types have been developed and used for converting inventoried forest volume to above ground biomass for C-estimation in large number of studies, considered a reasonable standard method of biomass C estimation. (e.g. Negi, 1984; Hall and Uhlig, 1991; Kauppi *et al.*, 1992; Fang *et al.*, 1992; Dadhwal *et al.*, 1997; Haripriya, 2000; Hu and Wang, 2008; Kun, and Dongsheng,2008; Zou *et al.*, 2008; Srivastava, 2009; Dadhwal, *et.al*, 2009; Kale *et al.*, 2004).

Chave et al. (2004) pointed out that there are four types of uncertainties to be considered. The presence of uncertainty at each step can lead to error propagation in estimated AGB. These uncertainty errors are due to tree measurements, choice of allometric equations, sampling usually related to plot size, and representative of small measurement plot networks across large forest landscape. Among these, the allometric equation is considered the most important source of error. In order to estimate AGB in tropical forests, the use of species specific allometric equations should be preferred due the fact that different species have different tree structure and wood density (Ketterings et al., 2001, Nunung, 2006). The 'Good Practice Guidance' IPCC, 2003 has also given priority for the selection and use of species specific or similar species allometric equations in the priority order of local to national to global scale in biomass calculation. In the present study, the species specific volume allometric equations of the local area developed and compiled by FSI, 1996 was used in all tree species except Sal trees. In case of Sal trees, the allometric biomass equation of local area developed by Negi (1984) was used to minimize the uncertainty error as far as possible.

2.4.1.2 Expansion ratio

Expansion ratio (ER) is utilized to account for the non-stem biomass such as twigs, foliage etc which is not accounted for during volume/biomass estimation (Cannell, 1982). Haripriya (2000) used expansion ratio of 1.59 for broad- leaved species, 1.51 for conifers and 1.55 for hardwoods mixed with confers. Lal and Singh (2003) used expansion ratio of 1.16 for Sal, 1.34 for Teak, 1.25 for conifers, 1.40 for broadleaved species and 1.32 for hardwood mixed with conifers for obtaining total volume of aboveground biomass which were determined on the basis of earlier studies in India, Nepal and Bhutan (Cannell, 1982).

2.4.2 Below ground biomass (BGB) estimation

Measuring AGB is relatively well established, however, BGB is difficult and time consuming to measure in all forest ecosystem and methods are not standardized. AGB is often estimated from root shoot ratios(R/S). Based on number of studies covering tropical, temperate and boreal forests the mean R/S reported by Cairns et al., 1997 was 0.26 with range from 0.18 to 0.30. It is also reported that R/S did not vary significantly with latitudinal zone, soil texture or tree type. Negi (1984) reported that the root biomass of Sal trees increased with increasing AGB, but the percentage contribution of BGB decreased from 38 % to 22% with increasing diameter and AGB. Similar trends were also observed in case of total biomass where the corresponding percentage contribution of root biomass decreased from 27% to 18%. In the present study, the mean R/S 0.266 was considered.

2.5 Remote sensing for biomass and carbon mapping

The remote sensing technique has been widely used in many studies on biomass assessment (e.g. Kale *et al.*, 2002; Zheng *et al.*, 2004; Srivastava, 2009; Dadhwal, *et.al* 2009; Kale *et al.*, 2009) The advantage of remote sensing data and high correlations between spectral data and vegetation make it useful for large scale AGB mapping. The biomass measurement from sample plot can be integrated into the remote sensing technique to get cost effective and large spatial information on AGB distribution (Deo, 2008). However, remote sensing based AGB estimation is a complex procedure in which many factors such as atmospheric conditions, mixed pixel, data saturation complex biophysical environments, insufficient sample data, extracted remote sensing variables and selected algorithms may interactively affect AGB estimation (Luther *et al.*, 2006).

2.6 Benefits from the forest

With the reference of ***"Gary Q. Bull Associate Professor and Steven Northway, Research Scientist Faculty of Forestry, University of British Columbia, Vancouver, BC, Canada, V6T 1Z4"*** *benefits from forests can be explained.*

It considers first industrial products, such as sawn timber, panels and paper, and then looks at fuel wood, a product that is often overlooked by policy-makers and planners but is of (literally) vital importance for the provision of domestic energy in developing countries – and is becoming more important as a source of renewable energy in developed economies.

2.7 Conclusion of review of literature

The summary of literature review concluded that forest degradation and deforestation are the most important source of CO_2 emission and cause loss of C pool. A good number of studies are available on the assessment of total loss of C and its variations with respect to different land-use, land cover classes and, changes occurred on conversion of forests into agriculture and other land uses. However, studies related with impact of various level of forest degradation on the process, relationship and variability occurred are not well understood, hence the present study on impact of forest degradation on C density in forest was undertaken.

3 REDD: Reducing emissions from Deforestation & Forest Degradation

The negative consequences of deforestation and forest degradation obviously exceed carbon emissions. Because of the crucial role that forests play in lowering the effects of climate change, because of the many other important roles they play in our lives, and because their destruction leads to more emissions it has become clear that we need to slow deforestation and forest degradation and maintain healthy old growth forest systems. They also have an impact on loss of biodiversity, flooding, siltation and soil degradation. Deforestation further poses threats to the livelihoods and cultural integrity of forest- dependent people and the supply of timber and non-timber forest products for future generations.

3.1 What is REDD?

REDD is an idea which involves simply trying to stop forests being cut down or degraded and thereby reducing the amount of CO_2 that is released into the air. At its simplest, this is all that 'redd' is. However this idea has been adopted by governments and inter-governmental bodies and agencies and has been developed into a more specific idea: that developed countries are paying developing countries large amounts of money so that various policies and projects are implemented in order to stop forest destruction and degradation in these countries. In some of these proposals developed countries receive the right to burn more fossil fuel than they are already doing in return for their payments, in others they do not. This particular set of policy ideas is known as **R**educing **E**missions from **D**eforestation and Forest **D**egradation in developing countries – **REDD.**

REDD is a very new idea, which is promoted by several Northern and Southern governments and large conservation NGOs. There are several different proposals for REDD mechanisms which differ mainly in how the financing for REDD would be organized and at what level REDD projects could be organized (i.e., whether at the national or sub-national level). In all these proposals the basic idea remains the same: that developed countries pay developing countries for reducing rates of deforestation or forest degradation – and that developed countries do not have to reduce their own emissions as much in return for payment of forests being maintained in developing countries.

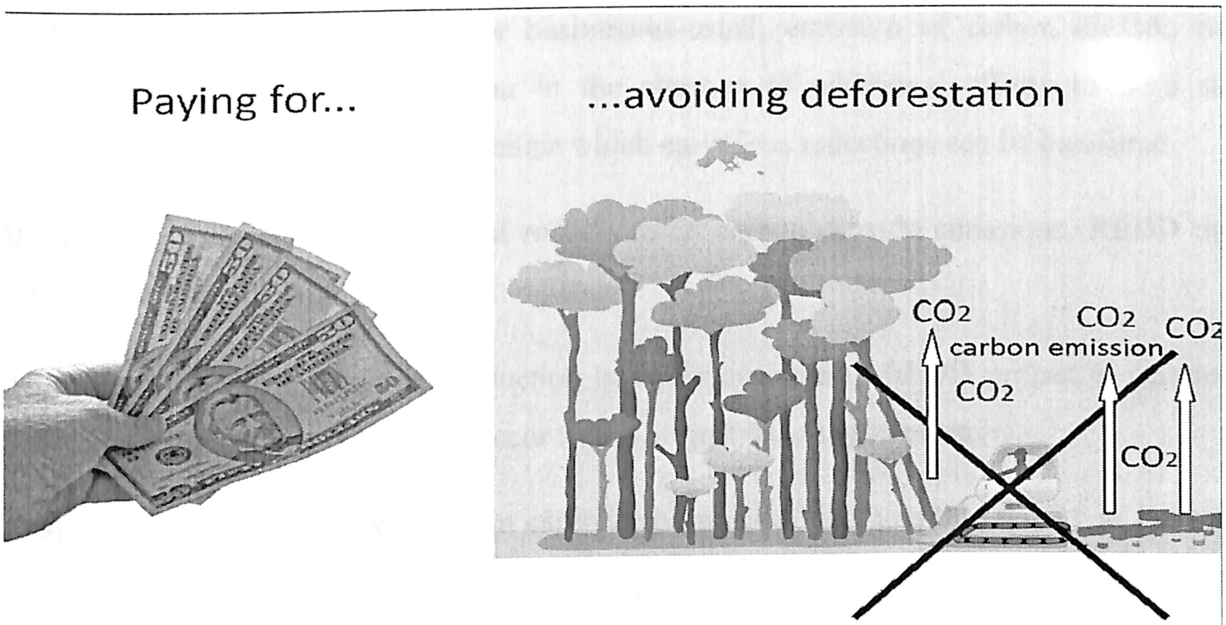

Figure 4: Deforestation

3.2 REDD: key terms

Here follows the definitions of some key concepts related to REDD.

REDD: The acronym stands for 'reducing emissions from deforestation and forest degradation'. This issue was first placed on the agenda of the 2005 international climate change negotiations. At that point the agenda item was called 'reducing emissions from deforestation in developing countries and approaches to stimulate action'. As a result, this is the name of the decision on REDD agreed at the 2007 UN Framework Convention on Climate Change (UNFCCC) in Bali, Indonesia (decision 2/CP.13). Decision 2/CP.13 acknowledges that forest degradation also leads to emissions and needs to be addressed when reducing emissions from deforestation. The 'DD' in REDD now stands for degradation and deforestation.

REDD+: REDD is included in the Bali Action Plan (decision 1/CP.13) as a component of enhanced action on mitigation (curbing emissions). Parties to the UNFCCC have agreed to consider policy approaches and positive incentives on issues relating to REDD in developing countries and *the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries*. It is this last clause on the role of conservation and sustainable management that has added the '+' to the REDD discussion.

REDD baseline: An expected, or business-as-usual, emission of carbon dioxide from deforestation and forest degradation in the absence of additional efforts to curb such emissions — used as a benchmark against which emissions reductions can be measured.

REDD conditions: To deliver real reductions in carbon dioxide emissions, REDD must satisfy the following conditions.

Additionality: Proof that any reduction in emissions from a REDD project is genuinely additional to reductions that would occur if that project were not in place.

Leakage: Leakage is a reduction in carbon emissions in one area that results in increased emissions in another. A classic example is where curbing clear felling in one region of forest drives farmers to clear fell in another.

REDD certified emission reduction or "REDD-CER" is a unit issued pursuant to the relevant provisions to be decided by the COP and is equal to one metric tons of carbon dioxide equivalent, calculated using global warming potentials defined by decision 2/CP.3 or as subsequently revised in accordance with Article 5.

3.3 How does REDD actually work?

The basic idea on which the REDD mechanism is being designed upon is to provide finance for developing countries to reduce emissions from deforestation or forest degradation through the implementation of various policies and measures. Such policies and measures may include strengthened law enforcement, fire management and sustainable forest management. In most proposals the magnitude of the emission reductions is assessed by comparing actual deforestation and degradation rates against a reference scenario commonly called as a baseline, of what would have happened in the absence of the policy measure. Such scenarios could be applied at a country and/or project level and may be based upon historical data only or include projections of expected future scenarios. Countries' actual emission from deforestation would be measured and revised and any country whose actual level of emissions from deforestation is less than its reference level would be eligible to credit this difference as an emissions reduction achievement.

What this means is that under REDD new kinds of "carbon protected areas" would be created over large areas of forests, with the main objective to cut CO_2 emissions by avoiding deforestation and degradation of these forests.

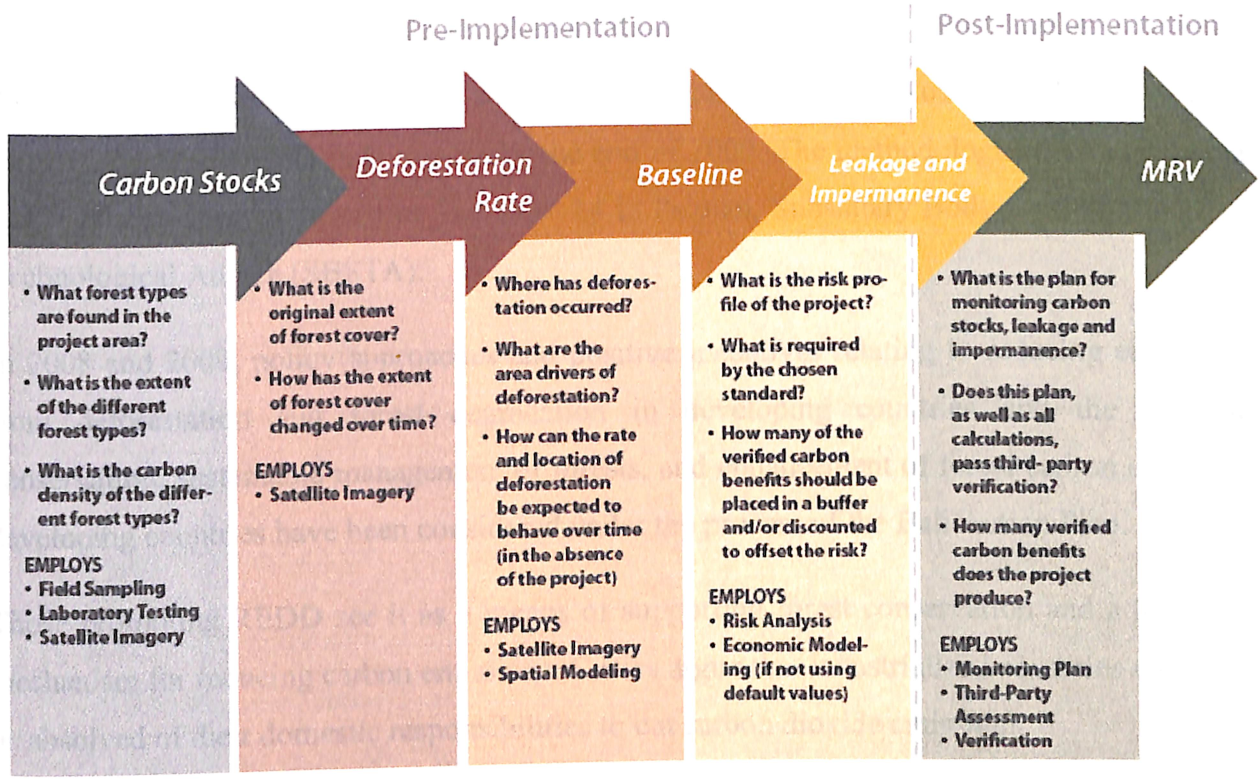

Figure 5: REDD Phases

For the REDD mechanism to produce credible carbon benefits, the baselines needs to demonstrate that the area was under threat of deforestation. There are several problems related to the monitoring of changes in forest cover; few developing countries have operational systems at place for monitoring deforestation at national scales. The accurate measurement of past deforestation for national baselines is one of the major issues in the REDD design.

3.4 What are the challenges of REDD?

Hence, while the basic idea may be simple designing such an instrument is not. There is a considerable amount of methodological and political subjects that must be discussed and decided upon.

A range of political and technical challenges stood in the way of REDD's recognition by the Kyoto Protocol. But the Coalition for Rainforest Nations ensured REDD re-emerged as an issue at the 2005 Conference of the Parties (COP) to the UN Framework Convention on Climate Change, in Montreal.

At the 2007 COP in Bali, REDD became a key element in the Bali Roadmap, the action plan for negotiating a new climate regime by the end of 2009. The methodological issues relating to REDD has been discussed in The COP 14 in Poznan, Subsidiary Body for Scientific and Technological Advice (SBSTA).

In 2008 and 2009, policy approaches and positive incentives relating to reducing emissions from deforestation and forest degradation in developing countries and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries have been considered under the process of the Bali Action Plan.

Those promoting REDD see it as a means of supporting forest conservation and a low-cost mechanism for reducing carbon emissions. Critics argue that industrialized countries must not be absolved of their domestic responsibilities to cut carbon dioxide emissions.

There are concerns, too, about the negative impacts REDD payments might have on forest-dependent communities, primarily through further weakening of their land and resource rights. There are also potential and complex links with agriculture. Limiting the expansion of agriculture could have impacts on the supply of food and other agricultural products.

To be effective as mitigation, REDD projects have to meet a number of stringent criteria. They must avoid 'leakage', for instance — where conservation in one area simply shifts deforestation to another. REDD projects and programs also need to be 'additional' – that is, they must lead directly to reductions in deforestation and degradation that would not have happened simply as a result of wider changes in the economy. A project baseline needs to be established to measure progress in reducing greenhouse gas emissions.

Land tenure and forest governance are also key factors that will determine the success or failure of any REDD initiative, and the mechanisms by which payments and benefits are shared will be critical.

So what appears to be a relatively straightforward solution to climate change – paying to keep forests standing – is much more complex than it appears at first glance. Because REDD is inseparable from the highly complex social, economic and biological realities of forests today, it remains controversial.

3.5 REDD Mechanism

A mechanism for REDD shall be defined in accordance to the principle of common but differentiated responsibilities and capabilities. The purpose of the REDD Mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments established under the framework of the Convention.

Under the REDD mechanism:

a) Parties not included in Annex I will benefit from project activities resulting in certified REDD emission reductions; and
b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under the framework of the Convention.

The Conference of the Parties to the Convention shall, at its sixteenth session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities. Participation in the REDD mechanism, including the acquisition of REDD certified emission reductions, may involve private and/or public entities.

3.5.1 Validation and Registration

REDD activities shall be validated and registered following the guidance to be developed by the COP.

3.5.2 Monitoring

The COP shall develop, based on the work already carried out by SBSTA and the IPCC, as well as on any other relevant data, adequate guidance for monitoring REDD activities, both at the sub national and national levels, in order to guarantee the environmental integrity of such activities.

