THEME 5

Forest and Climate Change

Planning Commission: Sub-Group on Climate Change for 12th Five Year Plan on Mitigation and Adaptation in the Forestry Sector[1]

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1. INTRODUCTION

Forestry sector is now widely recognized as offering unexplored potential for climate change mitigation. At home, Green India mission (GIM) recognizes adaptation potential of forests also, in addition to their key mitigation role. Mitigation and adaptation actions should be alive to the fact of the climate change impacting the forests themselves in due course. It may be difficult and undesirable to separate the adaptation contribution of a mitigation action or vice versa in forestry sector. It would, therefore, be desirable to explore synergy in planning and implementation of mitigation and adaptation projects to derive maximum benefits (Ravindranath 2007).

Forests and tree vegetation outside forests play an important role in the mitigation of climate change by absorbing CO_2 from atmosphere and turning it into biomass comprising microbes, herbs, shrubs, climbers and trees. Carbon is stored above ground in biomass and underground in biomass and soil. Use of forest products originating from sustainable sources as fuelwood, in manufacture of household fixtures and furniture, and in part replacement of cement concrete by lumber in house construction, is also capable of enhancing the mitigation service provided by forests. This report attempts to bring out the present and the future potential that the forestry sector can offer in mitigating the climate change by directly increasing the forest and tree carbon sink on one hand and by promoting efficiency of fuelwood use, and replacement of energy intensive building and household products with wood substitutes from sustainable sources on the other. Needless to say, actions aimed at, and resulting in sustainability of domestic supply of wood products for mitigation, would automatically aid adaptation efforts as sustained supplies would not be possible unless forests and tree vegetation themselves are first secured to the maximum possible extent against negative impacts of climate change.

As regards contribution of mitigation and adaptation actions in forestry sector in reducing emission intensity (EI), it is a fact that the investment in the sector would doubly effect the reduction in EI- one by increasing the forest carbon sink, and two by increasing the GDP. Thus, forestry sector has the distinction of positive contribution both in the numerator and the denominator of the EI in the context of its reduction as volunteered by India. Proper accounting and valuation of goods and services from forestry sector[1] could increase the contribution of forestry sector manifold in the national GDP.

2. ANALYSIS OF VULNERABILITY AND IMPACTS

Forests in India are lesser known for mitigation than for other ecosystem goods and services that they provide. A large number of people especially rural communities are dependent on forests for their livelihood needs like fuelwood, fodder, food supplement and medicinal herbs, etc. Anthropogenic view supports that ecosystem services are the conditions and processes through which natural ecosystems, and the species which make them up, sustain and fulfil human life. Forest ecosystems maintain biodiversity and produce ecosystem goods and services, which are their actual life-support functions (Daily 1997). Ecosystems goods are generally the tangible material products that result from ecosystem processes, whereas ecosystem services are in most cases improvements in the condition or location of resources of value. For convenience, the ecosystem functions of forest are classified into four primary categories (De Groot et al. 2002).

1. *Regulation functions*: It relates to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through bio-

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[1] Forestry sector termed as **Forestry and Logging** sector in National Accounting System (NAS) in India, till recently included i) Major forest products – Timber, Fuelwood ii) Minor forest products – Resins, Gums, etc. iii) Repairs, maintenance and operational costs. However, now industrial wood production from trees outside forests (TOF), and fodder derived from forest areas have also been added. This is a much needed step in the direction of proper accounting of contribution of forestry sector in the national accounts which presently is grossly underestimated in monetary terms due to non accounting of a few important tangible and intangible services generated by forests.

Impact of Climate Change on Forest Ecosystems in India

Indian Institute of Science has conducted an assessment of the impact of climate change on forest ecosystems in India. A dynamic vegetation model IBIS (Integrated Biosphere Simulator) was used (Chaturvedi et al. 2011) to assess the impacts of climate change on forests in India. The study indicates that about 39% and 34% of the forested grids are likely to undergo shifts in vegetation type under A2 and B2 climate scenarios, respectively with a trend towards increased occurrence of the wetter forest types. Approximately 47% and 42% of tropical dry deciduous grids are projected to undergo shifts under A2 and B2 scenarios respectively, as opposed to less than 16% grids comprising of tropical wet evergreen forests. Similarly, the tropical thorny scrub forest is projected to undergo shifts in majority of forested grids under A2 (more than 80%) as well as B2 scenarios (50% of grids). States such as Chhattisgarh, Karnataka and Andhra Pradesh are projected to experience change in 73%, 67% and 62% of the forested grids while in Madhya Pradesh it is about 50% under the A2 scenario.

Source: Indian Institute of Science. 2011

geochemical cycles and other biospheric processes. In addition to maintaining ecosystem (and biosphere) health, they also provide many services that comprise direct and indirect benefits to humans (such as clean air, water and soil, forest carbon and biological control services).

2. Habitat functions: These include provision of refuge and reproduction habitat to wild plants and animals and thereby contribute to the (in situ) conservation of biological and genetic diversity and evolutionary processes.

3. Production functions: Photosynthesis and nutrient uptake by autotrophs convert energy, carbon dioxide, water and nutrients into a wide variety of carbohydrate structures which are then used by secondary producers to create an even larger variety of living biomass. This broad diversity in carbohydrate structures provides many ecosystem goods for human consumption, ranging from food and raw materials of wood and timber, to energy resources and genetic material.

4. Information functions: Because most of human evolution took place within the domain of undomesticated habitat, natural ecosystems provide an essential 'reference function' and contribute to well-being and maintenance of human health by providing opportunities for reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience. Following table (Table 1) presents a summary of forest ecosystem goods and services.

All the above ecosystem functions are vulnerable to climate change although to varied degrees. In absence of adequate research on ascertainment of vulnerability of different forest types to climate change, it is difficult to predict with acceptable precision the reliable changes that the natural forests and plantations would undergo in short and long term due to climate change. However, it is certain that mixed natural vegetation is more resilient to changes in climatic conditions than the man grown plantations comprising a few species.