3.5.3 Verification and Certification

Emission reductions resulting from each national or sub-national RED activity shall be certified by a body (ies) or entities to be determined by the Conference of the Parties on the basis of:

a) Real, measurable and long-term benefits related to the mitigation of climate change;
b) Reductions in emissions that are additional; and
c) Sustainable development benefits, as determined by the participating developing country.

3.5.4 Issuance and accounting of REDD emission reductions

Emission reductions from activities that reduce emissions from deforestation may be accounted for out either at a national or sub-national scale, as decided by each participating Party. When a Party has decided to apply a national level accounting, this approach shall be maintained for the length of the commitment period. When a Party has selected to apply a sub national accounting, such Party may decide to scale it up, from sub national to national, during an ongoing commitment period or at the start of subsequent ones.

3.6 REDD+ Fund

A special climate change fund shall be established by the COP to finance activities, programs and measures, relating to REDD+, that are complementary to those funded by the resources allocated to the climate change focal area of Global Environment Facility and by bilateral and multilateral funding, in the following areas:

- Enhancing the capabilities of developing countries to monitor changes in their forest cover and the carbon stocks associated to them;
- Designing and implementing policies that reduce deforestation and degradation; and
- Supporting ongoing forest conservation and forest carbon stock enhancement efforts in developing countries.

4 Forest Carbon Accounting

Carbon accounting is the practice of making scientifically robust and verifiable measurements of GHG emissions. Although characteristics of forests have been recorded for numerous historical purposes, accounting for carbon is a more recent addition to forest inventories. This follows the growing need to quantify the stocks, sources and sinks of carbon and other GHGs in the context of anthropogenic impacts on the global climate.

Measuring and monitoring are the processes by which the amount of carbon stored in forests ("carbon stocks"), as well as changes in these amounts, are calculated and tracked, using both satellite technology and field measurements (complimented by laboratory testing). Measuring and monitoring fall under the larger category of "carbon accounting," this refers to the calculation of carbon benefits over time as a result of forest carbon activities. Carbon stocks are not isolated to the trees themselves, but instead are made up of several "carbon pools", as shown in Figure.

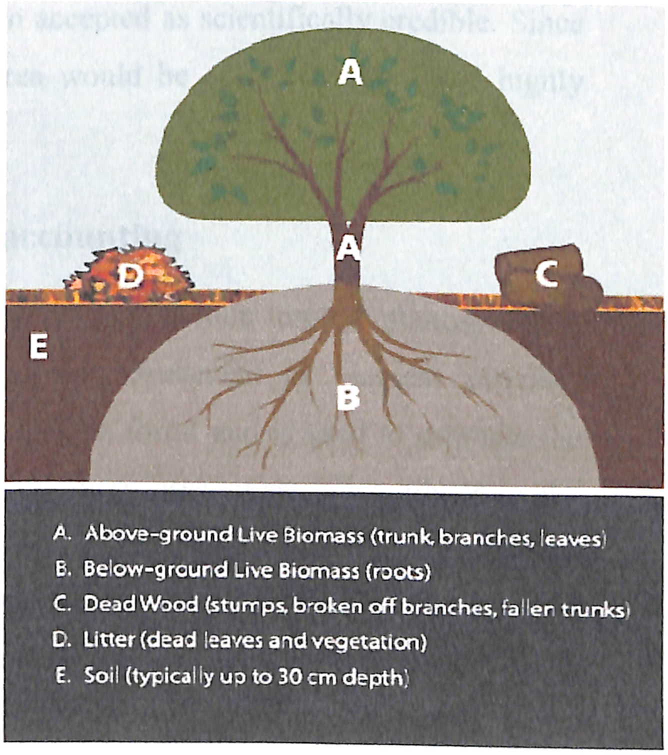

Figure 6: Carbon Pools

Soil and above-ground live biomass generally constitute the largest carbon pools.

While measuring and monitoring are perceived by some as a challenge to producing real, verifiable carbon credits, the methods used are time-tested and steeped in rigorous scientific theory. The basic steps involved in carbon accounting for REDD activities are illustrated in Figure.

4.1 Carbon Stocks

Describing forest type and area is generally accomplished using satellite imagery, cross-checked with on-the-ground observations. The types of forest present at a REDD project site, as well as the extent of these forest types, are very important for carbon calculations, as different forest types have different associated carbon density.

The density of carbon stocks associated with different forest types is determined with field surveys. On-the-ground field methods are used for determining carbon density, which have been employed for many years and have long been accepted as scientifically credible. Since measuring every single tree inside the project area would be cost prohibitive and highly inefficient, sampling methods are required.

4.2 Biomass, carbon pools and stock accounting

Forest biomass is organic matter resulting from primary production through photosynthesis minus consumption through respiration and harvest. Assessment of biomass provides information on the structure and functional attributes of a forest and is used to estimate the quantity of timber, fuel and fodder components biomass assessments also illustrate the amount of carbon that may lost or sequestered under different forest management regimes. Carbon is lost to the atmosphere as CO2. To convert carbon in biomass to CO2, the tonnes of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12). Estimating the biomass density of forest components is, therefore, the first step in forest carbon accounting.

Carbon pools are components of the ecosystem that can either accumulate or release carbon and have classically been split into five main categories: living above-ground biomass (AGB), living below-ground biomass (BGB), dead organic matter (DOM) in wood, DOM in litter and soil organic matter (SOM).

Stock accounting sums carbon pools at a single point in time. Decisions on which carbon pools should be included are largely dependent on the availability of existing data, costs of measurement and the level of conservativeness required.

4.3 Approaches to emission accounting

There are two main approaches to emissions accounting: the inventory approach and the activity-based approach, which are mathematically represented as:

Equation 1: Inventory/Periodic Accounting

$$\Delta C = \frac{\Sigma(Ct_1 - Ct_2)}{(t_2 - t_1)}$$

ΔC = carbon stock change, tonnes C per year

Ct_1 = carbon stock at time t_1, tonnes C

Ct_2 = carbon stock at time t_2, tonnes C

Equation 2: Activity-based/Flux Accounting

$$\Delta C = \Sigma\,[\,A * (\,C_I - C_L\,)]$$

A = area of land, ha

C_I = rate of gain of carbon, tonnes C per ha per year

C_L = rate of loss of carbon, tonnes C per ha per year

4.4 Types of data acquisition

- Collating existing forest data

Forest carbon accounting can make use of existing national, regional or global data. Sources will vary between territories, as will the reliability and uncertainty of the source. However, good quality secondary data reduces both time and cost requirements for accounting.

- Using remote sensing

Remote sensing is the acquisition of data from sensors on board aircraft or space-based platforms. Remote sensing is useful in forest carbon accounting for measurement of total forest area, forest types, canopy cover and height, and branch surface to volume ratios.

- Data from field sampling

Actual field data is preferable to default data for forest carbon accounting and is required to verify remotely sensed information and generalized data sets. Gathering field measurements for forest carbon accounting requires sampling as complete enumerations are neither practical nor efficient. By definition, sampling infers information about an entire population by observing only a fraction of it. In order to confidently scale up this data to the required geographical level, proper sampling design is vital.

4.5 Carbon accounting tools

Largely from developed countries, a number of forest carbon accounting models exist. For example, from the United States: COLE, the Carbon On-Line Estimator, The Center for Urban Forest Research Tree Carbon Calculator (CTCC), FORCARB and the Landscape Management System (LMS). From United Kingdom: CARBINE, C-Flow and C-Sort. From Australia: CAMfor (Richards & Evans, 2000). From Europe: the European Forest Information Scenario model (EFI-SCEN) (Nabuurs et al., 2000).

However, these tools are generally applicable only to forests of the nation, or region, in which they have been developed and are thus limited in application. Other tools are applicable over wider geographical areas: CBM-CFS3 for example, although developed in Canada, can be applied abroad to account for the carbon implications of forest management and land use change in forested landscapes.

Further broad forest carbon-inventory models include CO2FIX and Graz/Oak Ridge Carbon Accounting Model (GORCAM). Version 3 of CO2FIX (see Masera et al., 2003; Nabuurs et al., 2002) has detailed modules for biomass, soil, wood products and bioenergy, as well as modules for finance and carbon accounting. These models assume relatively homogenous forest stands in terms of vegetation structure, growth dynamics and species composition.

4.6 Total biomass Carbon Calculation

India ranks 10^{th} in the list of most forested nations in the world with 76.37 million ha of forest and tree cover. Like other forests of the world, our forests also provide critical ecosystem goods and services. It is now a well known fact that forests have the potential to be major carbon sinks. A recent study shows that India's forests neutralize more than 11% of India's GHG emissions. Improving the quality of our forest cover is a centerpiece of our strategy to combat climate change.

- Forest & tree cover of the country as per this assessment is 78.37 million ha in 2007, which is 23.84% of the geographical area. This includes 21.02% forest cover and 2.82% tree cover. The forest and tree cover becomes 25.25%, if the areas above tree line, i.e., 4,000m are excluded from the total geographic area. Over the past decades, national policies of India aimed at conservation and sustainable management of forests have transformed India's forests into a net sink of CO_2.
- There is a net increase in the forest & tree cover between the current and the previous assessment (2 year data interval) of 0.18 million ha (0.23%).
- The decadal increase, i.e., the increase in the forest cover between 1997 and 2007 is 3.13 million ha (4.75%).
- The growing stock of India's forests and trees outside forests is estimated as 6,098 million m3 in 2007.

Biomass carbon can be disaggregated into above ground and below ground biomass. Change in forest carbon stocks during a time period is an indicator of the net emissions or removals of CO2 in that period. Assessment of biomass was based on the consideration that all lands, more than one hectare in area, with a tree canopy density of more than 10 per cent are defined as 'Forest'. The country's forest carbon estimate is based on the forest cover assessment of 2007 by Forest Survey of India (FSI).

Suitable biomass increment values (expansion and conversion for calculating total tree above ground biomass) and the ratio of below and above ground biomass (for calculating total tree biomass above and below ground) as available in different studies covering a range of forest types of the country were used in the present study. The referred studies measured directly or indirectly the total biomass of the stand broken down into the individual components (Chhabra, *et al.,* 2002; Kaul, *et al.,* 2009). These components were stemwood, branches, leaves and roots of the tree in a stand or even in a larger area depending on the study. The biomass of other vegetation on forest floor (understory) was estimated based on the ratio of total tree biomass to the total forest floor biomass excluding the tree component in the area. However for this study, ratio was adopted based on the published records for different vegetation types and different localities, and also keeping in view its application and representation for the country level estimates (Singh and Singh, 1985; Rawat and Singh, 1988; Negi, 1984; Roy and Ravan, 1996). Mathematically, the above ground biomass of tree component is as follows:

$$GS_{Total} = GS_{Tree} + GS_{Other\ Vegetaion}$$

Where,

GS_{Total} = Total growing stock in forest

GS_{Tree} = Growing stock of tree component

$GS_{Other\ Vegetation}$ = Growing stock of other vegetation on forest floor

$$GS_{Tree} = V_{Above\ Ground} + V_{Below\ Ground}$$

Where,

$V_{Above\ Ground}$ = Above ground volume

$V_{Below\ Ground}$ = Below ground volume

$$V_{Above\ Ground} = GS_{Commercial} \times \text{Expansion factor}$$

Where,

$GS_{Commercial}$ = Growing stock of tree bole upto 10 cm diameter

Expansion factor = Adjusted mean biomass (volume) expansion factor for the country

$$V_{Below\ Ground} = V_{Above\ Ground} \times \text{Ratio}$$

Where,

Ratio = Adjusted mean ratio between below and above ground biomass (volume)

$$GS_{Other\ Vegetaion} = GS_{Tree} \times R$$

Where,

R = Ratio of other forest floor biomass to growing stock of tree component

The biomass is estimated by taking into account the total growing stock of the forest including the above and below ground volume of all vegetation in the forest and multiplying it with a 'volume to mass' conversion factor. The conversion factor adopted in this study is influenced by the contents of studies of Brown, Gillespie and Lugo, 1991; Rajput, *et al.,* 1996 and Kaul, *et al.,* 2009.

$$B = GS_{Total} \times MD$$

Where,

B = Biomass (million tonnes)

GS_{Total} = Total forest growing stock (million m3)

MD = Mean wood density

4.7 Total Soil Organic Carbon

Soil carbon stocks and the changes that occur in them are the results of climate, soil properties, litter quality and litter production by vegetation; the more productive the site is the more litter is fed into the soil. Soil carbon stocks are established during the time spans of tens of thousands years.

The vegetation produces organic matter (by litter and mortality), which is thereafter disintegrated by soil. Small fractions of this organic matter are left to accumulate and form more permanent carbon compounds. Inert carbon forms are also stored in soils during forest fires.

Soil carbon stock and its changes have been estimated by measurements, but the quantity of these changes has been extremely difficult to detect, due to relatively small changes of a large stock. Soil carbon content has high variation within sites and observations are correlated between each other within low distances. Kauppi et al. (1997) used statistical models to correlate NFI measurements with soil carbon measurements. The advantage of this approach was the easy extrapolation based on the measurements of soils and trees. The disadvantage of these statistical models is that they lack historical development of soils and due to that major part of the variation if often unexplained.

For estimating SOC, IPCC guidelines (IPCC, 1997) prescribe that only the upper 30 cm layer of soil, which contains the actively changing soil carbon pool in the forest, should be considered.

To fulfill reporting needs (UNFCCC 1997, IPCC 2003), countries must develop methods that allow the estimation of carbon pools soil, litter and deadwood. These estimates should be relevant at national scales, and thus up-scaling should only be done based on appropriate sampling methods such as NFI. Since nation-wide soil surveys have not been done as extensively as forest inventories focused on trees dynamic. Soil models are needed to estimate the rates of change of the carbon pools in soil, litter and deadwood.

The permanent sample plot data used were collected by NFI. Soil organic carbon stock Qi ($Mg\ m^{-2}$) in a soil layer i with a depth of Ei (m) depend on the carbon content Ci ($g\ C\ g^{-1}$), bulk density Di ($Mg\ m^{3}$) and on the volume fraction of coarse elements Gi, given by the formula (Batjes, 1996):

$$Q_i = C_i D_i E_i (1 - G_i)$$

Based on this equation the total SOC is calculated for year 1995, 2005 and 2008. Soil organic carbon pool for different forest groups was estimated based on the primary data as described above and reported in Table 3 for 1995 and 2005 and 2008.

4.8 Results

Table 2: Forest Biomass Carbon

Item with symbolic description	Factor	1995	2000	2003	2005	2007
Growing Stock of Country in Mm3- GS		5842.32	6151.78	6413.75	6218.282	6098
Mean Biomass Expansion Factor- EF	1.575					
Ratio (Below to Above Ground Biomass)- RBA	0.266					
Above Ground Biomass (Volume) - AGB		9201.654	9689.054	10101.656	9793.794	9604.35
Below Ground Biomass (Volume) - BGB		2447.640	2577.288	2687.041	2605.149	2554.757
Total Biomass (Volume) – TB		11649.294	12266.342	12788.697	12398.943	12159.107
Mean Density - MD	0.7116					
Biomass in trees Mt =Total Biomass(TB) x Mean Density (MD)		8289.638	8728.729	9100.437	8823.088	8652.421
Ratio (Other Forest Floor Biomass except tree to Tree Biomass)	0.015					
Growing Stock of Vegetation Mm3- GS_{Vag}		87.635	92.277	96.206	93.274	91.47
Above Ground Biomass (Volume) - AGB(Vag)		138.025	145.336	151.525	146.907	144.065
Below Ground Biomass (Volume) - BGB (Vag)		36.715	38.659	40.306	39.077	38.321
Total Biomass (Volume) – TB (Vag)		174.739	183.995	191.830	185.984	182.387
Biomass in Vagetation Mt =Total Biomass(TB) x Mean Density (MD)		124.345	130.931	136.507	132.346	129.786
Total Forest Biomass in Mt (Trees + Shrubs + Herbs)		8413.982	8859.660	9236.943	8955.434	8782.207
Dry Weight in Mt (80% of TFB)		6731.186	7087.728	7389.555	7164.348	7025.766
Carbon in Mt (40 % of DW)		2692.474	2835.091	2955.822	2865.739	2810.306

Table 3: Forest Soil Carbon

Forest Type (Group)	Area 1995	Area 2005	Mean Soil Carbon	Total SOC 1995	Total SOC 2005	Area 2008	Mean Soil Carbon	Total SOC 2008
Himalayan dry temperate forest	31.00	32.00	36.20	1122.14	1158.34	31.20	49.46	1543.15
Himalayan moist temperate	2230.00	2447.00	71.58	159616.71	175148.92	2201.20	86.07	189457.28
Littoral and swamp forest	383.00	481.00	71.06	27216.75	34180.82	404.60	107.37	43441.90
Montane wet temperate forest	2583.00	2593.00	115.46	298233.18	299387.78	2335.60	124.41	290572.00
Sub alpine and alpine forest	2021.00	2067.00	74.07	149697.49	153104.76	1862.80	89.70	167093.16
Sub tropical broad leaved hill forest	260.00	303.00	86.61	22518.86	26243.13	278.10	79.87	22211.85
Sub tropical dry evergreen forest	1223.00	1248.00	65.28	79836.22	81468.19	1253.80	65.27	81835.53
Sub tropical pine forest	4556.00	4743.00	50.27	229030.12	238430.61	4237.70	43.35	183704.30
Tropical dry deciduous forest	18233.00	19156.00	34.20	623477.44	655039.42	18662.00	37.66	702810.92
Tropical dry evergreen forest	134.00	165.00	52.40	7021.33	8645.67	140.40	32.08	4504.03
Tropical moist deciduous forest	23091.00	24284.00	55.01	1270212.82	1335838.56	23679.40	51.92	1229434.45
Tropical semi evergreen forest	2573.00	2946.00	54.63	140550.13	160925.25	2642.40	61.61	162798.26
Tropical thorn forest	1604.00	1827.00	20.38	32681.50	37225.13	1649.10	24.32	40106.11
Tropical wet evergreen	5040.00	5414.00	101.40	511076.16	549001.26	5124.90	107.22	549491.78
Total	63962.00	67706.00		3552290.83	3755797.83	64503.20		3669004.72
Total (Mt)				3552.29	3755.80			3669.00

Based on the figures for biomass carbon and SOC in forests given in Table 2 and Table 3 above, the estimates of total forest carbon stocks comprising components of biomass carbon and SOC for 1995, 2005 and 2008 were computed, and are presented below in Table 4. Component wise changes in the period from 1995-2008 were also worked out.

Table 4: Total Forest Carbon

Carbon	year 1995	year 2005	year 2008
In Biomass	2692.474	2835.091	2810.306
In Soil	3552.29	3755.797	3669.004
Total	6244.764	6590.888	6479.31

The analysis showed that there is improvement in forest carbon stocks on temporal basis from 1995 to 2005. The difference of 376.772 Mt between figures of 1995 and 2005 shows the incremental carbon accumulation in India's forests during the period but the total carbon difference between 2005 and 2008 is 111.578 Mt shows the decrement due to the decrement of growing stock of country.

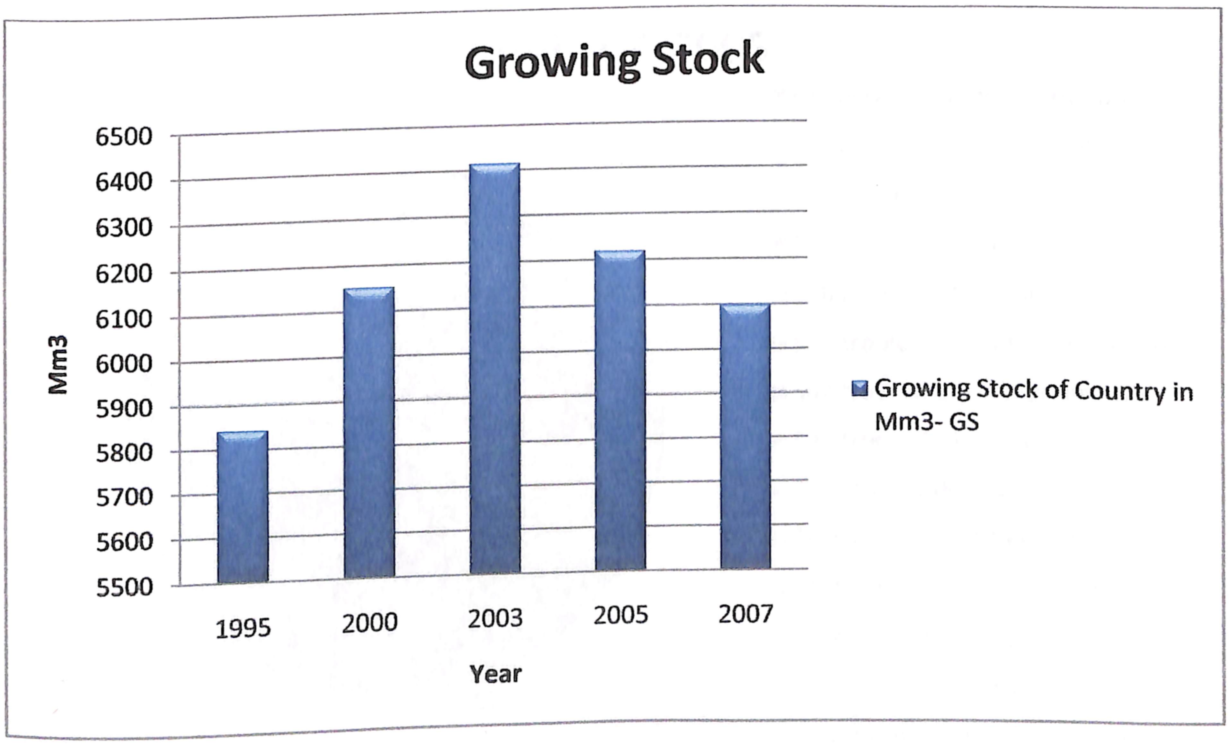

Figure 7: Growing Stock

Total Soil Organic Carbon for different forest groups for the year 1995, 2005 and 2008 are shown in figure 10, 11 and 12 respectively.

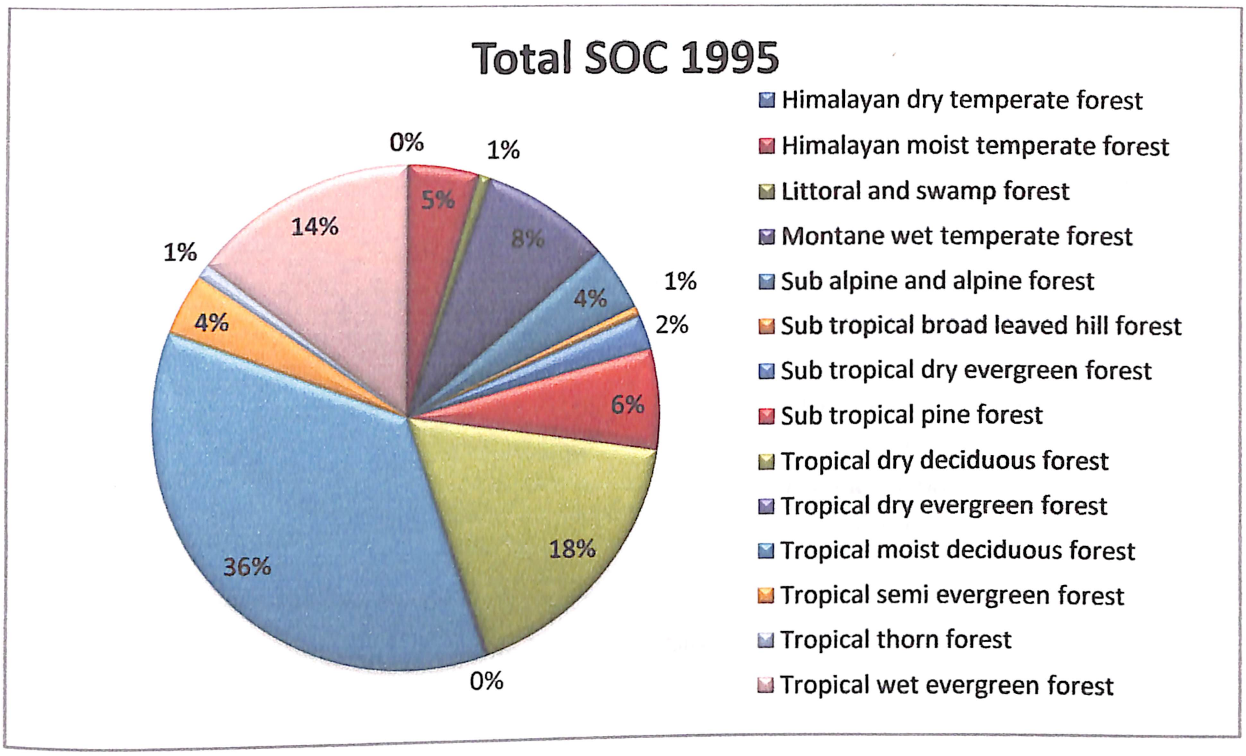

Figure 8: Total SOC for 1995

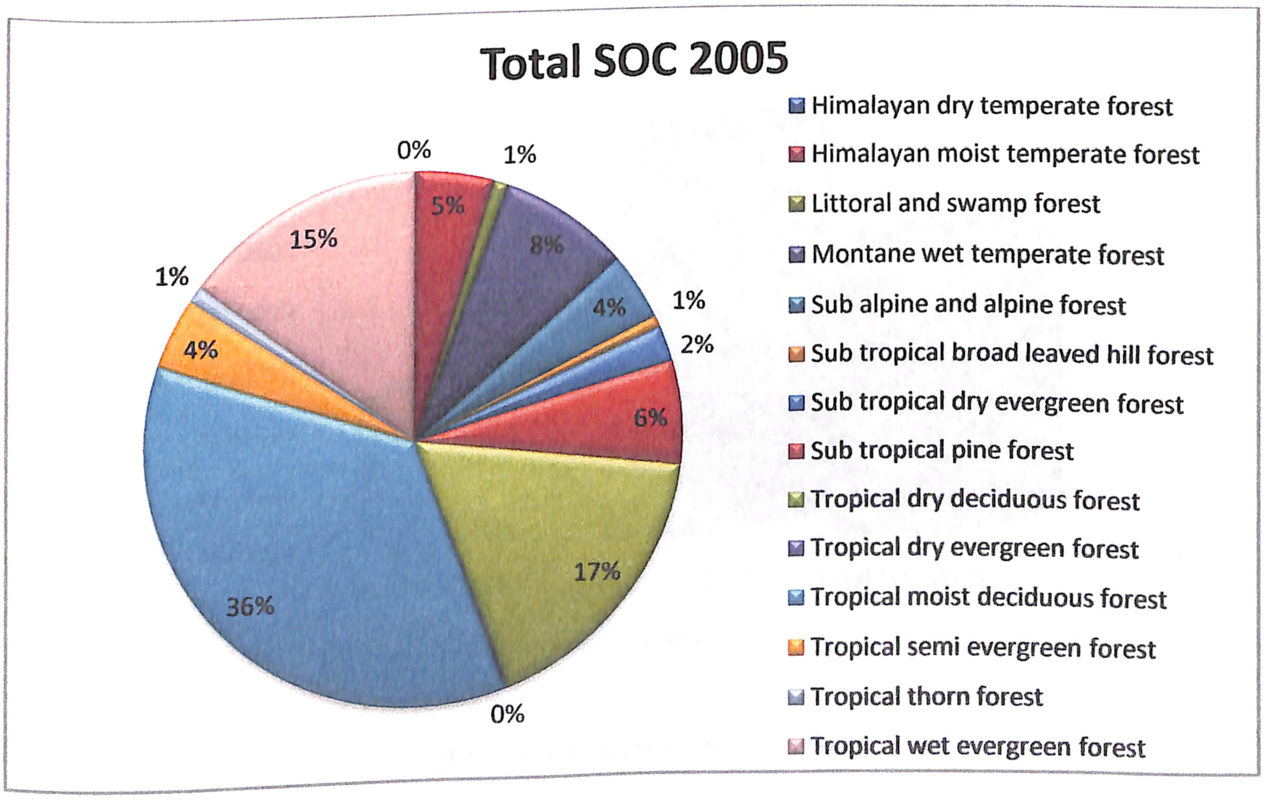

Figure 9: Total SOC 2005

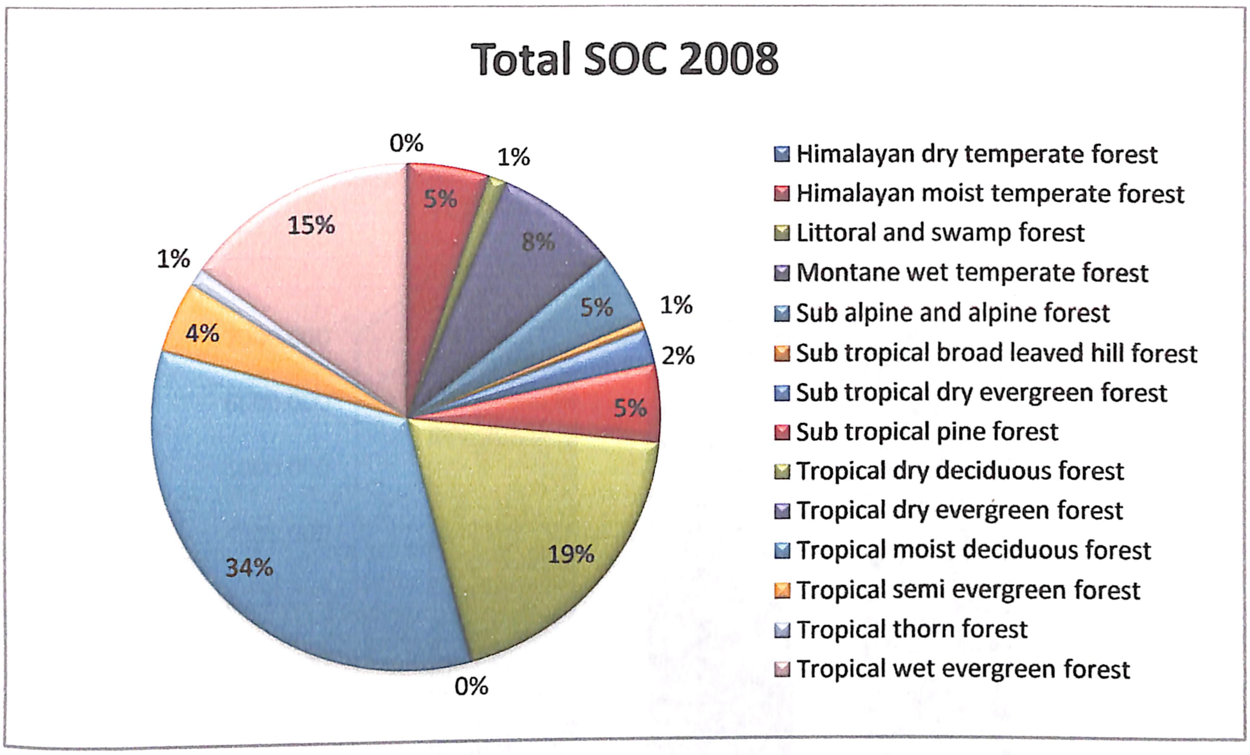

Figure 10: Total Soil Carbon 2008

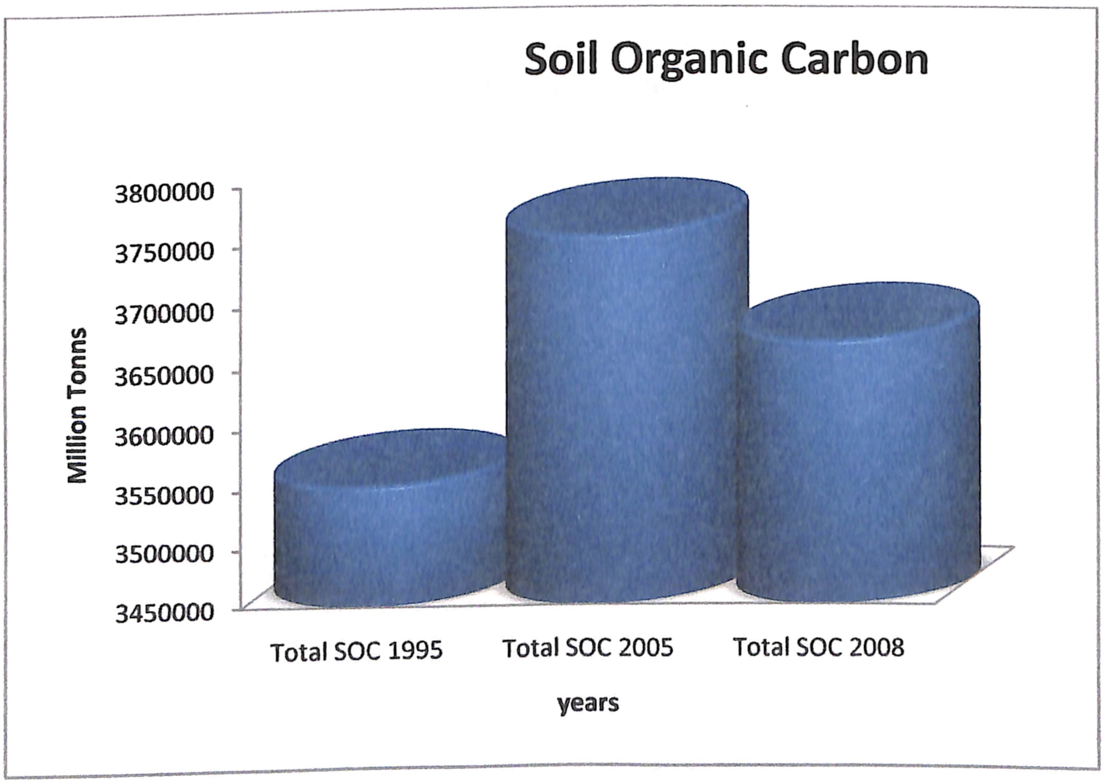

Figure 11: Soil Organic Carbon for India

Comparison for Soil Organic Carbon between different years is shown in figure 13. Component wise changes in the period from 1995-2008 are shown below.