Local livelihoods sustaining on forests are most likely to be impacted adversely because of climate change, and continued pressure of land use change for developmental and other purposes.

3. STRATEGY

Strategy proposed to realize enhanced potential of forestry sector in mitigation and adaptation of climate change is two pronged-first to focus on actions that promote removals and reduce emissions, and second the actions that improve and enhance ecosystem goods and services. In real practical sense, both actions are closely interrelated. For mitigation, the strategy aims to i) expand and improve the present forest and tree cover, and ii) to promote more efficient use of fuelwood and replacement of energy intensive metal and plastic products with wood substitutes in building sector. At the biophysical level, the two basic carbon mitigation options resulting in expansion and improvement of forest and tree cover are: (1) avoiding (saving) carbon emissions, and, (2) increasing carbon fixation and storage. Constant monitoring and estimation with respect to quantity and quality of forest and tree cover are basic prerequisites of a sound carbon accounting system at the national level. As regards efficient use of fuelwood and replacement of energy intensive building products with wood substitutes, more details are given in the succeeding paragraphs.

India's Forest and Tree Cover: Contribution as a Carbon Sink

India's forest and tree cover accounts for about 23.4% of the total geographical area of the country. 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 CO2. From 1995 to 2005, carbon stocks stored in our forests have increased from 6244.78 to 6621.55 million tonnes (mt) registering an annual increment of 37.68 mt of carbon = 138.15 mt of CO2eq. This annual removal by forests is enough to neutralize 9.31% of our total annual emissions of 2000.

Source: Kishwan, et al. 2009

4. EXISTING PROGRAMMES, POLICIES AND INITIATIVES

In tune with the nation's forest policy, the national strategy aims at enhancing and improving the forest and tree cover of the country thereby enhancing the quantum of forest ecosystem services that flow to the local communities. The services include fuelwood, timber, fodder, NTFP and also carbon sequestration. It is underlined that in the Indian context, carbon service from forest and plantations is one of the co-benefits and not the main or the sole benefit. Present initiatives like National Afforestation Programme (NAP) of the MoEF, together with programmes in sectors like agriculture and rural development are on an average adding or improving 1mha of forest and tree cover annually in our country. This annually adds about 1 million tonne of carbon incrementally, and combined with the accretion of biomass in our managed forests, protected areas, and in tree cover outside the government forests, the total carbon service at present is estimated at 138 mt CO_2eq every year (Kishwan *et. al*. 2009). The cost of the BAU reforestation and afforestation activities contributing in mitigation and adaptation is estimated at Rs 5,000 crore annually for the 12th Five Year Plan (FYP), or Rs 25,000 crore for the entire FYP.

5. ANALYSIS AND RECOMMENDATIONS FOR MITIGATION AND ADAPTATION

The scenario that has been presented in the above paragraph conforms to the 'business-as-usual' (BAU) trend or BAU Scenario. Additional scenarios can also be presented by integrating with the BAU, new actions, schemes and programmes in the pipeline, and even potential concepts and approaches that are neither the part of BAU, nor yet conceived. Following this approach, two more scenarios are presented below:

ACCELERATED SCENARIO

Based on integration of the proposed National Mission for A Green India or Green India Mission (GIM) which is being finalized with the BAU, the carbon service will get enhanced by 50 to 60 mt CO_2eq every year by 2020 and onwards. The GIM is estimated to cost Rs 46,000 crore in 10 years @ Rs 4,600 crore a year. GIM is intended to cover 12th and 13th Five Year Plans, and is to be implemented by the MoEF. GIM aims at increasing the quantity and quality of 10 million hectares of forest and tree cover. The main objectives of the Mission are:

a) Increased forest/tree cover on 5 m ha of forest/non-forest lands and improved quality of forest cover on another 5 m ha (a total of 10 m ha).
b) Improved ecosystem services including biodiversity, hydrological services and carbon sequestration as a result of treatment of 10 m ha.
c) Increased forest-based livelihood income to about 3 million households living in and around the forests.
d) Enhanced annual CO_2eq sequestration by 50 to 60 million tonnes in the year 2020 and beyond.

For this enhanced BAU or Accelerated Scenario, an additional amount of about Rs 4,600 crore will be required every year during the 12th FYP. Total requirement of the Accelerated Scenario which includes BAU Scenario also will be Rs 4,600+5,000= Rs 9,600 crore annually, or Rs 48,000 crore during 12th FYP.

AGGRESSIVE SCENARIO

This scenario goes beyond the accelerated scenario which includes present set and level of activities and GIM, and expands the scope of forestry mitigation by intensifying creation of forest in forest fringe villages, further improvement in quality of open forest cover, encouraging use of harvested wood products to replace metallic fixtures and cement concrete in house construction, initiating replacement of office and domestic metal and plastic based furniture with wood based substitutes, and aggressively introducing energy efficient wood burning cookstoves in rural India. The aggressive scenario is capable of adding an additional 63.7 mt CO_2eq every year by 2020 and onwards. The additional finances required for implementing the Aggressive Scenario are estimated at Rs 10,467 crore annually. Total cost of implementing the scenario will be Rs 20,067 crore annually, or Rs 100,335 crore for the whole 12th FYP. Approach and activities in addition to Accelerated Scenario that are proposed to be part of the Aggressive Scenario are described below.

To begin with, a carbon mitigation option in the forestry sector can be defined as any action that results in a net increase in the carbon sequestration potential of a given forest land and/or the land that supports tree or woody vegetation. This can be achieved by saving existing forest carbon stocks and simultaneously by adding more carbon stocks through new plantations. Management of harvested wood products in a manner that would enhance the life and quantum of locked up carbon in wood products would also qualify to be a mitigation measure. Similarly, part replacement of energy intensive products like cement, plastics and metals in buildings[2] – official and residential – by durable wood products would not only indirectly reduce emissions, but would also increase forest/wood carbon sink. Fossil fuel substitution by forest products like fuelwood and biodiesel is an accepted mitigation option.

Controlling deforestation and forest degradation would result in avoiding emissions or saving existing forest carbon stocks. Best examples in this category are our national parks, sanctuaries and conservation areas. Practices for management of such areas can basically be lumped under conservation (CN) and sustainable management of forests (SMF). Management practices of CN and SMF over a period of time would not only result in

33% Forest Cover Scenario

Government of India has set a long term goal of bringing 33% of geographic area under forest cover. The mitigation potential of afforestation policy in India for the forest sector over the period of 2010–2030 was assessed (Chaturvedi et al 2010), considering two scenarios:

Rapid afforestation rate scenario-2020 (achieving the 33% goal by 2020) and a **moderate afforestation rate scenario-2030** (achieving the 33% goal by 2030). The projected afforestation could mitigate 5.2 $GtCO_2$ under scenario-2020 over the 2010–2030 period, compared with 3.96 $GtCO_2$ under scenario-2030, over the same period. The aggregate mitigation potential in scenario-2020 is estimated to be approximately 3.2 $GtCO_2$ over the baseline, while in scenario-2030, the overall increase in mitigation potential is approximately 1.8 $GtCO_2$ which shows that rapid afforestation under scenario-2020 will lead to an incremental 1.4 $GtCO_2$ mitigation potential over scenario-2030.

Source: Indian Institute of Science. 2011

[2] The report does not intend that there is going to be a dramatic switchover from use of cement, metals and plastics in favour of wood based alternatives in building sector in India, but, all the same, it is worthwhile to outline mitigation initiatives that can possibly have the scope of being introduced at appropriate time in future.

saving of existing forest carbon stocks, but would also effect an increment in their quantum due to natural process of growth of conserved vegetation. Use of improved and more energy efficient wood-burning cookstoves can also help in saving wood biomass and thus contributing towards conservation of forests and trees. Addition or enhancement of forest carbon stocks can be achieved by increasing the carbon density and/or increasing the pool of carbon stored in a given forest or wooded area. In this case, the basic actions would comprise afforestation, reforestation, agro-forestry, and energy plantations (fuelwood and biodiesel).

Carbon emissions in other sectors like energy can also be avoided to some extent by burning sustainably produced and harvested biomass instead of fossil fuels, e.g., using energy plantations to run a power plant, substituting industrial products that are currently fossil-fuel intensive in their manufacture (e.g., substituting cement by lumber) with wood products.

Options and actions in forestry sector for saving, maintaining and increasing forest carbon stocks are enumerated below:

Conservation and Sustainable Management of Forests

(1) Conservation of natural forests and protected areas
(2) Sustainable management of native forests
(3) Dissemination of improved and efficient wood-burning cookstoves

Afforestation

(1) Restoration plantations
(2) Pulpwood plantations
(3) Energy plantations (use of forestry products for bio-energy to replace fossil fuel use, for example, in railways)
(4) Agroforestry systems
(5) National Mission for a Green India

Wood Products use Management

(1) Replacement of energy intensive building materials like cement with lumber, iron and steel fixtures like door, window frames and shutters with wood based products
(2) Replacement of office and domestic furniture made with metals by wood based furniture

Each mitigation option when accounted for separately would result in a specific quantum of net carbon sequestered. In deriving the estimates for net carbon captured and stored, it is assumed that different options will remain in place for a long time unless specified to the contrary.

Table 1: **Conservative Estimates of Net Carbon Sequestration by Forestry Mitigation Options/Actions**

Option	Net Carbon Sequestration
Conservation	
(1) Natural Protected Areas (NPAs)	Avoided emissions from deforestation and forest degradation. Maintain and add forest carbon stocks. To be counted under improvement of forest and tree cover under forest carbon accounting. New forested areas are capable of adding 1 tonne of dry biomass per ha on an average every year. Already forested areas capable of adding from 0.2 to 1 tonne of dry biomass every year per ha depending on the composition and density of the area
(2) Sustainable Management of Forests	Unlike NPAs, the forests are subject to sustainable harvests also. However, wood removed is less than annual increment resulting in net addition of forest carbon stocks. To be counted under improvement of forest and tree cover under forest carbon accounting
(3) Improved Wood-burning Cookstoves	Avoided emissions from unsustainable fuelwood use. Carbon sequestration incorporates fuelwood saved at the end use because of improved efficiency of cookstoves. It is presumed that cookstoves can reduce the fuelwood consumption by about 30% by improving energy efficiency, and also that 75% of the fuel biomass used in rural areas comes from forests. This can reduce the emissions from forest fuelwood by about 30%. If it is further presumed that fuelwood supply from forests is not sustainable because of heavy withdrawal, the entire quantum of fuelwood saved would result in reduction of emissions.
Afforestation	
(4) Increase Forest and Tree Cover	Additional area of 1 mha is afforested/reforested every year presuming that each ha would add 1 tonne of dry biomass every year
(5) Improvement in Forest and Tree Cover	Aims at improving 1 mha area each of open forests and medium dense forests with a view to upgrading these forests to the next higher category, i.e., open forest (OF) to medium dense forest (MDF), and medium dense forest to very dense forest category (VDF). Underlying assumption of carbon enhancement is that upgradation of OF to MDF and MDF to VDF will respectively add 0.2 and 0.3 tonnes of dry biomass per ha every year
(6) Energy Plantations	Would result in incremental carbon content in biomass of vegetation, and reduction in emissions due to replacement of fossil fuel use with renewables like fuelwood and biodiesel wherever applicable[1]