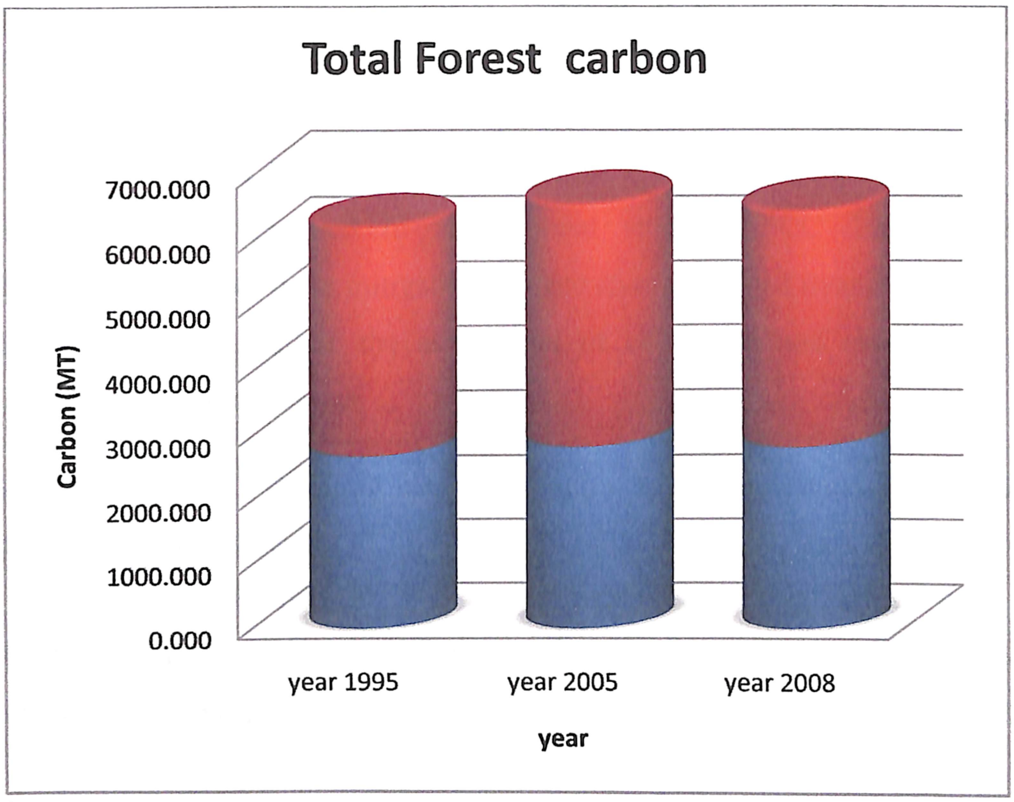

Figure 12: Total Forest Carbon

5 Carbon storage and sequestration potential of selected tree species

Forest vegetation and soils constitute a major terrestrial carbon pool with the potential to absorb and store carbon dioxide (CO_2) from the atmosphere. The CO_2 source and sink dynamics as trees grow, die, and decay are subjected to disturbance and forest management. Evidence of climate change linked to human-induced increase in greenhouse gas (GHG) concentrations is well-documented in international studies (IPCC 2001, 2007). The recognized importance of forests in mitigating climate change has led countries to study their forest carbon budgets and initiate the assessment of enhancing and maintaining carbon sequestration of their forests resource.

In this study, I have used a dynamic model of carbon storage in forests, CO2FIX v. 3.1 (Masera et al. 2003; Schelhaas et al. 2004) to investigate the full carbon cycle of some important species in natural and short rotation plantation forestry in India. These are Sal (Shorea robusta Gaertn. F.) as representative of natural forests, and poplar (Populus deltoides Marsh) as exotic plantation species.

5.1 The model CO2FIX

The CO2FIX stand level simulation model is a tool which quantifies the C stocks and fluxes in the forest biomass, the soil organic matter and the wood products chain. The model calculates the carbon balance with a time-step of one year. Basic input is stem volume growth and allocation pattern to the other tree compartments (foliage, branches and roots). Carbon stocks in living biomass are calculated as the balance between growth on the one hand and turnover, mortality and harvest on the other hand. Litter from turnover and mortality processes and logging slash form the input for the soil module. The organic matter decomposes and transforms into soil organic matter. The model produces output in tabular and graphic forms. It allows estimating the time evolution at the stand level of the carbon stored in different pools of the system. The CO2FIX model V 3.1 is applicable to many different situations: afforestation projects, agro forestry systems, and selective logging systems. The model is freely available from the web, together with numerous examples.

Figure 13 illustrates the modular structure of the model. The biomass module converts volumetric net annual increment data with the help of additional parameters to annual carbon stocks in the biomass compartment. Turnover and harvest parameters drive the fluxes into the soil and the products compartment. In the soil module, decomposition of litter and harvest residues is simulated using basic climate and litter quality information. The fate of the harvested carbon is determined in the wood products module, using parameters like processing efficiency, product longevity and recycling. In the bioenergy module, discarded products or by-products from the product module can be used to generate bioenergy, using varying technologies. The carbon accounting module keeps track of all fluxes to and from the atmosphere and determines the effects of the chosen scenarios, using different carbon accounting approaches.

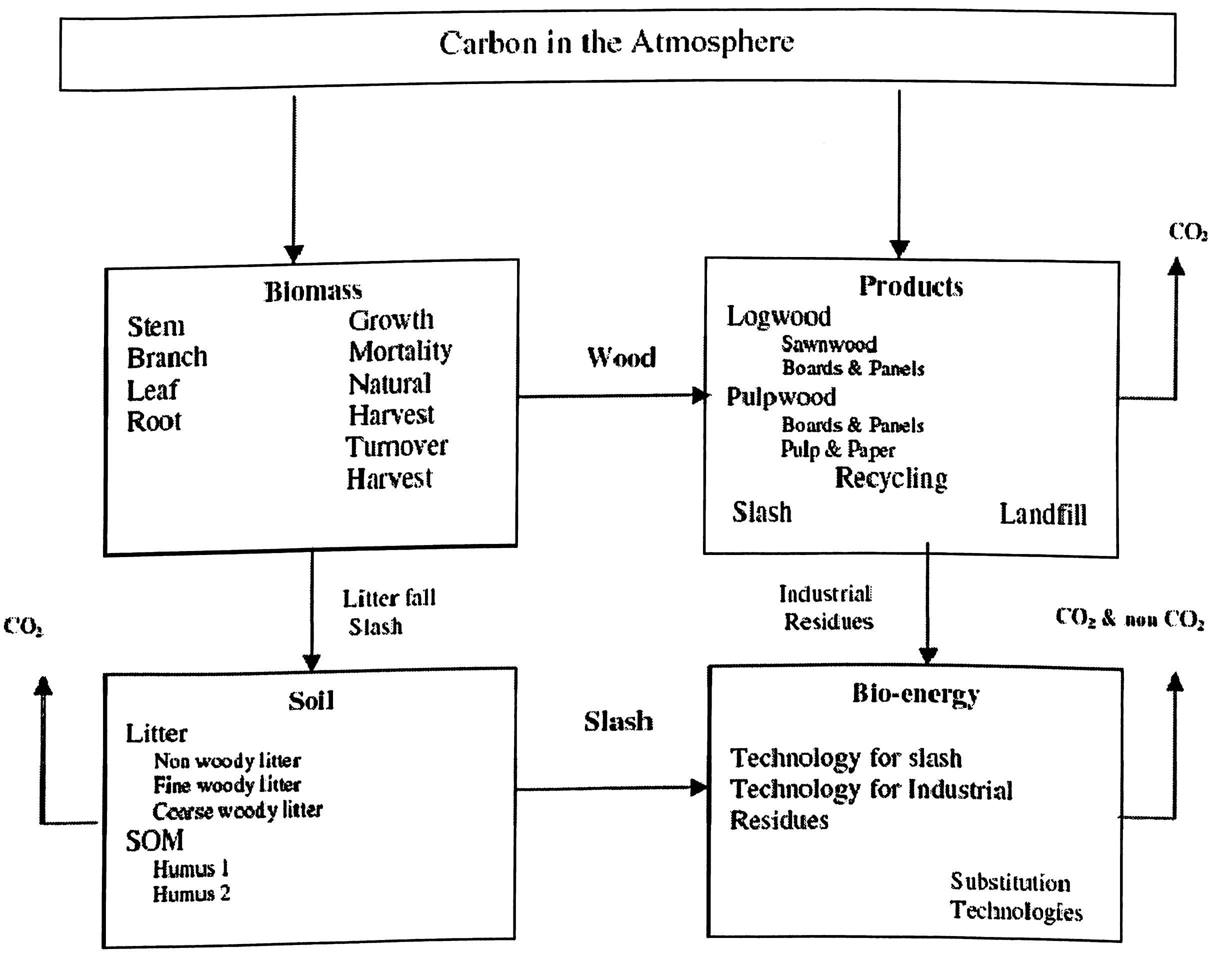

Figure 13: Structure of CO2FIX V3 Model

5.2 Description of the species

In India, sal (fam. Dipterocarpaceae), a fairly large deciduous tree is found in forests covering about 12 million ha, representing about 16% of the total forested area. Sal is the dominant species forming nearly pure stands, due to its resistance to fire, coppicing ability and adaptability to various conditions of soil and site. Sal is one of the most important timber-yielding plants in India, and is known for its heavy, hard and tough wood. Sal occurs in mixed forests with other trees in Himalayan foothills and central Indian belts. This type occurs throughout northern India except in the dry north-west and much of the wet north-east. The type is important in Uttarakhand, Uttar Pradesh, Bihar, Assam, Orissa, Madhya Pradesh, and Bengal, and constitutes their most important forests. The mean annual temperature typically lies between 21°C and 26°C. The typical rainfall is around 1,300 mm to 1,500 mm.

Poplar is a very prominent taxonomical group of tree species in plantation forestry in India. It occurs in natural forests also. However, its population in natural stands is small and is gradually declining. Bulk of the plantations is composed of *Populus deltoides,* an exotic species. The area coverage and productivity of this species is bound to increase further, due to concerted research and development efforts aiming at its genetic improvement. Indigenous poplars occur only in the mountains and are still to acquire greater role and share in afforestation/reforestation programs and conservation. The type is important in North- West India, i.e., Western Uttar, Pradesh, Punjab and Haryana and to some extent in the outer plains/ valleys of Uttarakhand and Himachal Pradesh.

5.3 Simulation approach

The model was parameterized for the simulations using published data on growth rate and biomass amounts (Table 5). The carbon content of dry matter was calculated assuming that the carbon fraction in live biomass is 50%. Wood densities for all the species were derived from Haripriya (2000). The litter production rate for the separate biomass compartments was derived by multiplying the biomass stock with corresponding turnover coefficients (per year). Turnover coefficients for foliage, branches and roots are taken from Dhaval (2010) (Table 6). Growth of foliage, branches and roots is incorporated as an additional allocation of dry matter increment relative to the stem wood derived from the ratio of net primary productivity (NPP) per component, estimated by Negi (1984) & Lodhiyal and Lodhiyal (1997) for sal and poplar respectively (Table 7 & 8). For each tree species a general management regime was defined, which consists of the ages when thinning takes place as shown in Table 9. In case of poplar, no thinning was done and final harvest took place at 9 years of age where 90% of the total volume was removed. The Current Annual Increment (CAI) was derived from the yield tables and computed from stem biomass using wood density (Table 10 & 11). The CAI for sal was taken from local growth and yield tables (Tewari 1995). In case of poplar, age-related stem biomass data from Lodhiyal et al. (1995) and Lodhiyal and Lodhiyal (1997) was used, and stem biomass was converted to stem volume using a wood density of 380 kg m^3.

Table 5: Wood Density

Parameter	**Sal**	**Poplar**
Basic Wood Density (Kg m^3)	672	380

Table 6: Turnover rates

Turnover rates (1/yr)	**Sal**	**Poplar**
Foliage	1	.95
Branches	.01	.1
Roots	.01	.04

Table 7: Ratio of dry weight increase relative to dry weight increase of stem - Sal

	0	22	33	36	43	47	52	55	91	93
Foliage	1	0.73	0.64	0.94	1.02	1.01	1.12	0.98	0.75	0.85
Branches	0.2	0.18	0.15	0.17	0.16	0.16	0.16	0.15	0.14	0.14
Roots	0.4	0.39	0.3	0.34	0.31	0.32	0.31	0.29	0.27	0.37

Table 8: Ratio of dry weight increase relative to dry weight increase of stem - Poplar

Stand Age	1	2	3	4	5	6	7	8
Foliage	0.45	0.43	0.55	0.64	0.8	0.98	1.13	1.33
Branches	0.4	0.41	0.34	0.32	0.4	0.57	0.69	0.97
Roots	0.4	0.42	0.43	0.44	0.46	0.53	059	0.69

Table 9: Fraction removed during thinning or harvest

Age	9	10	20	30	40	50	60	70	90	100	120
Sal		0.02	0.02	0.06	0.07	0.07	0.07	0.08	0.08	0.08	1
Poplar	0.9										

Table 10: Current Annual Increment as a function of stand age for Sal

Age	10	15	20	25	30	35	40	45	50
CAI	4.3	5.1	5.8	6.4	7	7.5	8	8.4	8.7
Age	55	60	65	70	75	80	85	90	95
CAI	9	9.3	9.5	9.6	9.7	9.7	9.7	9.6	9.5
Age	100	105	110	115	120				
CAI	9.3	9	8.7	8.4	8				

Table 11: Current Annual Increment as a function of stand age for Poplar

Age	1	2	3	4	5	6	7	8	9
CAI	16.56	23.7	26.58	27.68	27.4	26.5	25.9	23	19.2

5.4 Results

Using CO2FIX parameters simulation of biomass carbon pools was carried out for poplar (Populus deltoides Marsh) and sal (Shorea robusta Gaertn. F.) with rotation length of 9 and 120 years, respectively. Figure 14 shows the average carbon stocks in soil and tree biomass. Even though the natural sal forest looses carbon from soil, it however maintains the largest long-term carbon stock in a simulation period of 300 years. The soil compartment displays a slow decrease in stock from 119 Mg Cha^{-1} in the initial year to 52 after 300 years (a net source of 0.2 Mg Cha^{-1} per year). The larg carbon stock in biomass was achieved in sal forests (101 Mg Cha^{-1}).

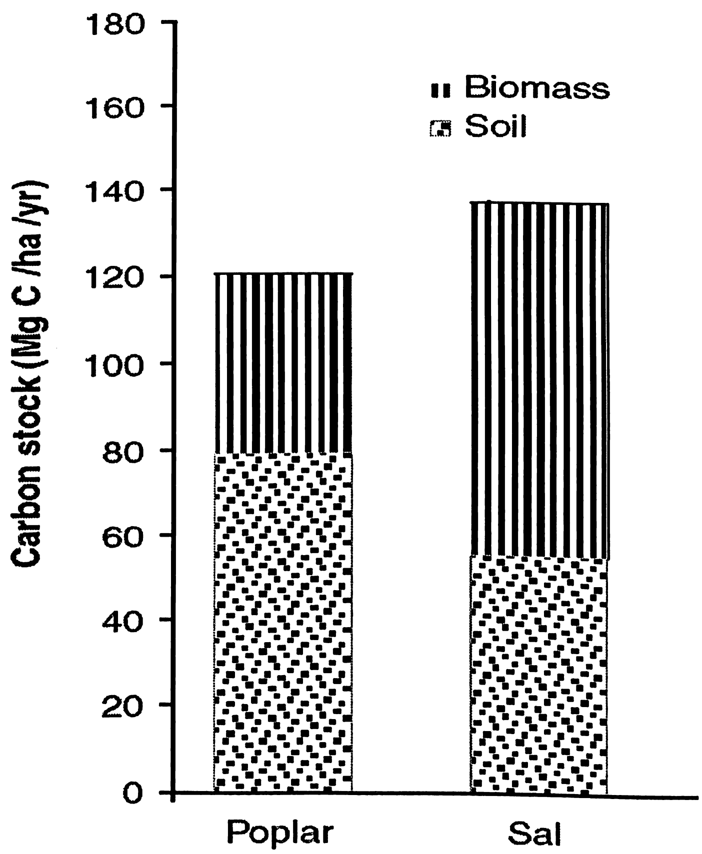

Figure 14: Average Carbon stock in Soil & Tree biomass

The initial soil C pool based on the use of Yasso (Liski et al. 2003) model was 67 Mg Cha^{-1}

for poplar and increased to 102 Mg Cha^{-1} by the end of the first rotation. This slow increase is mainly due to accumulation of litter and dead wood. Where as in case of natural sal forests, after a slow decrease from 118 Mg Cha^{-1} from the initial year to 49 Mg Cha^{-1}, soil carbon gradually increases to 117 Mg Cha^{-1} by the end of first rotation.

In case of sal forests, the simulation results show that, before the final cut, the amount of carbon in forest biomass was limited to 156 Mg C ha^{-1} respectively. By this time, the amount of carbon in the litter layer had increased to 14 Mg Cha^{-1} and the amount in the stable humus remained stable at 40 Mg Cha^{-1}. After the final cut, the amount of carbon in the forest biomass was reduced to 0, the amount in the litter layer rose to 70 Mg Cha^{-1}.

Maximum net annual carbon storage flux was 1 Mg $Cha^{-1}yr^{-1}$ for slow-growing long rotation sal forests and 8 Mg $Cha^{-1}yr^{-1}$ for fast-growing short rotation poplar forests. Figure shows the model results on net annual carbon stock since starting year for all the species. The largest carbon sequestration potential was found for poplar (with peaks in the advancing mean in the range of 3–8.5 Mg $Cha^{-1}yr^{-1}$) and for sal forests (with peak in the advancing mean around 1.2 Mg $Cha^{-1}yr^{-1}$).