(7) Agroforestry Systems	Capable of sequestering additional carbon in woody biomass and soil when combined with current agricultural systems. Estimates of mitigation would vary depending on agro-ecological zone, crop combination and level of investment[2]
(8) Green India Mission	6 mha of degraded forest lands to be planted under the Mission for A Green India[3]
Wood Products Use Management	
(9) Harvested Wood Products Management (as substitutes)	Wood products store carbon for a long time, and encouraging their use in building construction substituting cement by lumber, and metallic door and window frames and wall cabinets with wood based products has the potential of saving 2 tonnes of CO_2eq emissions for each cubic m of metallic hardware replaced
(10) Replacement of office and domestic furniture using metals with wooden furniture	It is estimated that at present 35 % of furniture used in office and homes is made of metals and plastics. Replacing metallic and plastic furniture with wooden products would not only enable storage of carbon in wooden furniture, but would also replace more energy intensive metal and plastic use. Presuming that 50% of the furniture made of metals and plastics can be substituted by wood based furniture would result in replacing about 1.5 million cubic m of metal and plastic sequestering an additional 3 milion tonnes of CO_2eq every year

6. ADAPTATION

In respect of a forestry activity, it is difficult and undesirable to separate its mitigation and adaptation potential and contribution. All the same, many experts see more prominent contribution of certain forestry actions towards adaptation than mitigation. Some examples of the 'win-win' adaptation practices are as follows (Murthy *et al.* 2011):

i) Expand Protected Areas and link them wherever possible to promote migration of species
ii) Promote forest conservation since biodiversity rich forest are less vulnerable due to varying temperature tolerance of plant species
iii) Anticipatory planting of species along latitude and altitude
iv) Promote assisted natural regeneration
v) Promote mixed species forestry
vi) Promote species mix adapted to different temperature tolerance regimes
vii) Develop and implement fire protection and management practices
viii) Adopt thinning, sanitation and other silvicultural practices
ix) Promote in situ and ex situ conservation of genetic diversity
x) Develop temperature, drought and pest resistance in commercial tree species
xi) Develop and adopt sustainable forest management practices
xii) Conserve forests and reduce forest fragmentation to enable species migration
xiii) Adoption of energy efficient fuelwood cooking devices to reduce pressure on forests.

Forest planning and development programmes and policies may have to be altered to address the likely impacts of climate change and appropriately adopt various policy and management practices to minimize the adverse impacts and vulnerability.

High resolution Climate Modeling and Ecosystem Responses

Most of the focus on climate simulations is towards monsoonal prediction and rainfall pattern. While the precipitation is paramount indicator of the climate change, however it is essential some of the subtle changes in response to minor perturbations in the climate variables induce severe impact on eco-system functions either on agriculture, forestry and animal system. In order to understand the feedback mechanisms it is essential that Climate Change Research modeling should necessarily incorporate eco-system responses as assimilation to the modeling and provide model simulations both in agriculture, forestry, grazing resources, Himalayan glaciers, Hydrological system etc. should begin involving the departments associated with research activities of observatory networks related to climate change and eco- system processes.

Source: CBS Dutt, National Remote Sensing Centre

7. RESEARCH

Short term and long term research covering adaptation and mitigation aspects of forests, as also relevant ecological research, and development of vegetation and carbon modeling of forests would be required to be undertaken on priority. Since no single organization would have captive expertise to initiate and pursue research in all identified fields, it would be imperative that collaborative research amongst concerned organizations is encouraged. Indian Council of Forestry Research and Education, and Indian Institute of Science could take lead in operationalizing the collaborative research approach wherever required. It is proposed that an amount of Rs 235 crore may be set aside for implementation of projects on research priorities identified for the 12th Five Year Plan[3]. An Action plan for collaborative research involving leading Indian institutions along with approximate financial outlay is given in Annexure 1.

The proposed outlay for research is not included in the BAU Scenario, but is embedded in the Accelerated Scenario and Aggressive Scenario.

[3] From Report on 'Climate Change, Forests and Other Ecosystems in India: Strategies for Adaptation' submitted to Chidambaram Committee on 'Impact of Climate Change and Adaptation' (2008).

8. MONITORING AND EVALUATION

A strong monitoring and evaluation mechanism is considered essential to ascertain contribution of mitigation and adaptation actions in forestry. The monitoring and evaluation should be sensitive to effects of climate change on forests.

9. FORESTRY SECTOR AND EMISSION INTENSITY

As per definition of Emission Intensity (EI), it is determined by the quantum of total emissions in Kg CO_2 divided by GDP in USD. In other words, EI can be reduced by decreasing emissions or increasing GDP, or both. India's goal of a reduction of 20-25% in EI by 2020 compared to 2005 level is achievable by initiating appropriate action in all relevant sectors of energy, power, transport, buildings, forestry and agriculture. Forestry sector can contribute in reduction of EI by increasing the size of India's forest carbon sink. The increase can be effected by direct actions like increase and improvement in forest and tree cover, or by indirect actions like promoting use of wood in household fixtures and furniture, and encouraging adoption of fuel efficient stoves to economize on use of fuelwood. All these actions would contribute in enhancing the size of carbon sink. For example, the effect of use of fuel efficient stoves on forest carbon sink would be very pronounced in areas burdened with unsustainable harvest and use of fuelwood from forest.

Also, mitigation actions of increase and improvement in forest and tree cover would increase the supply of forest goods like timber, fuelwood, resin, gums, and fodder. This will simultaneously increase the contribution of the forests in the GDP of the country.

10. FORESTRY MITIGATION OPTIONS AND ESTIMATES OF CARBON SEQUESTRATION UNDER AGGRESSIVE SCENARIO

It is estimated that the different activities planned under conservation, sustainable management of forests and increase in forest and tree cover (afforestation and reforestation), and wood products use management in India would result in sequestration of additional 63.7 mt CO_2eq every year as explained below.

i) **Increase in forest and tree cover by 1 mha every year**: It is proposed to afforest/reforest 1 mha of area every year. The area to be forested would include forest and non-forest lands both. Actions will focus on forest lands away from habitations and non-forest lands available in more than 400,000 villages that are away from forests. This would in general amount to doubling the present gross forestation targets. Presuming that each planted ha would sequester at least 1 tonne dry biomass every year, the total CO_2 captured would be =9*0.4=3.6 mt C yr^{-1}=3.6*44/12 = **13.2 mt CO_2eq every year**.

ii) **Creation of 100 ha of forest in 170,000 forest fringe villages:** It is proposed to create 100 ha of forest in each of the 170,000 forest fringe villages in the country to meet the needs of the forest products of the villagers, and also to simultaneously provide carbon service. Land for the purpose will comprise both forest and non-forest lands. Presuming that 50% of the biomass will be taken away by the locals to meet their needs, the effort will still be able to capture = 17*0.5*0.4=3.4 mt C yr^{-1}=3.4*44/12 = **12.5 mt CO_2eq every year**.

iii) **Improvement in forest cover:** It is intended to improve the quality of the existing forest cover by aiming at upgradation of 1 mha of open forest to medium dense forest, and another 1 mha of medium dense forest to very dense forest category. The effort will result in capture of 9*(0.2+0.3)*0.4= 1.8 mt C yr^{-1}=1.8*44/12 = **6.6 mt CO_2eq every year**.

iv) **Harvested wood products as substitutes:** It is intended that use of lumber, and wood based products like door window frames and shutters etc. would be encouraged to replace cement, and building hardware made of metals and alloys. Every year, 1 million cubic m of metallic hardware products would be replaced by wood based products. This would result in reducing emissions by **2 mt CO_2eq every year**.

v) **Replacement of office and domestic metal and plastic based furniture:** If 50% of all metallic and plastic furniture is replaced by wood based products, an estimated 1.5 million cubic m of metals and plastics would get replaced every year. This would result in reducing emissions by **3 mt CO_2eq every year**.

vi) **Use of improved wood burning cookstoves:** Presuming that 800 million people (80%) use biomass as fuel, and 75% of this biomass is forest based and is not sustainable, it is estimated that about 120 m tonnes of forest biomass is burnt as fuel every year. This results in emissions of 88 mt CO_2eq each year. If it is presumed that improved cookstoves can save 30% of biomass (forest) used as fuel, this would result in a reduction of emissions by **26.4 mt CO_2eq every year** (NSSO. 2002).

All the aforesaid options if taken up simultaneously have the potential of capturing an additional **63.7 mt CO_2eq every year** 2020 onwards, i.e., at the end of the proposed action period, and thus neutralizing this much quantum of emissions annually. The mitigation service thus provided will be able to offset an additional **5.2% of India's emissions at 1994 levels.**

11. ROLE OF INDUSTRY

Industry in general and wood based industry in particular is expected to contribute in mitigating climate change by direct and indirect involvement in raising plantations. The plantations can be raised by the industry on its own captive land (example: Mysore Paper Mills) or through local people on private and community lands (example: ITC, Bhadrachalam). Industry must commit itself as part of its social corporate responsibility (SCR) to support local communities in raising plantations including orchards on private and community lands. These actions would enhance the present size of the forest and tree cover carbon sink of the country, and thus improve overall mitigation contribution of the forestry sector. Industry by expanding its SCR coverage can help

PPP Model–ITC Bhadrachalam

To promote farm forestry plantations on marginal agricultural lands by **providing high quality seedlings, technical extension services and buy-back guarantees** at remunerative prices to farmers, the **Clonal Technology Research and Development** programme of the ITC came up with the objective of improving farmers' economic status, and simultaneously achieving self-sufficiency in supply of wood based raw material. For self sufficiency in cellulosic raw materials (present requirement approx 400,000 tpy and likely to grow to 600,000 tpy and then 800,000 tpy), ITC launched a plantation programme (Farm Forestry). In early stages, the programme encouraged 6,185 farmers in 1,138 villages to cover 7,441 hectares with Eucalyptus seed route plantations in the districts of Khammam, West Godavari, Krishna, Guntur, Prakasam, Nalgonda and Warangal of Andhra Pradesh.

Increase in present productivity level of 6-10 CuM/ha (Mean Annual Increment) to 20-58 CuM/ha has demonstrated to the conventional agri farmers the best alternative land use option.

Similarly through its **Farm Forestry** initiative for commercial and sustainable tree growing, ITC developed a package of scientific silvicultural practices and transferred it to the farmers to enable them to raise and maintain highly productive and successful plantations with a buy back arrangement at prevailing market price. So far the initiative has provided 40 million persondays employment to the disadvantaged, particularly tribals and marginal farmers, and covered an area of 90,681 ha involving more than 45,000 farmers.

Source: Based on contents of ITC reports and website-ITC Paperboards and Specialty Papers Division

the rural entrepreneurs in setting up small-scale or micro forestry enterprises to provide new avenues of improving the livelihood opportunities of the rural poor. Improvement in economic status of rural people will help in institutionalization of the joint venture of the industry and the community.

Industry may also even seriously consider bringing present unused vacant lands in the factory or industry complexes under tree cover which would help in increasing CO_2 removals. Increasing productivity of present green cover in such complexes can also enhance the present sequestration capability of India's forest and tree cover.

Industry on its part is willing to contribute in enhancing the mitigation potential of forestry sector, but would expect supportive policy initiatives and financial incentives from the government. Some of the expectations in this regard are listed below[4]:

i. Policy initiatives to encourage participation of the industry in forestry mitigation actions should have long term perspective corresponding to the longer gestation period of the actions.
ii. Positive incentives should be provided for reducing carbon footprint through afforestation, reforestation or other carbon sequestration action(s).
iii. Tax incentives should be given to the industry for investment in research and development initiatives leading to enhanced mitigation in forestry sector.
iv. Concessional power and loans on flexible and easy terms should be made available to the farmers.
v. Transit and felling regime relating to the trees grown by farmers on non-forest lands should be rationalized.
vi. Wood import should be disincentivized.

12. COORDINATING AND IMPLEMENTING AGENCIES

Government of India in the Ministry of Environment and Forests will be the central nodal agency for guiding, coordinating and monitoring implementation of the mitigation and adaptation options described in this chapter. At the State level, this role will be discharged by the Forest Departments.