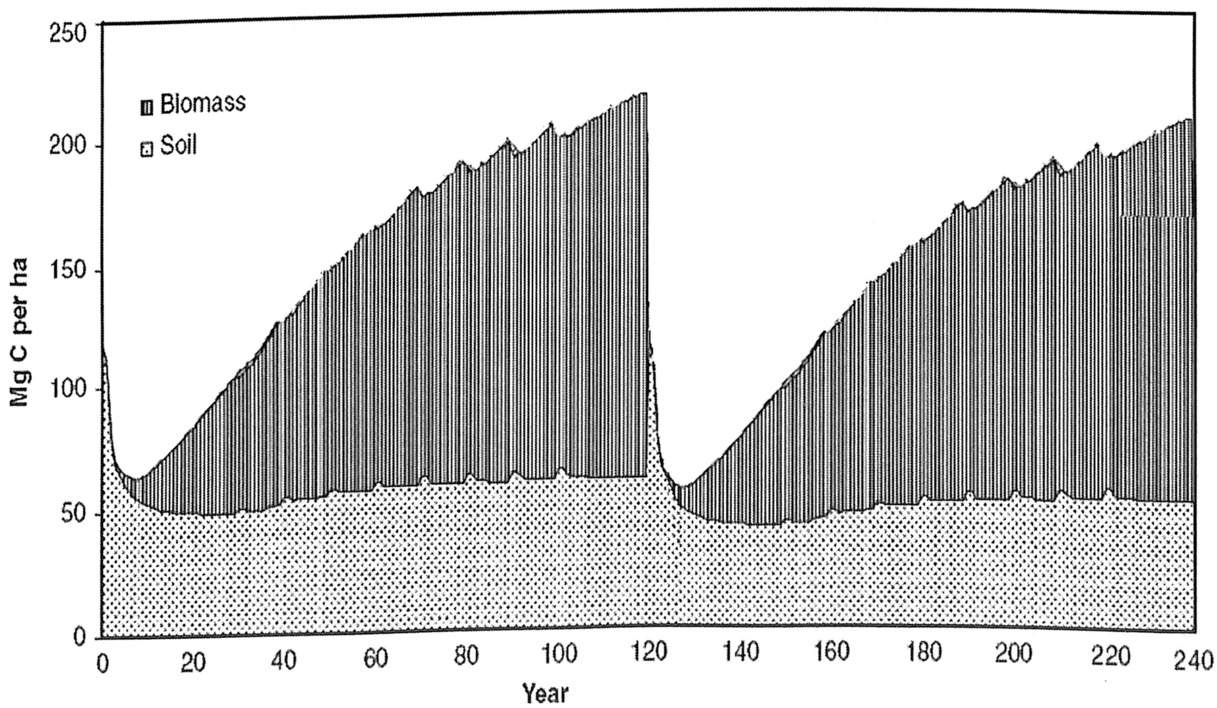

Figure 15: Carbon stock in Sal Forest

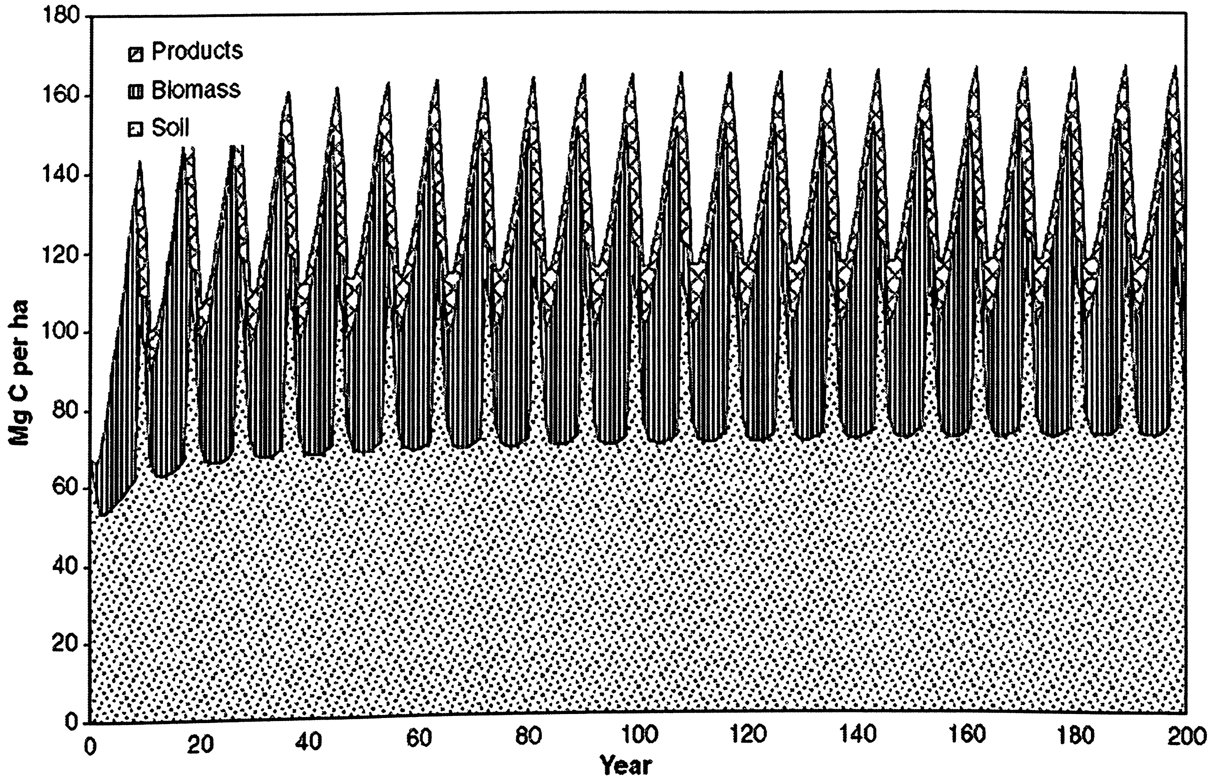

Figure 16: Carbon stock in Poplar

The model simulated data for tree biomass carbon is shown in table below in which scenario1 represents sal forests and scenario 2 represents poplar forests.

year [yr]	Scenario 1 Biomass stems carbon [MgC/ha]	Scenario 1 Biomass stems dry weight [MgDM/ha	Scenario 1 Biomass stems volume [m3/ha]	Scenario 1 Biomass stems CAI [m3/ha/yr]	Scenario 1 Biomass foliage carbon [MgC/ha]	Scenario 1 Biomass foliage dry weight [MgDM/ha	Scenario 1 Biomass branches carbon [MgC/ha]
0	52	104	165.87	0	0	0	0
1	52.13	104.27	166.3	0.43	0.13	0.27	0.03
2	52.4	104.81	167.16	0.86	0.26	0.53	0.08
3	52.81	105.62	168.45	1.29	0.39	0.78	0.16
4	53.35	106.7	170.17	1.72	0.51	1.03	0.26
5	54.02	108.04	172.32	2.15	0.63	1.27	0.39
6	54.83	109.66	174.9	2.58	0.75	1.5	0.55
7	55.77	111.55	177.91	3.01	0.86	1.73	0.72
8	56.85	113.71	181.35	3.44	0.97	1.95	0.92
9	58.07	116.13	185.22	3.87	1.08	2.16	1.15
10	57.33	114.65	182.86	4.3	1.14	2.28	1.34
11	57.87	115.75	184.6	4.46	1.19	2.38	1.57
12	58.52	117.05	186.68	4.62	1.22	2.44	1.81
13	59.27	118.55	189.07	4.78	1.24	2.49	2.04
14	60.12	120.25	191.78	4.94	1.27	2.54	2.29
15	61.08	122.15	194.82	5.1	1.29	2.58	2.54
16	62.13	124.25	198.17	5.24	1.31	2.62	2.79
17	63.27	126.54	201.82	5.38	1.32	2.65	3.05
18	64.52	129.03	205.79	5.52	1.34	2.68	3.31
19	65.86	131.72	210.08	5.66	1.35	2.7	3.58
20	65.16	130.31	207.84	5.8	1.32	2.64	3.73
21	65.9	131.8	210.21	5.92	1.35	2.71	3.96
22	66.73	133.47	212.87	6.04	1.36	2.72	4.19
23	67.66	135.32	215.82	6.16	1.37	2.75	4.43
24	68.68	137.36	219.08	6.28	1.39	2.77	4.66
25	69.8	139.59	222.63	6.4	1.4	2.8	4.9
26	71	142.01	226.49	6.52	1.41	2.82	5.13
27	72.31	144.62	230.65	6.64	1.42	2.84	5.37
28	73.71	147.42	235.13	6.76	1.43	2.86	5.61
29	75.21	150.43	239.92	6.88	1.44	2.88	5.85
30	71.31	142.62	227.46	7	1.34	2.69	5.66
31	72.14	144.28	230.11	7.1	1.43	2.87	5.83
32	73.06	146.11	233.03	7.2	1.44	2.87	6.01
33	74.06	148.13	236.25	7.3	1.44	2.88	6.18
34	75.16	150.32	239.75	7.4	1.69	3.38	6.38
35	76.35	152.7	243.54	7.5	1.95	3.89	6.6
36	77.63	155.26	247.63	7.6	2.21	4.42	6.84
37	79	158.01	252.01	7.7	2.27	4.53	7.09

38	80.47	160.94	256.69	7.8	2.33	4.65	7.34
39	82.04	164.07	261.68	7.9	2.39	4.77	7.59
40	77.05	154.11	245.78	8	2.25	4.51	7.22
41	78.07	156.15	249.04	8.08	2.48	4.96	7.42
42	79.18	158.36	252.57	8.16	2.53	5.07	7.62
43	80.37	160.75	256.38	8.24	2.59	5.18	7.82
44	81.66	163.31	260.46	8.32	2.61	5.22	8.03
45	83.02	166.05	264.83	8.4	2.63	5.27	8.25
46	84.48	168.95	269.46	8.46	2.65	5.3	8.47
47	86.02	172.03	274.37	8.52	2.66	5.33	8.7
48	87.64	175.28	279.55	8.58	2.74	5.49	8.93
49	89.36	178.71	285.02	8.64	2.82	5.65	9.17
50	83.92	167.85	267.7	8.7	2.67	5.35	8.67
51	85.02	170.05	271.21	8.76	2.96	5.92	8.86
52	86.21	172.42	274.99	8.82	3.04	6.08	9.04
53	87.48	174.96	279.04	8.88	2.94	5.87	9.23
54	88.84	177.68	283.37	8.94	2.83	5.66	9.41
55	90.28	180.57	287.99	9	2.72	5.45	9.6
56	91.83	183.67	292.93	9.1	2.74	5.48	9.79
57	93.49	186.97	298.2	9.2	2.75	5.51	9.99
58	95.24	190.49	303.81	9.3	2.77	5.54	10.2
59	97.11	194.22	309.77	9.4	2.78	5.56	10.42
60	91.22	182.44	290.98	9.5	2.57	5.15	9.81
61	92.42	184.83	294.79	9.52	2.76	5.51	9.96
62	93.69	187.38	298.85	9.54	2.75	5.49	10.12
63	95.04	190.09	303.17	9.56	2.74	5.47	10.28
64	96.48	192.96	307.74	9.58	2.73	5.45	10.45
65	98	195.99	312.58	9.6	2.72	5.43	10.63
66	99.6	199.19	317.69	9.62	2.71	5.41	10.81
67	101.29	202.57	323.08	9.64	2.69	5.39	11
68	103.06	206.12	328.75	9.66	2.68	5.37	11.2
69	104.93	209.86	334.7	9.68	2.67	5.35	11.4
70	97.35	194.69	310.51	9.7	2.42	4.85	10.58
71	98.48	196.96	314.13	9.7	2.62	5.24	10.71
72	99.69	199.39	318	9.7	2.6	5.2	10.84
73	100.99	201.98	322.13	9.7	2.59	5.17	10.99
74	102.36	204.73	326.52	9.7	2.57	5.14	11.14
75	103.82	207.65	331.18	9.7	2.55	5.11	11.29
76	105.37	210.74	336.1	9.7	2.54	5.07	11.45
77	107	214	341.31	9.7	2.52	5.04	11.62
78	108.72	217.44	346.8	9.7	2.5	5.01	11.8
79	110.53	221.06	352.58	9.7	2.49	4.97	11.99
80	112.44	224.88	358.65	9.7	2.47	4.94	12.18
81	114.44	228.88	365.04	9.7	2.45	4.91	12.38

82	116.54	233.08	371.74	9.7	2.44	4.87	12.59
83	118.74	237.49	378.77	9.7	2.42	4.84	12.8
84	121.05	242.11	386.14	9.7	2.4	4.8	13.03
85	123.48	246.95	393.86	9.7	2.39	4.77	13.26
86	126	252.01	401.93	9.68	2.36	4.73	13.5
87	128.65	257.29	410.35	9.66	2.34	4.68	13.75
88	131.4	262.81	419.15	9.64	2.32	4.64	14.01
89	134.29	268.57	428.34	9.62	2.3	4.6	14.28
90	123.79	247.57	394.85	9.6	2.05	4.1	13.13
91	124.38	248.76	396.74	9.58	2.21	4.42	13.16
92	125.08	250.17	398.99	9.56	2.35	4.71	13.21
93	125.9	251.79	401.59	9.54	2.5	5	13.27
94	126.82	253.64	404.53	9.52	2.5	4.99	13.34
95	127.85	255.7	407.82	9.5	2.49	4.99	13.41
96	128.99	257.97	411.44	9.46	2.49	4.97	13.5
97	130.22	260.45	415.38	9.42	2.48	4.96	13.6
98	131.57	263.13	419.67	9.38	2.47	4.94	13.71
99	133.01	266.03	424.29	9.34	2.46	4.92	13.83
100	122.55	245.11	390.92	9.3	2.23	4.47	12.71
101	123.07	246.14	392.56	9.24	2.42	4.83	12.75
102	123.68	247.36	394.51	9.18	2.4	4.8	12.79
103	124.39	248.77	396.77	9.12	2.39	4.78	12.84
104	125.19	250.38	399.33	9.06	2.38	4.75	12.9
105	126.09	252.19	402.21	9	2.36	4.72	12.96
106	127.09	254.18	405.39	8.94	2.35	4.7	13.04
107	128.19	256.37	408.89	8.88	2.34	4.67	13.13
108	129.38	258.76	412.69	8.82	2.32	4.64	13.22
109	130.67	261.35	416.82	8.76	2.31	4.62	13.33
110	132.07	264.13	421.26	8.7	2.3	4.59	13.44
111	133.56	267.12	426.03	8.64	2.28	4.56	13.56
112	135.16	270.32	431.14	8.58	2.27	4.54	13.69
113	136.87	273.74	436.58	8.52	2.25	4.51	13.83
114	138.68	277.37	442.37	8.46	2.24	4.48	13.98
115	140.61	281.22	448.52	8.4	2.23	4.45	14.14
116	142.65	285.29	455.01	8.32	2.21	4.42	14.31
117	144.79	289.59	461.86	8.24	2.19	4.38	14.48
118	147.06	294.11	469.08	8.16	2.17	4.34	14.66
119	149.44	298.88	476.68	8.08	2.15	4.3	14.86
120	0	0	0	8	0	0	0
121	0.13	0.26	0.42	0.43	0.13	0.26	0.03
122	0.39	0.79	1.26	0.86	0.26	0.52	0.08
123	0.79	1.57	2.51	1.29	0.38	0.77	0.15
124	1.3	2.61	4.16	1.72	0.5	1.01	0.25
125	1.95	3.9	6.21	2.15	0.62	1.25	0.38

126	2.72	5.44	8.67	2.58	0.74	1.48	0.52
127	3.61	7.23	11.53	3.01	0.85	1.7	0.69
128	4.64	9.27	14.79	3.44	0.96	1.92	0.88
129	5.79	11.57	18.45	3.87	1.07	2.13	1.09
130	6.98	13.96	22.26	4.3	1.16	2.31	1.31
131	8.37	16.74	26.69	4.46	1.21	2.42	1.56
132	9.82	19.63	31.31	4.62	1.24	2.47	1.82
133	11.32	22.63	36.09	4.78	1.26	2.52	2.08
134	12.86	25.73	41.03	4.94	1.28	2.57	2.35
135	14.46	28.93	46.13	5.1	1.3	2.61	2.63
136	16.11	32.21	51.37	5.24	1.32	2.64	2.91
137	17.79	35.58	56.75	5.38	1.33	2.67	3.19
138	19.52	39.05	62.27	5.52	1.35	2.7	3.47
139	21.3	42.59	67.93	5.66	1.36	2.72	3.76
140	22.52	45.03	71.82	5.8	1.34	2.67	3.95
141	24.25	48.5	77.35	5.92	1.37	2.74	4.23
142	26.04	52.08	83.06	6.04	1.38	2.75	4.51
143	27.89	55.77	88.95	6.16	1.39	2.78	4.79
144	29.79	59.59	95.04	6.28	1.4	2.8	5.08
145	31.77	63.54	101.33	6.4	1.41	2.83	5.36
146	33.81	67.62	107.85	6.52	1.43	2.85	5.66
147	35.89	71.79	114.49	6.64	1.43	2.87	5.95
148	38.01	76.02	121.25	6.76	1.44	2.89	6.23
149	40.17	80.34	128.13	6.88	1.45	2.9	6.52
150	39.03	78.05	124.48	7	1.34	2.69	6.26
151	40.47	80.94	129.08	7.1	1.43	2.87	6.42
152	41.96	83.91	133.83	7.2	1.44	2.87	6.58
153	43.49	86.98	138.73	7.3	1.44	2.88	6.74
154	45.08	90.16	143.79	7.4	1.69	3.38	6.93
155	46.72	93.44	149.02	7.5	1.95	3.89	7.13
156	48.41	96.83	154.43	7.6	2.21	4.42	7.36
157	50.17	100.33	160.02	7.7	2.27	4.53	7.6
158	51.98	103.96	165.81	7.8	2.33	4.65	7.83
159	53.86	107.72	171.8	7.9	2.39	4.77	8.08
160	51.37	102.75	163.87	8	2.25	4.51	7.66
161	52.88	105.76	168.68	8.08	2.48	4.96	7.85
162	54.44	108.88	173.66	8.16	2.53	5.07	8.03
163	56.06	112.11	178.81	8.24	2.59	5.18	8.22
164	57.73	115.45	184.13	8.32	2.61	5.22	8.42
165	59.45	118.91	189.64	8.4	2.63	5.27	8.63
166	61.24	122.47	195.33	8.46	2.65	5.3	8.84
167	63.08	126.15	201.2	8.52	2.66	5.33	9.06
168	64.98	129.95	207.26	8.58	2.74	5.49	9.29
169	66.94	133.88	213.53	8.64	2.82	5.65	9.52