13. VALUE OF ADDITIONAL MITIGATION ACTIONS IN AGGRESSIVE SCENARIO

Additional forestry options outlined in the Aggressive Scenario would result in capturing of additional 63.7 m tonnes CO_2eq which is worth USD 764.40 million @ USD 12 per tonne of CO_2eq [5] = Rs 3,822 crore annually. If we take into account the present carbon service of 138 mt CO_2eq being provided by the forestry sector every year (Kishwan et al. 2009), the total mitigation service (forestry) would be worth **Rs 12,102 crore annually[6]**.

14. COSTS OF ADDITIONAL ACTIONS/ REQUIREMENT OF FINANCES FOR AGGRESSIVE SCENARIO

Actions enumerated in paragraph 5 of this report are estimated to cost Rs 11,630 crore every year over the action period of 9 years. The total amount required for the 9 year period will be Rs 104,670 crore. Break-up of the annual cost of Rs 11,630 crore is given below:

Addition of 1 mha @ Rs 50,000/- per ha=1mha*50,000
=Rs 5,000 cr yr^{-1}

Upgradation of 2 mha of forest land
@ Rs 20,000/- per ha=2mha*20,000
= Rs 4,000 cr yr^{-1}

Addition of 100 ha of forest in forest fringe villages
@ Rs 10,000/- per ha=2 mha*10,000
= Rs 2,000 cr yr^{-1}

Improved 1.1 crore cookstoves
@ Rs 300/- per piece **= Rs 330 cr yr^{-1}**

Wood based products as substitutes (lumpsum)
= Rs 300 cr yr^{-1}

Total cost of forestry mitigation actions
= Rs 11,630 cr yr^{-1}

[4] Based on inputs received from Mr. Anil Rajput of FICCI and Ms. Seema Arora of CII. Some of the recommended initiatives may not be practically feasible in near future. For example, curbing wood imports may not be a good idea unless the domestic production is able to meet the domestic needs.

[5] Based on CDM revenue estimates of USD 18 billion for 1.5 Gt CO_2eq emission reduction by U. Sankar, Madras School of Economics (page 18 of 'Policy instruments for Achieving Low Carbon and High Economic Growth in India').
[6] Does not include the contribution of the GIM.

16. RESOURCE MOBILIZATION

Resources will be mobilized on the principle of "Emitter Pays". Possible mechanism for implementing the principle could be a system of compulsory carbon credits purchase by emitting entities equal to their emissions from the State Forest Departments (SFDs), or a carbon tax regime with proceeds going to the carbon service providers including the SFDs in proportion to the quantum of carbon service provided. In any case, the private sector is expected to be the biggest financier of the forestry mitigation options or actions. Payment due from agricultural sector will need to be paid by the central government. Break-up of resource mobilization is as under:

a. Private sector= Rs 8,350 crore[7]
b. Government = Rs 3,280 crore in addition to present level of funding
c. REDD-plus funds from UNFCCC (no estimates till culmination of negotiations)[8]

Total = Rs 11,630 cr yr^{-1}

15. IMPACT OF FORESTRY MITIGATION ACTIONS ON EMISSION INTENSITY

Athematically, percentage reduction in overall Emission Intensity (EI) due to contribution of forestry options mentioned heretofore would be equal to the additional offsetting capacity of 5.2% generated because of implementation of these options by 2020. (WG7 of the Expert Group may please comment).

16. REDD-PLUS

Negotiations on REDD+ in UNFCCC are slowly but steadily moving towards an agreed outcome. The understanding on methodological issues relating to estimation, reporting and verification of forest carbon stocks, and for reporting on safeguards for rights of local communities has tremendously improved. The crucial and central issue of financial support for full implementation of REDD+ results based actions undertaken and proposed to be undertaken by developing countries is yet to be resolved as there is no unanimity of views amongst the Parties on the complete set of options for the purpose. While India, like most other countries favours a flexible combination of market and non-market based approaches, a few countries notably Brazil, Bolivia and Tuvalu do not support the market based mechanism for incentivizing REDD+ actions. Negotiations may still take some more time to culminate in an agreement on all issues- financial as well as methodological. However, the country should be well prepared with requisite technical and infrastructural backup and support to meet the standards of forest carbon stock estimation, reporting and verification. For this, it will be necessary to put in place a national REDD+ framework. Based on India's submissions to the UNFCCC, outlines of the possible framework are given below.

National Strategy:[9]

India's national REDD+ strategy will focus on actions that will enhance and improve the forest and tree cover of the country thereby augmenting all forest ecosystem services including the carbon service.

Initiatives like Green India Mission (GIM) and National Afforestation Programme (NAP), together with programmes in sectors like agriculture and rural development will be integrated with respect to national level accounting of forest carbon stocks. These efforts are estimated to add at least 2 million tonnes of carbon incrementally, and post 2020, the forest and tree cover will be adding at least 20 million tonnes (mt) of carbon or 73 mt CO_2eq every year. This would require an investment of Rs. 90 billion (USD 2 billion) every year for 10 years. Country expects substantial part of this investment under REDD+ financial support from UNFCCC.

Institutional Mechanism for REDD+ at National Level

The Government of India has established a REDD+ Cell in the Ministry of Environment and Forests having the task of coordinating and guiding REDD+ related actions at the national level, and to discharge the role of guiding, and collaborating with the State Forest Departments (SFDs) to collect, process and manage all relevant information and data relating to forest carbon accounting. National REDD+ Cell would also guide formulation, development, funding, implementation, monitoring and evaluation of REDD+ activities in the States. The Cell will assist the Ministry of Environment and Forests and its appropriate agencies in developing and implementing appropriate policies relating to REDD+ implementation in the country. Proper functioning of the Cell will require posting of some scientific and technical staff. Funds for operationalizing the Cell by providing basic minimum infrastructure including staff should be provided in the 12[th] FYP.

Institutionalization of National level forest carbon stocks accounting

It is not adequate to have only the capability for estimation (measuring) and reporting of the forest carbon stocks, but it will be essential to institutionalize such national level accounting. For this purpose, the roles and responsibilities of different organizations will need to be clearly defined.

In so far as national forest carbon stocks accounting is concerned, the Forest Survey of India (FSI) has adequate capability in this field. Backed by its expertise in estimation of forest and tree cover in the country, the FSI is capable of handling this national responsibility. The FSI will act as the Lead Institution for the country and will have a networking approach involving Indian Council of Forestry Research and Education (ICFRE), Indian Institute of Remote Sensing (IIRS), Indian Institute of Science (IISc), Wildlife Institute of India (WII), and any other

[7] Proportion of financial contribution proposed to be based on proportion of 1994 level GHG contribution of different sectors (Ref: GOI, NATCOM 1) excluding Agriculture. Industry= 52%, Transport= 7%, Municipalities/Local Bodies= 10%, Agriculture= 31%.

[8] REDD-plus negotiations on policy, financial and technological aspects have not yet reached final stage, and, therefore, no estimates about inflow of financial incentives can be made

[9] The national strategy takes into account only the current programmes and schemes, and the GIM, and does not include other activities included in the Aggressive Scenario.

organization that FSI deems fit to co-opt.

India's future strategy in this regard is to devolve more and more responsibility on the State Forest Departments (SFDs) to carry out the assessment and estimation of forest carbon stocks (FCS) in conjunction with the biennial exercise of assessment of forest and tree cover (FTC).

This is considered essential to improve the precision level for estimation of FCS as the State Governments can cover more number of sample points, than that being covered by the FSI at present due to constraints of time, finances and inadequate number of technical experts. In future, the SFDs can take the responsibility of carrying out the inventories for FTC and FCS by more effectively utilizing the services of their Remote Sensing Centres/Space Application Centres. Adequate resources may be budgeted in the 12th FYP for building requisite capacity and capability of the SFDs to gradually take on the responsibility of making inventories of green cover and forest carbon stocks.

At National level, further work on (i) technological and methodological issues, and (ii) policy and definitional issues is required so as to be in readiness for meeting the future stipulations of estimation and reporting of forest carbon stocks likely to be prescribed by the UNFCCC on REDD+. Review and fine-tuning of technological, methodological and connected infrastructural capabilities are considered to be essential for operationalizing the national level FCS accounting.

Local communities and co-benefits of forest ecosystem services including carbon service

While moving forward towards implementation of REDD+, participation of local communities with compulsory representation of women will be the central theme. Government of India is committed to ensure that full and adequate incentives from REDD+ go to the local communities as and when these become available. In India's context, the forest will not be managed for carbon service alone, but for all the ecosystem services that are flowing to the local community from the forest. Incentives for carbon service will be an add-on to the benefits that the local communities are already receiving from the forest ecosystems. In future, whenever the REDD+ incentives begin to flow, these will be transmitted from the Centre to State Governments and then to District level. The State Government and District level authorities will plan and manage the flows further down to the local communities. Broad guidelines for flow of incentives from the Government of India (GOI) to State Governments will be developed by the Ministry of Environment and Forests (MoEF). In the longer term, guidelines for flow of funds from district to the lower levels will also be developed. In the interim period, the States/Districts will make and adopt their own procedures and arrangements for the purpose with prior approval of the MoEF.

National forest reference level

Highest priority for the country is to fix the reference level for carbon stocks in its forest and tree cover with a view to making assessment, monitoring, reporting and verification of i) baseline forest carbon stocks, and ii) incremental forest carbon stocks India considers that the reference level in essence will be a baseline forest carbon stocks position corresponding to a specific year, which may be called as the zero year. The zero year would need to be fixed with consensus amongst intra-country stakeholders which would include the Central Government, State Governments, forest experts and scientists, local community and civil society. It is presumed that the starting point for fixing a forest reference level will be agreement on the zero year backed by sound logic, timeseries of scientific historical data, and milestones of relevant legislation and/or policy prescriptions. The reference level would need to be agreed at the technical level, i.e., amongst scientific organizations, and subsequently at the government level involving the Central and the State Governments. Government of India may form a consortium of following scientific organizations for evolving consensus on a reference level, and zero year:

- Indian Institute of Science, Bangalore
- Forest Survey of India, Dehradun
- Indian Council of Forestry research and Education, Dehradun
- Wildlife Institute of India, Dehradun
- Indian Institute of Remote Sensing, Dehradun
- National Remote Sensing Centre, Hyderabad
- Centre for Environmental Education, Ahmedabad
- Central Government, Ministry of Environment and Forests (REDD+ Cell)
- State Forest Departments

Safeguards

Developing countries including India are expected to follow safeguards, as mandated in relevant decision of the UNFCCC with a view to ensuring i) full participation of indigenous peoples, local communities and other stakeholders, and ii) conservation of natural forests and biodiversity in implementing the REDD+ activities. India intends to ensure that all REDD+ incentives available from international sources will flow fully and adequately to the local communities which participate in management or manage the forest resources or are dependent on the forest resources for sustenance of their livelihood. Part of the incentives are expected to be invested in conservation and improvement of the ecosystem services like biodiversity and non-timber forest produce (NTFP). Local communities would be encouraged to develop microplans to incorporate such priorities.