170	63.5	126.99	202.54	8.7	2.67	5.35	8.99
171	64.98	129.97	207.28	8.76	2.96	5.92	9.16
172	66.53	133.06	212.21	8.82	3.04	6.08	9.34
173	68.13	136.27	217.34	8.88	2.94	5.87	9.52
174	69.8	139.6	222.66	8.94	2.83	5.66	9.7
175	71.53	143.07	228.18	9	2.72	5.45	9.87
176	73.35	146.69	233.96	9.1	2.74	5.48	10.06
177	75.24	150.48	240	9.2	2.75	5.51	10.25
178	77.22	154.43	246.31	9.3	2.77	5.54	10.46
179	79.28	158.56	252.89	9.4	2.78	5.56	10.67
180	74.97	149.94	239.15	9.5	2.57	5.15	10.03
181	76.48	152.95	243.94	9.52	2.76	5.51	10.18
182	78.04	156.07	248.92	9.54	2.75	5.49	10.33
183	79.66	159.31	254.08	9.56	2.74	5.47	10.49
184	81.34	162.67	259.44	9.58	2.73	5.45	10.65
185	83.08	166.16	265.01	9.6	2.72	5.43	10.83
186	84.89	169.78	270.78	9.62	2.71	5.41	11
187	86.77	173.54	276.78	9.64	2.69	5.39	11.19
188	88.72	177.44	283	9.66	2.68	5.37	11.38
189	90.75	181.49	289.46	9.68	2.67	5.35	11.58
190	84.56	169.12	269.72	9.7	2.42	4.85	10.74
191	85.94	171.87	274.12	9.7	2.62	5.24	10.86
192	87.37	174.75	278.71	9.7	2.6	5.2	11
193	88.88	177.76	283.5	9.7	2.59	5.17	11.13
194	90.45	180.9	288.51	9.7	2.57	5.14	11.28
195	92.09	184.17	293.74	9.7	2.55	5.11	11.43
196	93.8	187.59	299.19	9.7	2.54	5.07	11.59
197	95.58	191.16	304.88	9.7	2.52	5.04	11.76
198	97.44	194.87	310.8	9.7	2.5	5.01	11.93
199	99.37	198.74	316.98	9.7	2.49	4.97	12.11
200	101.39	202.78	323.41	9.7	2.47	4.94	12.3
201	103.49	206.98	330.11	9.7	2.45	4.91	12.5
202	105.68	211.36	337.09	9.7	2.44	4.87	12.71
203	107.96	215.92	344.36	9.7	2.42	4.84	12.92
204	110.33	220.67	351.94	9.7	2.4	4.8	13.14
205	112.81	225.61	359.83	9.7	2.39	4.77	13.38
206	115.38	230.76	368.03	9.68	2.36	4.73	13.62
207	118.05	236.1	376.56	9.66	2.34	4.68	13.87
208	120.83	241.66	385.43	9.64	2.32	4.64	14.13
209	123.72	247.45	394.65	9.62	2.3	4.6	14.39
210	114.26	228.53	364.47	9.6	2.05	4.1	13.23
211	115.04	230.08	366.95	9.58	2.21	4.42	13.26
212	115.91	231.82	369.73	9.56	2.35	4.71	13.3
213	116.88	233.76	372.82	9.54	2.5	5	13.36

214	117.95	235.89	376.23	9.52	2.5	4.99	13.42
215	119.11	238.22	379.94	9.5	2.49	4.99	13.5
216	120.37	240.74	383.95	9.46	2.49	4.97	13.59
217	121.72	243.44	388.25	9.42	2.48	4.96	13.69
218	123.16	246.32	392.86	9.38	2.47	4.94	13.79
219	124.7	249.41	397.78	9.34	2.46	4.92	13.91
220	115.06	230.12	367.02	9.3	2.23	4.47	12.78
221	115.72	231.43	369.11	9.24	2.42	4.83	12.81
222	116.46	232.92	371.48	9.18	2.4	4.8	12.85
223	117.29	234.58	374.13	9.12	2.39	4.78	12.9
224	118.21	236.42	377.06	9.06	2.38	4.75	12.96
225	119.22	238.43	380.27	9	2.36	4.72	13.03
226	120.31	240.62	383.76	8.94	2.35	4.7	13.1
227	121.49	242.99	387.54	8.88	2.34	4.67	13.19
228	122.77	245.53	391.6	8.82	2.32	4.64	13.28
229	124.13	248.27	395.96	8.76	2.31	4.62	13.38
230	125.59	251.18	400.61	8.7	2.3	4.59	13.5
231	127.15	254.29	405.57	8.64	2.28	4.56	13.62
232	128.8	257.59	410.83	8.58	2.27	4.54	13.75
233	130.55	261.09	416.42	8.52	2.25	4.51	13.88
234	132.4	264.8	422.33	8.46	2.24	4.48	14.03
235	134.36	268.72	428.58	8.4	2.23	4.45	14.19
236	136.42	272.84	435.15	8.32	2.21	4.42	14.35
237	138.59	277.17	442.06	8.24	2.19	4.38	14.53
238	140.86	281.72	449.32	8.16	2.17	4.34	14.71
239	143.25	286.5	456.94	8.08	2.15	4.3	14.91
240	0	0	0	8	0	0	0
241	0.13	0.26	0.42	0.43	0.13	0.26	0.03
242	0.39	0.79	1.26	0.86	0.26	0.52	0.08
243	0.79	1.57	2.51	1.29	0.38	0.77	0.15
244	1.3	2.61	4.16	1.72	0.5	1.01	0.25
245	1.95	3.9	6.21	2.15	0.62	1.25	0.38
246	2.72	5.44	8.67	2.58	0.74	1.48	0.52
247	3.61	7.23	11.53	3.01	0.85	1.7	0.69
248	4.64	9.27	14.79	3.44	0.96	1.92	0.88
249	5.79	11.57	18.45	3.87	1.07	2.13	1.09
250	6.98	13.96	22.26	4.3	1.16	2.31	1.31
251	8.37	16.74	26.69	4.46	1.21	2.42	1.56
252	9.82	19.63	31.31	4.62	1.24	2.47	1.82
253	11.32	22.63	36.09	4.78	1.26	2.52	2.08
254	12.86	25.73	41.03	4.94	1.28	2.57	2.35
255	14.46	28.93	46.13	5.1	1.3	2.61	2.63
256	16.11	32.21	51.37	5.24	1.32	2.64	2.91
257	17.79	35.58	56.75	5.38	1.33	2.67	3.19

258	19.52	39.05	62.27	5.52	1.35	2.7	3.47
259	21.3	42.59	67.93	5.66	1.36	2.72	3.76
260	22.52	45.03	71.82	5.8	1.34	2.67	3.95
261	24.25	48.5	77.35	5.92	1.37	2.74	4.23
262	26.04	52.08	83.06	6.04	1.38	2.75	4.51
263	27.89	55.77	88.95	6.16	1.39	2.78	4.79
264	29.79	59.59	95.04	6.28	1.4	2.8	5.08
265	31.77	63.54	101.33	6.4	1.41	2.83	5.36
266	33.81	67.62	107.85	6.52	1.43	2.85	5.66
267	35.89	71.79	114.49	6.64	1.43	2.87	5.95
268	38.01	76.02	121.25	6.76	1.44	2.89	6.23
269	40.17	80.34	128.13	6.88	1.45	2.9	6.52
270	39.03	78.05	124.48	7	1.34	2.69	6.26
271	40.47	80.94	129.08	7.1	1.43	2.87	6.42
272	41.96	83.91	133.83	7.2	1.44	2.87	6.58
273	43.49	86.98	138.73	7.3	1.44	2.88	6.74
274	45.08	90.16	143.79	7.4	1.69	3.38	6.93
275	46.72	93.44	149.02	7.5	1.95	3.89	7.13
276	48.41	96.83	154.43	7.6	2.21	4.42	7.36
277	50.17	100.33	160.02	7.7	2.27	4.53	7.6
278	51.98	103.96	165.81	7.8	2.33	4.65	7.83
279	53.86	107.72	171.8	7.9	2.39	4.77	8.08
280	51.37	102.75	163.87	8	2.25	4.51	7.66
281	52.88	105.76	168.68	8.08	2.48	4.96	7.85
282	54.44	108.88	173.66	8.16	2.53	5.07	8.03
283	56.06	112.11	178.81	8.24	2.59	5.18	8.22
284	57.73	115.45	184.13	8.32	2.61	5.22	8.42
285	59.45	118.91	189.64	8.4	2.63	5.27	8.63
286	61.24	122.47	195.33	8.46	2.65	5.3	8.84
287	63.08	126.15	201.2	8.52	2.66	5.33	9.06
288	64.98	129.95	207.26	8.58	2.74	5.49	9.29
289	66.94	133.88	213.53	8.64	2.82	5.65	9.52
290	63.5	126.99	202.54	8.7	2.67	5.35	8.99
291	64.98	129.97	207.28	8.76	2.96	5.92	9.16
292	66.53	133.06	212.21	8.82	3.04	6.08	9.34
293	68.13	136.27	217.34	8.88	2.94	5.87	9.52
294	69.8	139.6	222.66	8.94	2.83	5.66	9.7
295	71.53	143.07	228.18	9	2.72	5.45	9.87
296	73.35	146.69	233.96	9.1	2.74	5.48	10.06
297	75.24	150.48	240	9.2	2.75	5.51	10.25
298	77.22	154.43	246.31	9.3	2.77	5.54	10.46
299	79.28	158.56	252.89	9.4	2.78	5.56	10.67
300	74.97	149.94	239.15	9.5	2.57	5.15	10.03

Biomass Carbon for Sal Poplar

Scenario 1 Biomass branches dry weight [MgDM/ha	Scenario 1 Biomass roots carbon [MgC/ha]	Scenario 1 Biomass roots dry weight [MgDM/ha	Scenario 1 Biomass carbon [MgC/ha]	Scenario 1 Biomass dry weight [MgDM/ha	Scenario 1 Total carbon [MgC/ha]	Scenario 1 Atmospher carbon [MgC/ha]	Scenario 2 Biomass stems carbon [MgC/ha]
0	0	0	52	104	52	0	0
0.05	0.05	0.11	52.35	104.7	52.35	-0.35	3.15
0.16	0.16	0.32	52.91	105.82	53.04	-1.04	7.65
0.32	0.32	0.64	53.68	107.36	54.08	-2.08	12.7
0.53	0.53	1.06	54.66	109.31	55.42	-3.42	17.96
0.78	0.79	1.59	55.84	111.68	57.06	-5.06	23.16
1.09	1.11	2.22	57.23	114.47	58.96	-6.96	28.2
1.45	1.47	2.94	58.83	117.66	61.12	-9.12	33.12
1.85	1.88	3.77	60.63	121.27	63.53	-11.53	37.49
2.29	2.35	4.69	62.64	125.28	66.17	-14.17	4.11
2.69	2.76	5.51	62.57	125.13	69.03	-17.03	7.26
3.15	3.23	6.46	63.87	127.74	71.91	-19.91	11.76
3.61	3.72	7.44	65.27	130.54	74.77	-22.77	16.81
4.09	4.22	8.44	66.78	133.56	77.62	-25.62	22.07
4.58	4.73	9.47	68.41	136.83	80.48	-28.48	27.28
5.07	5.26	10.52	70.16	140.32	83.35	-31.35	32.31
5.58	5.8	11.59	72.02	144.03	86.22	-34.22	37.23
6.09	6.35	12.69	73.99	147.97	89.1	-37.1	41.6
6.62	6.91	13.82	76.07	152.14	92	-40	4.53
7.15	7.48	14.97	78.27	156.55	94.91	-42.91	7.67
7.45	7.82	15.64	78.02	156.05	97.86	-45.86	12.17
7.92	8.32	16.65	79.54	159.07	100.82	-48.82	17.22
8.39	8.84	17.68	81.13	162.25	103.74	-51.74	22.48
8.86	9.35	18.7	82.81	165.62	106.67	-54.67	27.69
9.33	9.85	19.71	84.58	169.17	109.58	-57.58	32.73
9.8	10.36	20.71	86.45	172.9	112.48	-60.48	37.65
10.27	10.86	21.71	88.4	176.81	115.39	-63.39	42.02
10.74	11.35	22.7	90.45	180.91	118.29	-66.29	4.57
11.22	11.85	23.69	92.6	185.2	121.2	-69.2	7.71
11.7	12.34	24.68	94.84	189.68	124.11	-72.11	12.22
11.31	11.91	23.82	90.22	180.43	127.03	-75.03	17.27
11.66	12.26	24.51	91.66	183.32	129.95	-77.95	22.53
12.02	12.6	25.2	93.1	186.2	132.71	-80.71	27.73
12.37	12.94	25.87	94.62	189.25	135.43	-83.43	32.77
12.76	13.32	26.63	96.55	193.1	138.44	-86.44	37.69
13.2	13.74	27.48	98.64	197.28	141.75	-89.75	42.06
13.69	14.21	28.43	100.9	201.79	145.39	-93.39	4.57
14.18	14.69	29.37	103.05	206.09	149.03	-97.03	7.72

14.68	15.17	30.33	105.3	210.61	152.66	-100.66	12.22
15.18	15.65	31.3	107.66	215.33	156.24	-104.24	17.27
14.45	14.86	29.72	101.39	202.78	159.79	-107.79	22.53
14.84	15.22	30.45	103.2	206.39	163.31	-111.31	27.74
15.24	15.59	31.18	104.92	209.85	166.59	-114.59	32.77
15.64	15.96	31.92	106.74	213.49	169.84	-117.84	37.69
16.06	16.35	32.7	108.64	217.29	173.04	-121.04	42.06
16.49	16.76	33.52	110.66	221.32	176.2	-124.2	4.57
16.93	17.19	34.38	112.78	225.56	179.32	-127.32	7.72
17.39	17.64	35.28	115.01	230.03	182.43	-130.43	12.22
17.86	18.1	36.2	117.41	234.82	185.58	-133.58	17.27
18.34	18.57	37.13	119.92	239.84	188.79	-136.79	22.53
17.35	17.53	35.07	112.81	225.61	192.06	-140.06	27.74
17.71	17.87	35.74	114.71	229.41	195.39	-143.39	32.77
18.09	18.21	36.43	116.51	233.01	198.51	-146.51	37.69
18.46	18.56	37.11	118.2	236.4	201.44	-149.44	42.06
18.83	18.89	37.79	119.98	239.95	204.16	-152.16	4.57
19.19	19.23	38.46	121.83	243.67	206.68	-154.68	7.72
19.58	19.59	39.17	123.95	247.89	209.23	-157.23	12.22
19.98	19.96	39.92	126.19	252.38	211.82	-159.82	17.27
20.4	20.35	40.71	128.57	257.14	214.49	-162.49	22.53
20.84	20.77	41.53	131.08	262.17	217.22	-165.22	27.74
19.61	19.52	39.04	123.12	246.24	220.03	-168.03	32.77
19.92	19.79	39.59	124.93	249.85	222.83	-170.83	37.69
20.23	20.08	40.17	126.64	253.28	225.36	-173.36	42.06
20.56	20.39	40.77	128.45	256.89	227.85	-175.85	4.57
20.9	20.7	41.4	130.36	260.71	230.29	-178.29	7.72
21.26	21.03	42.06	132.37	264.74	232.71	-180.71	12.22
21.62	21.37	42.75	134.49	268.97	235.12	-183.12	17.27
22	21.73	43.46	136.71	273.42	237.54	-185.54	22.53
22.4	22.1	44.2	139.04	278.09	239.96	-187.96	27.74
22.81	22.49	44.97	141.49	282.98	242.4	-190.4	32.77
21.16	20.84	41.69	131.19	262.38	244.85	-192.85	37.69
21.42	21.08	42.16	132.89	265.77	247.3	-195.3	42.06
21.69	21.33	42.66	134.47	268.94	249.43	-197.43	4.57
21.97	21.6	43.19	136.16	272.31	251.51	-199.51	7.72
22.27	21.87	43.75	137.94	275.89	253.54	-201.54	12.22
22.58	22.17	44.33	139.83	279.67	255.54	-203.54	17.27
22.91	22.47	44.94	141.83	283.66	257.55	-205.55	22.53
23.25	22.79	45.58	143.94	287.87	259.56	-207.56	27.74
23.6	23.13	46.25	146.15	292.3	261.58	-209.58	32.77
23.97	23.48	46.95	148.48	296.96	263.61	-211.61	37.69
24.36	23.84	47.68	150.92	301.85	265.67	-213.67	42.06
24.76	24.22	48.44	153.49	306.98	267.73	-215.73	4.57

Biomass Carbon for Sal Poplar

25.17	24.61	49.23	156.18	312.35	269.82	-217.82	7.72
25.6	25.03	50.05	158.99	317.98	271.93	-219.93	12.22
26.05	25.46	50.91	161.94	323.88	274.06	-222.06	17.27
26.52	25.9	51.8	165.02	330.05	276.21	-224.21	22.53
27.01	26.36	52.73	168.24	336.47	278.38	-226.38	27.74
27.51	26.84	53.69	171.59	343.17	280.56	-228.56	32.77
28.03	27.34	54.69	175.08	350.16	282.75	-230.75	37.69
28.57	27.86	55.72	178.73	357.45	284.96	-232.96	42.06
26.26	25.6	51.2	164.57	329.14	287.2	-235.2	4.57
26.33	25.66	51.32	165.41	330.82	289.46	-237.46	7.72
26.42	25.89	51.77	166.53	333.07	291.65	-239.65	12.22
26.53	26.28	52.56	167.94	335.89	294.05	-242.05	17.27
26.67	26.69	53.37	169.34	338.68	296.37	-244.37	22.53
26.83	27.11	54.22	170.87	341.74	298.62	-246.62	27.74
27.01	27.54	55.09	172.52	345.04	300.78	-248.78	32.77
27.21	27.99	55.99	174.3	348.59	302.87	-250.87	37.69
27.42	28.46	56.91	176.2	352.41	304.91	-252.91	42.06
27.66	28.93	57.87	178.24	356.48	306.91	-254.91	4.57
25.43	26.8	53.59	164.3	328.6	308.89	-256.89	7.72
25.49	27.08	54.15	165.31	330.61	310.84	-258.84	12.22
25.57	27.37	54.74	166.24	332.47	312.37	-260.37	17.27
25.67	27.67	55.35	167.29	334.57	313.78	-261.78	22.53
25.79	27.99	55.99	168.46	336.91	315.11	-263.11	27.74
25.93	28.33	56.65	169.75	339.49	316.38	-264.38	32.77
26.09	28.67	57.35	171.16	342.31	317.62	-265.62	37.69
26.26	29.03	58.07	172.68	345.37	318.84	-266.84	42.06
26.45	29.41	58.82	174.34	348.67	320.06	-268.06	4.57
26.66	29.8	59.6	176.11	352.22	321.27	-269.27	7.72
26.88	30.21	60.41	178.01	356.02	322.48	-270.48	12.22
27.13	30.63	61.26	180.03	360.07	323.69	-271.69	17.27
27.39	31.07	62.13	182.19	364.38	324.9	-272.9	22.53
27.67	31.52	63.04	184.48	368.95	326.12	-274.12	27.74
27.96	31.99	63.99	186.9	373.8	327.35	-275.35	32.77
28.28	32.49	64.97	189.46	378.92	328.59	-276.59	37.69
28.61	32.99	65.99	192.15	384.3	329.82	-277.82	42.06
28.96	33.52	67.04	194.98	389.96	331.05	-279.05	4.57
29.33	34.06	68.12	197.95	395.9	332.29	-280.29	7.72
29.71	34.62	69.25	201.07	402.14	333.53	-281.53	12.22
0	0	0	0	0	334.77	-282.77	17.27
0.05	0.05	0.11	0.34	0.68	330.52	-278.52	22.53
0.16	0.16	0.31	0.89	1.78	321.92	-269.92	27.74
0.31	0.31	0.62	1.63	3.27	312.86	-260.86	32.77
0.51	0.51	1.03	2.58	5.15	304.13	-252.13	37.69
0.76	0.77	1.53	3.71	7.43	296.12	-244.12	42.06

1.05	1.06	2.13	5.05	10.09	288.96	-236.96	4.57
1.39	1.41	2.82	6.57	13.14	282.7	-230.7	7.72
1.77	1.8	3.6	8.28	16.56	277.3	-225.3	12.22
2.19	2.24	4.48	10.19	20.37	272.71	-220.71	17.27
2.62	2.69	5.38	12.14	24.27	268.86	-216.86	22.53
3.13	3.21	6.42	14.35	28.7	265.47	-213.47	27.74
3.64	3.75	7.5	16.62	33.25	262.48	-210.48	32.77
4.17	4.3	8.61	18.96	37.93	259.85	-207.85	37.69
4.71	4.87	9.74	21.37	42.74	257.54	-205.54	42.06
5.26	5.45	10.9	23.85	47.69	255.53	-203.53	4.57
5.81	6.04	12.08	26.37	52.75	253.77	-201.77	7.72
6.38	6.64	13.29	28.96	57.92	252.24	-200.24	12.22
6.95	7.25	14.51	31.6	63.2	250.93	-198.93	17.27
7.53	7.88	15.75	34.3	68.6	249.82	-197.82	22.53
7.9	8.29	16.58	36.09	72.19	248.89	-196.89	27.74
8.45	8.88	17.77	38.73	77.47	248.12	-196.12	32.77
9.02	9.5	18.99	41.42	82.84	247.46	-195.46	37.69
9.58	10.11	20.22	44.17	88.35	246.93	-194.93	42.06
10.15	10.72	21.44	46.99	93.99	246.52	-194.52	4.57
10.73	11.34	22.67	49.88	99.76	246.22	-194.22	7.72
11.31	11.95	23.9	52.84	105.69	246.03	-194.03	12.22
11.89	12.56	25.12	55.83	111.67	245.94	-193.94	17.27
12.47	13.16	26.31	58.84	117.69	245.97	-193.97	22.53
13.04	13.74	27.48	61.88	123.76	246.09	-194.09	27.74
12.53	13.19	26.38	59.82	119.64	246.3	-194.3	32.77
12.85	13.5	27	61.82	123.65	246.59	-194.59	37.69
13.17	13.81	27.61	63.78	127.56	246.79	-194.79	42.06
13.49	14.11	28.22	65.79	131.57	247.02	-195.02	4.57
13.85	14.46	28.92	68.16	136.32	247.58	-195.58	7.72
14.27	14.86	29.72	70.66	141.31	248.51	-196.51	12.22
14.72	15.3	30.61	73.29	146.58	249.81	-197.81	17.27
15.19	15.75	31.51	75.78	151.57	251.18	-199.18	22.53
15.67	16.21	32.42	78.35	156.7	252.57	-200.57	27.74
16.15	16.67	33.34	80.99	161.99	253.97	-201.97	32.77
15.32	15.78	31.56	77.07	154.14	255.4	-203.4	37.69
15.69	16.12	32.24	79.32	158.65	256.85	-204.85	42.06
16.07	16.46	32.92	81.47	162.94	258.1	-206.1	4.57
16.45	16.8	33.61	83.67	167.35	259.37	-207.37	7.72
16.84	17.17	34.34	85.93	171.86	260.64	-208.64	12.22
17.26	17.56	35.13	88.28	176.55	261.93	-209.93	17.27
17.68	17.97	35.95	90.7	181.4	263.22	-211.22	22.53
18.12	18.41	36.81	93.21	186.41	264.55	-212.55	27.74
18.57	18.85	37.7	95.86	191.71	265.97	-213.97	32.77
19.04	19.3	38.6	98.59	197.18	267.49	-215.49	37.69

17.98	18.2	36.39	93.36	186.71	269.11	-217.11	42.06
18.32	18.51	37.03	95.62	191.23	270.84	-218.84	4.57
18.68	18.84	37.68	97.75	195.5	272.39	-220.39	7.72
19.04	19.16	38.33	99.75	199.51	273.8	-221.8	12.22
19.39	19.49	38.97	101.82	203.63	275.04	-223.04	17.27
19.74	19.81	39.62	103.94	207.88	276.12	-224.12	22.53
20.11	20.15	40.3	106.29	212.58	277.26	-225.26	27.74
20.51	20.51	41.02	108.76	217.51	278.48	-226.48	32.77
20.92	20.89	41.79	111.34	222.67	279.82	-227.82	37.69
21.35	21.3	42.59	114.03	228.07	281.26	-229.26	42.06
20.07	19.99	39.99	107.57	215.15	282.8	-230.8	4.57
20.36	20.26	40.52	109.67	219.34	284.37	-232.37	7.72
20.66	20.53	41.07	111.65	223.3	285.7	-233.7	12.22
20.98	20.82	41.65	113.71	227.41	287.02	-235.02	17.27
21.31	21.13	42.26	115.84	231.69	288.33	-236.33	22.53
21.65	21.45	42.89	118.07	236.14	289.64	-237.64	27.74
22.01	21.78	43.56	120.38	240.76	290.98	-238.98	32.77
22.38	22.13	44.25	122.78	245.56	292.35	-240.35	37.69
22.77	22.49	44.98	125.28	250.55	293.75	-241.75	42.06
23.17	22.87	45.73	127.87	255.74	295.19	-243.19	4.57
21.48	21.18	42.36	118.9	237.81	296.67	-244.67	7.72
21.73	21.41	42.82	120.83	241.66	298.18	-246.18	12.22
21.99	21.65	43.3	122.62	245.25	299.39	-247.39	17.27
22.27	21.91	43.82	124.51	249.01	300.57	-248.57	22.53
22.56	22.18	44.36	126.48	252.95	301.73	-249.73	27.74
22.86	22.46	44.93	128.53	257.07	302.89	-250.89	32.77
23.18	22.76	45.52	130.69	261.37	304.07	-252.07	37.69
23.52	23.07	46.15	132.93	265.86	305.28	-253.28	42.06
23.86	23.4	46.81	135.27	270.55	306.52	-254.52	4.57
24.23	23.75	47.49	137.72	275.44	307.79	-255.79	7.72
24.61	24.1	48.21	140.27	280.53	309.1	-257.1	12.22
25	24.48	48.96	142.92	285.85	310.44	-258.44	17.27
25.41	24.87	49.74	145.69	291.38	311.82	-259.82	22.53
25.84	25.28	50.56	148.58	297.15	313.24	-261.24	27.74
26.29	25.7	51.41	151.58	303.17	314.7	-262.7	32.77
26.75	26.15	52.29	154.71	309.43	316.19	-264.19	37.69
27.23	26.6	53.21	157.96	315.93	317.71	-265.71	42.06
27.73	27.08	54.16	161.34	322.68	319.26	-267.26	4.57
28.25	27.58	55.15	164.85	329.71	320.84	-268.84	7.72
28.79	28.09	56.18	168.51	337.01	322.45	-270.45	12.22
26.46	25.81	51.61	155.35	310.7	324.09	-272.09	17.27
26.52	25.86	51.72	156.37	312.73	325.77	-273.77	22.53
26.61	26.08	52.16	157.65	315.3	327.4	-275.4	27.74
26.71	26.47	52.94	159.21	318.41	329.25	-277.25	32.77

26.85	26.87	53.74	160.74	321.48	331.04	-279.04	37.69
27	27.29	54.58	162.4	324.79	332.76	-280.76	42.06
27.18	27.72	55.44	164.16	328.32	334.41	-282.41	4.57
27.37	28.17	56.33	166.05	332.09	336	-284	7.72
27.58	28.62	57.25	168.05	336.1	337.55	-285.55	12.22
27.82	29.1	58.19	170.17	340.34	339.08	-287.08	17.27
25.57	26.94	53.89	157.02	314.05	340.59	-288.59	22.53
25.63	27.22	54.44	158.17	316.33	342.09	-290.09	27.74
25.7	27.51	55.02	159.22	318.45	343.18	-291.18	32.77
25.8	27.81	55.62	160.39	320.78	344.17	-292.17	37.69
25.92	28.13	56.25	161.67	323.34	345.07	-293.07	42.06
26.05	28.45	56.91	163.06	326.12	345.94	-293.94	4.57
26.2	28.8	57.6	164.56	329.12	346.78	-294.78	7.72
26.37	29.16	58.31	166.17	332.34	347.62	-295.62	12.22
26.56	29.53	59.06	167.9	335.8	348.46	-296.46	17.27
26.77	29.92	59.83	169.74	339.49	349.3	-297.3	22.53
26.99	30.32	60.64	171.7	343.41	350.15	-298.15	27.74
27.23	30.74	61.48	173.78	347.57	351.01	-299.01	32.77
27.49	31.18	62.35	175.99	351.98	351.89	-299.89	37.69
27.77	31.63	63.26	178.32	356.63	352.77	-300.77	42.06
28.06	32.1	64.2	180.78	361.55	353.67	-301.67	4.57
28.38	32.59	65.18	183.37	366.73	354.59	-302.59	7.72
28.71	33.1	66.2	186.08	372.16	355.51	-303.51	12.22
29.06	33.62	67.24	188.93	377.85	356.44	-304.44	17.27
29.43	34.16	68.33	191.91	383.81	357.37	-305.37	22.53
29.81	34.72	69.45	195.03	390.06	358.32	-306.32	27.74
0	0	0	0	0	359.28	-307.28	32.77
0.05	0.05	0.11	0.34	0.68	354.74	-302.74	37.69
0.16	0.16	0.31	0.89	1.78	345.88	-293.88	42.06
0.31	0.31	0.62	1.63	3.27	336.57	-284.57	4.57
0.51	0.51	1.03	2.58	5.15	327.62	-275.62	7.72
0.76	0.77	1.53	3.71	7.43	319.39	-267.39	12.22
1.05	1.06	2.13	5.05	10.09	312.03	-260.03	17.27
1.39	1.41	2.82	6.57	13.14	305.59	-253.59	22.53
1.77	1.8	3.6	8.28	16.56	300.01	-248.01	27.74
2.19	2.24	4.48	10.19	20.37	295.26	-243.26	32.77
2.62	2.69	5.38	12.14	24.27	291.25	-239.25	37.69
3.13	3.21	6.42	14.35	28.7	287.71	-235.71	42.06
3.64	3.75	7.5	16.62	33.25	284.57	-232.57	4.57
4.17	4.3	8.61	18.96	37.93	281.8	-229.8	7.72
4.71	4.87	9.74	21.37	42.74	279.35	-227.35	12.22
5.26	5.45	10.9	23.85	47.69	277.21	-225.21	17.27
5.81	6.04	12.08	26.37	52.75	275.32	-223.32	22.53
6.38	6.64	13.29	28.96	57.92	273.67	-221.67	27.74

6.95	7.25	14.51	31.6	63.2	272.23	-220.23	32.77
7.53	7.88	15.75	34.3	68.6	271	-219	37.69
7.9	8.29	16.58	36.09	72.19	269.95	-217.95	42.06
8.45	8.88	17.77	38.73	77.47	269.06	-217.06	4.57
9.02	9.5	18.99	41.42	82.84	268.29	-216.29	7.72
9.58	10.11	20.22	44.17	88.35	267.65	-215.65	12.22
10.15	10.72	21.44	46.99	93.99	267.12	-215.12	17.27
10.73	11.34	22.67	49.88	99.76	266.71	-214.71	22.53
11.31	11.95	23.9	52.84	105.69	266.41	-214.41	27.74
11.89	12.56	25.12	55.83	111.67	266.22	-214.22	32.77
12.47	13.16	26.31	58.84	117.69	266.13	-214.13	37.69
13.04	13.74	27.48	61.88	123.76	266.14	-214.14	42.06
12.53	13.19	26.38	59.82	119.64	266.25	-214.25	4.57
12.85	13.5	27	61.82	123.65	266.44	-214.44	7.72
13.17	13.81	27.61	63.78	127.56	266.54	-214.54	12.22
13.49	14.11	28.22	65.79	131.57	266.66	-214.66	17.27
13.85	14.46	28.92	68.16	136.32	267.12	-215.12	22.53
14.27	14.86	29.72	70.66	141.31	267.95	-215.95	27.74
14.72	15.3	30.61	73.29	146.58	269.15	-217.15	32.77
15.19	15.75	31.51	75.78	151.57	270.42	-218.42	37.69
15.67	16.21	32.42	78.35	156.7	271.72	-219.72	42.06
16.15	16.67	33.34	80.99	161.99	273.02	-221.02	4.57
15.32	15.78	31.56	77.07	154.14	274.35	-222.35	7.72
15.69	16.12	32.24	79.32	158.65	275.71	-223.71	12.22
16.07	16.46	32.92	81.47	162.94	276.87	-224.87	17.27
16.45	16.8	33.61	83.67	167.35	278.04	-226.04	22.53
16.84	17.17	34.34	85.93	171.86	279.22	-227.22	27.74
17.26	17.56	35.13	88.28	176.55	280.41	-228.41	32.77
17.68	17.97	35.95	90.7	181.4	281.62	-229.62	37.69
18.12	18.41	36.81	93.21	186.41	282.86	-230.86	42.06
18.57	18.85	37.7	95.86	191.71	284.19	-232.19	4.57
19.04	19.3	38.6	98.59	197.18	285.62	-233.62	7.72
17.98	18.2	36.39	93.36	186.71	287.15	-235.15	12.22
18.32	18.51	37.03	95.62	191.23	288.79	-236.79	17.27
18.68	18.84	37.68	97.75	195.5	290.26	-238.26	22.53
19.04	19.16	38.33	99.75	199.51	291.59	-239.59	27.74
19.39	19.49	38.97	101.82	203.63	292.74	-240.74	32.77
19.74	19.81	39.62	103.94	207.88	293.74	-241.74	37.69
20.11	20.15	40.3	106.29	212.58	294.79	-242.79	42.06
20.51	20.51	41.02	108.76	217.51	295.93	-243.93	4.57
20.92	20.89	41.79	111.34	222.67	297.19	-245.19	7.72
21.35	21.3	42.59	114.03	228.07	298.55	-246.55	12.22
20.07	19.99	39.99	107.57	215.15	300.01	-248.01	17.27

Scenario 2 Biomass stems dry weight [MgDM/ha	Scenario 2 Biomass stems volume [m3/ha]	Scenario 2 Biomass stems CAI [m3/ha/yr]	Scenario 2 Biomass foliage carbon [MgC/ha]	Scenario 2 Biomass foliage dry weight [MgDM/ha	Scenario 2 Biomass branches carbon [MgC/ha]	Scenario 2 Biomass branches dry weight [MgDM/ha	Scenario 2 Biomass roots carbon [MgC/ha]
0	0	0	0	0	0	0	0
6.29	16.56	16.56	1.42	2.83	1.26	2.52	1.26
15.3	40.26	23.7	2.01	4.01	2.98	5.96	3.1
25.4	66.84	26.58	2.88	5.76	4.4	8.8	5.15
35.92	94.52	27.68	3.51	7.02	5.64	11.28	7.26
46.33	121.92	27.4	4.34	8.68	7.16	14.32	9.36
56.4	148.42	26.5	5.15	10.3	9.31	18.63	11.65
66.24	174.32	25.9	5.82	11.64	11.78	23.56	14.09
74.98	197.32	23	6.1	12.21	14.84	29.68	16.54
8.23	21.65	19.2	0.52	1.03	1.69	3.38	1.84
14.52	38.21	16.56	1.44	2.88	2.78	5.56	3.02
23.53	61.91	23.7	2.01	4.02	4.35	8.69	4.8
33.63	88.49	26.58	2.88	5.76	5.63	11.26	6.77
44.15	116.17	27.68	3.51	7.02	6.75	13.5	8.82
54.56	143.57	27.4	4.34	8.68	8.16	16.31	10.86
64.63	170.07	26.5	5.15	10.3	10.21	20.42	13.09
74.47	195.97	25.9	5.82	11.64	12.59	25.17	15.47
83.21	218.97	23	6.1	12.21	15.57	31.13	17.87
9.05	23.82	19.2	0.52	1.03	1.75	3.51	1.97
15.34	40.38	16.56	1.44	2.88	2.84	5.68	3.15
24.35	64.08	23.7	2.01	4.02	4.4	8.8	4.91
34.45	90.66	26.58	2.88	5.76	5.68	11.35	6.89
44.97	118.34	27.68	3.51	7.02	6.79	13.59	8.93
55.38	145.74	27.4	4.34	8.68	8.2	16.39	10.96
65.45	172.24	26.5	5.15	10.3	10.25	20.49	13.19
75.29	198.14	25.9	5.82	11.64	12.62	25.23	15.57
84.03	221.14	23	6.1	12.21	15.59	31.19	17.96
9.13	24.03	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.59	16.56	1.44	2.88	2.84	5.68	3.16
24.43	64.29	23.7	2.01	4.02	4.4	8.8	4.92
34.53	90.87	26.58	2.88	5.76	5.68	11.36	6.9
45.05	118.55	27.68	3.51	7.02	6.79	13.59	8.93
55.46	145.95	27.4	4.34	8.68	8.2	16.39	10.97
65.53	172.45	26.5	5.15	10.3	10.25	20.49	13.2
75.37	198.35	25.9	5.82	11.64	12.62	25.24	15.58
84.11	221.35	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16

24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98

15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97

9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58

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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
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84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97

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75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
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9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9
45.06	118.58	27.68	3.51	7.02	6.79	13.59	8.93
55.47	145.98	27.4	4.34	8.68	8.2	16.39	10.97
65.54	172.48	26.5	5.15	10.3	10.25	20.49	13.2
75.38	198.38	25.9	5.82	11.64	12.62	25.24	15.58
84.12	221.38	23	6.1	12.21	15.6	31.19	17.97
9.14	24.06	19.2	0.52	1.03	1.76	3.51	1.98
15.43	40.62	16.56	1.44	2.88	2.84	5.68	3.16
24.44	64.32	23.7	2.01	4.02	4.4	8.8	4.92
34.54	90.9	26.58	2.88	5.76	5.68	11.36	6.9

Scenario 2 Biomass roots dry weight [MgDM/ha	Scenario 2 Biomass carbon [MgC/ha]	Scenario 2 Biomass dry weight [MgDM/ha	Scenario 2 Total carbon [MgC/ha]	Scenario 2 Atmosphere carbon [MgC/ha]	
0	0	0	0	0	
2.52	7.08	14.16	7.08	-7.08	
6.2	15.73	31.47	17.26	-17.26	
10.29	25.12	50.25	28.97	-28.97	
14.51	34.37	68.73	41.21	-41.21	
18.72	44.02	88.05	54.25	-54.25	
23.31	54.32	108.64	68.43	-68.43	
28.18	64.81	129.62	83.33	-83.33	
33.09	74.98	149.95	98.26	-98.26	
3.68	8.16	16.32	109.63	-109.63	
6.05	14.51	29.01	112.82	-112.82	
9.59	22.91	45.83	114.18	-114.18	
13.55	32.1	64.19	118.39	-118.39	
17.64	41.15	82.3	124.14	-124.14	
21.72	50.64	101.27	131.51	-131.51	
26.19	60.77	121.54	140.7	-140.7	
30.95	71.11	142.22	151.24	-151.24	
35.74	81.14	162.29	162.35	-162.35	
3.93	8.76	17.53	170.36	-170.36	
6.29	15.1	30.2	170.62	-170.62	
9.82	23.5	46.99	169.23	-169.23	
13.78	32.67	65.34	170.99	-170.99	
17.85	41.71	83.43	174.53	-174.53	
21.93	51.19	102.38	179.93	-179.93	
26.39	61.32	122.63	187.35	-187.35	
31.14	71.65	143.3	196.3	-196.3	
35.92	81.68	163.35	205.96	-205.96	
3.95	8.82	17.63	212.68	-212.68	
6.31	15.15	30.3	211.74	-211.74	
9.84	23.55	47.09	209.24	-209.24	
13.79	32.72	65.44	209.96	-209.96	
17.87	41.76	83.53	212.55	-212.55	
21.94	51.24	102.48	217.05	-217.05	
26.4	61.37	122.73	223.63	-223.63	
31.15	71.7	143.4	231.78	-231.78	
35.94	81.72	163.45	240.69	-240.69	
3.95	8.82	17.64	246.69	-246.69	
6.31	15.15	30.31	245.06	-245.06	

9.84	23.55	47.1	241.9	-241.9
13.79	32.72	65.45	241.99	-241.99
17.87	41.77	83.54	243.97	-243.97
21.94	51.24	102.49	247.87	-247.87
26.4	61.37	122.74	253.88	-253.88
31.15	71.7	143.41	261.48	-261.48
35.94	81.73	163.46	269.85	-269.85
3.95	8.82	17.64	275.32	-275.32
6.31	15.16	30.31	273.18	-273.18
9.84	23.55	47.1	269.53	-269.53
13.79	32.72	65.45	269.13	-269.13
17.87	41.77	83.54	270.64	-270.64
21.94	51.24	102.49	274.08	-274.08
26.4	61.37	122.74	279.64	-279.64
31.15	71.7	143.41	286.79	-286.79
35.94	81.73	163.46	294.73	-294.73
3.95	8.82	17.64	299.78	-299.78
6.31	15.16	30.31	297.23	-297.23
9.84	23.55	47.1	293.17	-293.17
13.79	32.72	65.45	292.38	-292.38
17.87	41.77	83.54	293.49	-293.49
21.94	51.24	102.49	296.56	-296.56
26.4	61.37	122.74	301.75	-301.75
31.15	71.7	143.41	308.53	-308.53
35.94	81.73	163.46	316.12	-316.12
3.95	8.82	17.64	320.81	-320.81
6.31	15.16	30.31	317.92	-317.92
9.84	23.55	47.1	313.53	-313.53
13.79	32.72	65.45	312.41	-312.41
17.87	41.77	83.54	313.2	-313.2
21.94	51.24	102.49	315.95	-315.95
26.4	61.37	122.74	320.82	-320.82
31.15	71.7	143.41	327.31	-327.31
35.94	81.73	163.46	334.59	-334.59
3.95	8.82	17.64	339	-339
6.31	15.16	30.31	335.82	-335.82
9.84	23.55	47.1	331.14	-331.14
13.79	32.72	65.45	329.75	-329.75
17.87	41.77	83.54	330.27	-330.27
21.94	51.24	102.49	332.75	-332.75
26.4	61.37	122.74	337.37	-337.37
31.15	71.7	143.41	343.59	-343.59
35.94	81.73	163.46	350.63	-350.63
3.95	8.82	17.64	354.79	-354.79

6.31	15.16	30.31	351.37	-351.37
9.84	23.55	47.1	346.45	-346.45
13.79	32.72	65.45	344.83	-344.83
17.87	41.77	83.54	345.12	-345.12
21.94	51.24	102.49	347.38	-347.38
26.4	61.37	122.74	351.78	-351.78
31.15	71.7	143.41	357.79	-357.79
35.94	81.73	163.46	364.62	-364.62
3.95	8.82	17.64	368.57	-368.57
6.31	15.16	30.31	364.95	-364.95
9.84	23.55	47.1	359.84	-359.84
13.79	32.72	65.45	358.02	-358.02
17.87	41.77	83.54	358.12	-358.12
21.94	51.24	102.49	360.19	-360.19
26.4	61.37	122.74	364.41	-364.41
31.15	71.7	143.41	370.24	-370.24
35.94	81.73	163.46	376.89	-376.89
3.95	8.82	17.64	380.67	-380.67
6.31	15.16	30.31	376.87	-376.87
9.84	23.55	47.1	371.59	-371.59
13.79	32.72	65.45	369.61	-369.61
17.87	41.77	83.54	369.55	-369.55
21.94	51.24	102.49	371.46	-371.46
26.4	61.37	122.74	375.52	-375.52
31.15	71.7	143.41	381.2	-381.2
35.94	81.73	163.46	387.7	-387.7
3.95	8.82	17.64	391.33	-391.33
6.31	15.16	30.31	387.39	-387.39
9.84	23.55	47.1	381.97	-381.97
13.79	32.72	65.45	379.85	-379.85
17.87	41.77	83.54	379.65	-379.65
21.94	51.24	102.49	381.43	-381.43
26.4	61.37	122.74	385.36	-385.36
31.15	71.7	143.41	390.91	-390.91
35.94	81.73	163.46	397.28	-397.28
3.95	8.82	17.64	400.79	-400.79
6.31	15.16	30.31	396.72	-396.72
9.84	23.55	47.1	391.18	-391.18
13.79	32.72	65.45	388.94	-388.94
17.87	41.77	83.54	388.63	-388.63
21.94	51.24	102.49	390.3	-390.3
26.4	61.37	122.74	394.11	-394.11
31.15	71.7	143.41	399.55	-399.55
35.94	81.73	163.46	405.82	-405.82

3.95	8.82	17.64	409.21	-409.21
6.31	15.16	30.31	405.05	-405.05
9.84	23.55	47.1	399.41	-399.41
13.79	32.72	65.45	397.06	-397.06
17.87	41.77	83.54	396.65	-396.65
21.94	51.24	102.49	398.22	-398.22
26.4	61.37	122.74	401.94	-401.94
31.15	71.7	143.41	407.29	-407.29
35.94	81.73	163.46	413.46	-413.46
3.95	8.82	17.64	416.77	-416.77
6.31	15.16	30.31	412.52	-412.52
9.84	23.55	47.1	406.79	-406.79
13.79	32.72	65.45	404.36	-404.36
17.87	41.77	83.54	403.86	-403.86
21.94	51.24	102.49	405.35	-405.35
26.4	61.37	122.74	408.99	-408.99
31.15	71.7	143.41	414.25	-414.25
35.94	81.73	163.46	420.35	-420.35
3.95	8.82	17.64	423.58	-423.58
6.31	15.16	30.31	419.25	-419.25
9.84	23.55	47.1	413.44	-413.44
13.79	32.72	65.45	410.94	-410.94
17.87	41.77	83.54	410.38	-410.38
21.94	51.24	102.49	411.79	-411.79
26.4	61.37	122.74	415.36	-415.36
31.15	71.7	143.41	420.56	-420.56
35.94	81.73	163.46	426.59	-426.59
3.95	8.82	17.64	429.75	-429.75
6.31	15.16	30.31	425.36	-425.36
9.84	23.55	47.1	419.49	-419.49
13.79	32.72	65.45	416.92	-416.92
17.87	41.77	83.54	416.29	-416.29
21.94	51.24	102.49	417.65	-417.65
26.4	61.37	122.74	421.16	-421.16
31.15	71.7	143.41	426.3	-426.3
35.94	81.73	163.46	432.26	-432.26
3.95	8.82	17.64	435.37	-435.37
6.31	15.16	30.31	430.92	-430.92
9.84	23.55	47.1	425	-425
13.79	32.72	65.45	422.38	-422.38
17.87	41.77	83.54	421.7	-421.7
21.94	51.24	102.49	423	-423
26.4	61.37	122.74	426.45	-426.45
31.15	71.7	143.41	431.54	-431.54

35.94	81.73	163.46	437.46	-437.46
3.95	8.82	17.64	440.52	-440.52
6.31	15.16	30.31	436.02	-436.02
9.84	23.55	47.1	430.05	-430.05
13.79	32.72	65.45	427.38	-427.38
17.87	41.77	83.54	426.66	-426.66
21.94	51.24	102.49	427.91	-427.91
26.4	61.37	122.74	431.32	-431.32
31.15	71.7	143.41	436.37	-436.37
35.94	81.73	163.46	442.24	-442.24
3.95	8.82	17.64	445.26	-445.26
6.31	15.16	30.31	440.72	-440.72
9.84	23.55	47.1	434.7	-434.7
13.79	32.72	65.45	432	-432
17.87	41.77	83.54	431.23	-431.23
21.94	51.24	102.49	432.45	-432.45
26.4	61.37	122.74	435.82	-435.82
31.15	71.7	143.41	440.82	-440.82
35.94	81.73	163.46	446.66	-446.66
3.95	8.82	17.64	449.64	-449.64
6.31	15.16	30.31	445.06	-445.06
9.84	23.55	47.1	439.01	-439.01
13.79	32.72	65.45	436.27	-436.27
17.87	41.77	83.54	435.47	-435.47
21.94	51.24	102.49	436.65	-436.65
26.4	61.37	122.74	439.99	-439.99
31.15	71.7	143.41	444.96	-444.96
35.94	81.73	163.46	450.77	-450.77
3.95	8.82	17.64	453.71	-453.71
6.31	15.16	30.31	449.1	-449.1
9.84	23.55	47.1	443.02	-443.02
13.79	32.72	65.45	440.25	-440.25
17.87	41.77	83.54	439.42	-439.42
21.94	51.24	102.49	440.57	-440.57
26.4	61.37	122.74	443.88	-443.88
31.15	71.7	143.41	448.82	-448.82
35.94	81.73	163.46	454.6	-454.6
3.95	8.82	17.64	457.52	-457.52
6.31	15.16	30.31	452.88	-452.88
9.84	23.55	47.1	446.77	-446.77
13.79	32.72	65.45	443.97	-443.97
17.87	41.77	83.54	443.11	-443.11
21.94	51.24	102.49	444.23	-444.23
26.4	61.37	122.74	447.52	-447.52

31.15	71.7	143.41	452.43	-452.43
35.94	81.73	163.46	458.19	-458.19
3.95	8.82	17.64	461.08	-461.08
6.31	15.16	30.31	456.42	-456.42
9.84	23.55	47.1	450.28	-450.28
13.79	32.72	65.45	447.46	-447.46
17.87	41.77	83.54	446.57	-446.57
21.94	51.24	102.49	447.68	-447.68
26.4	61.37	122.74	450.94	-450.94
31.15	71.7	143.41	455.83	-455.83
35.94	81.73	163.46	461.56	-461.56
3.95	8.82	17.64	464.43	-464.43
6.31	15.16	30.31	459.75	-459.75
9.84	23.55	47.1	453.59	-453.59
13.79	32.72	65.45	450.75	-450.75
17.87	41.77	83.54	449.84	-449.84
21.94	51.24	102.49	450.92	-450.92
26.4	61.37	122.74	454.16	-454.16
31.15	71.7	143.41	459.04	-459.04
35.94	81.73	163.46	464.75	-464.75
3.95	8.82	17.64	467.6	-467.6
6.31	15.16	30.31	462.89	-462.89
9.84	23.55	47.1	456.72	-456.72
13.79	32.72	65.45	453.85	-453.85
17.87	41.77	83.54	452.93	-452.93
21.94	51.24	102.49	454	-454
26.4	61.37	122.74	457.22	-457.22
31.15	71.7	143.41	462.07	-462.07
35.94	81.73	163.46	467.77	-467.77
3.95	8.82	17.64	470.6	-470.6
6.31	15.16	30.31	465.88	-465.88
9.84	23.55	47.1	459.69	-459.69
13.79	32.72	65.45	456.81	-456.81
17.87	41.77	83.54	455.87	-455.87
21.94	51.24	102.49	456.91	-456.91
26.4	61.37	122.74	460.12	-460.12
31.15	71.7	143.41	464.96	-464.96
35.94	81.73	163.46	470.64	-470.64
3.95	8.82	17.64	473.45	-473.45
6.31	15.16	30.31	468.72	-468.72
9.84	23.55	47.1	462.51	-462.51
13.79	32.72	65.45	459.61	-459.61
17.87	41.77	83.54	458.66	-458.66
21.94	51.24	102.49	459.69	-459.69

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26.4	61.37	122.74	462.88	-462.88
31.15	71.7	143.41	467.71	-467.71
35.94	81.73	163.46	473.37	-473.37
3.95	8.82	17.64	476.18	-476.18
6.31	15.16	30.31	471.43	-471.43
9.84	23.55	47.1	465.21	-465.21
13.79	32.72	65.45	462.3	-462.3
17.87	41.77	83.54	461.33	-461.33
21.94	51.24	102.49	462.35	-462.35
26.4	61.37	122.74	465.53	-465.53
31.15	71.7	143.41	470.34	-470.34
35.94	81.73	163.46	475.99	-475.99
3.95	8.82	17.64	478.78	-478.78
6.31	15.16	30.31	474.02	-474.02
9.84	23.55	47.1	467.79	-467.79
13.79	32.72	65.45	464.86	-464.86
17.87	41.77	83.54	463.88	-463.88
21.94	51.24	102.49	464.89	-464.89
26.4	61.37	122.74	468.06	-468.06
31.15	71.7	143.41	472.86	-472.86
35.94	81.73	163.46	478.5	-478.5
3.95	8.82	17.64	481.28	-481.28
6.31	15.16	30.31	476.51	-476.51
9.84	23.55	47.1	470.26	-470.26
13.79	32.72	65.45	467.33	-467.33
17.87	41.77	83.54	466.34	-466.34
21.94	51.24	102.49	467.34	-467.34
26.4	61.37	122.74	470.49	-470.49
31.15	71.7	143.41	475.28	-475.28
35.94	81.73	163.46	480.91	-480.91
3.95	8.82	17.64	483.68	-483.68
6.31	15.16	30.31	478.9	-478.9
9.84	23.55	47.1	472.64	-472.64
13.79	32.72	65.45	469.7	-469.7
17.87	41.77	83.54	468.7	-468.7
21.94	51.24	102.49	469.69	-469.69
26.4	61.37	122.74	472.83	-472.83
31.15	71.7	143.41	477.62	-477.62
35.94	81.73	163.46	483.23	-483.23
3.95	8.82	17.64	485.99	-485.99
6.31	15.16	30.31	481.2	-481.2
9.84	23.55	47.1	474.94	-474.94

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