19. CONCLUSIONS

It is beyond doubt that forests and tree plantations are playing an important positive role in mitigating, and adapting to, climate change. But, more important is the fact that this sector still has sizable untapped potential of mitigation which can be easily accessed provided adequate finances are made available for the purpose. This paper outlines three investment and action scenarios, viz, (a) BAU Scenario, (b) Accelerated Scenario, and (c) Aggressive Scenario. Cost requirement of the three scenarios during the 12th FYP is given below:

a) BAU Scenario : Rs 25,000 crore
b) Accelerated Scenario : Rs 48,000 crore
c) Aggressive Scenario : Rs 100,335 crore

Additional activities included in the Aggressive Scenario that can contribute significantly in providing enhanced mitigation service over and above the BAU and Accelerated (GIM) scenarios in forestry sector are following:

i) Increase in forest and tree cover by 1 mha every year:
By afforesting/reforesting 1 mha of area every year, additional sequestration of **13.2 mt CO_2eq every year** can be achieved.

ii) Creation of 100 ha of forest in 170,000 forest fringe villages:
This initiative will be able to capture additional **12.5 mt CO_2eq every year**.

iii) Improvement in forest cover:
Upgradation of 1 mha of open forest to medium dense forest, and another 1 mha of medium dense forest to very dense forest category can help in capturing an additional **6.6 mt CO_2eq every year**.

iv) Harvested wood products as substitutes: If every year, 1 million cubic m of metallic hardware products are replaced by wood based products, an additional emissions reduction of **2 mt CO_2eq every year** can be achieved.

v) Replacement of office and domestic metal and plastic based furniture: Replacement of all metallic and plastic furniture by wood based products is capable of reducing emissions by **3 mt CO_2eq every year**.

vi) Use of improved wood burning cookstoves: This is a very potent initiative and has the capability of reducing emissions by **26.4 mt CO_2eq every year** (NSSO. 2002).

All the aforesaid options of Aggressive Scenario if taken up simultaneously have the potential of capturing an additional **63.7 mt CO_2eq every year** 2020 onwards, and thus neutralizing this much quantum of emissions annually. The mitigation service thus provided will be able to offset an additional **5.2% of India's emissions at 1994 levels.** This performance can further be improved if industry comes forward as part of its social corporate responsibility, and creates awareness and motivation amongst village communities in raising tree plantations and orchards on private and community lands with a view to improving the socio-economic conditions of the rural people, and simultaneously contributing in climate change mitigation and adaptation by effecting increase in the carbon sink of forest and tree cover in the country. Needless to say, the initiative would be a win-win situation for both, local community as well as industry. The former will benefit by enhanced income generation and latter by having access to increased availability of the wood based industrial raw material.

Total cost of additional forestry mitigation actions in Aggressive Scenario is estimated at Rs 11,630 crore per year, whereas the value of mitigation after 2020 will be worth Rs 12,102 crore every year. Resource mobilization is proposed to be based on the concept of "Emitter Pays", and therefore, most investment is expected to come from industry and municipal and local bodies with agricultural sector being the only exception.

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SOURCE: http://www.naturallywood.com/climate_change.aspx?id=69 (assessed on 22nd March, 2010)

Annexure 1

Forests and Climate Change Research Programme
SHORT TERM RESEARCH

	Proposed Short-term Research Projects	Duration	Budget (Crore)	Possible lead and collaborating institutions
1	**Impacts and Adaptation to climate change in forests and other natural ecosystems** Adapt and develop dynamic vegetation models relevant to tropical and sub-tropical forest types, plantations as well as other natural ecosystems such as wetlands and grasslands	5 years	2 crore	IISc
	Initiate focused short term field ecological and physiological studies in selected forest type sites to generate parameters for various plant functional types required for dynamic vegetation models	5 years	5 crore	IISc, KFRI
	Initiate studies to assess the likely impacts of climate change on natural ecosystems and identify vulnerable and sensitive ecosystems such as mangroves, other forests, montane grasslands, plantation systems, etc	5 years	5 crore	IISc, GB Pant Institute, WII, MSSRF
	Develop adaptation framework relevant to forest and grassland ecosystems and develop adaptation strategies, practices and management systems	5 years	5 crore	ICFRE
	Plan and implement *pilot* adaptation projects to demonstrate effectiveness of adaptation practices	5 years	50 crore	ICFRE & state forest department/s
2	**Socio-economic adaptation among forest-dependent people to climate change** Assess the vulnerability of forest-dependent communities to climate impacts	5 years	2 crore	IIFM, Universities
	Develop programmes to enhance adaptive capacity of forest-dependent communities.	5 years	5 crore	ICFRE
3	**Policy research to assist policy making and UNFCCC negotiations on forestry issues** Assessment of implications of Bali Action Plan of REDD, forest conservation and sustainable management of forests for India	3 years	1 crore	ICFRE, MoEF
	Development of methodological understanding of carbon stock changes under REDD, forest conservation and sustainable management activities	3 years	2 crore	ICFRE/FSI
	Consultation workshops and development of Indian policy framework for UNFCCC negotiations.	3 years	1 crore	ICFRE

4	**Carbon inventory and mitigation studies** Developing models for assessing carbon sequestration and mitigation potential of different forestry and plantation activities.	5 years	2 crore	IISc
	Developing rates of changes in carbon pools under different forest and plantation systems to assist development of CDM projects, based on cross-sectional studies	5 years	5 crore	ICFRE
	Developing emission factors for GHG inventories in land use sectors, forests, grasslands, wetlands, etc.	5 years	10 crore	ICFRE
5	**Assessment of the ecological and economic potential of biofuels for climate mitigation and energy security:** There has been a lot of controversy surrounding the use of "biofuels" as a strategy for climate mitigation and ensuring energy security for our rapidly growing economy. A sound assessment of the economic and ecological dimensions of biofuel production has to be carried out before we adopt biofuels on a large scale. Among aspects to be studied would include • Assessment of the mitigation potential of different bioenergy technologies • Estimating the land availability for biomass feedstock (woody biomass and oil seeds) production for energy • Competition for land for carbon sequestration vs bioenergy for fossil fuel substitution • Assessment of impacts of climate change on sustainable biomass feedstock production for energy • Competition of land for biofuel crops vs food crops and implications for food grain prices in the long term.	5 Years	5 crore	ICFRE, MNRE, Forestry universities

LONG-TERM RESEARCH

Sl. No.	Proposed Research Projects	Duration	Budget	Lead and collaborating institutions
1	Vegetation dynamics in preservation plots with reference to climate change Permanent preservation plots act as miniature labs for observing and understanding the interaction of plant species and communities with climatic variables. These are valuable resources to study the impact of climatic factors over time periods of decades in different forest types or sub-types. These should be accessed from permanent field laboratories and infrastructure such as weather stations in order to derive a holistic scientific understanding of vegetation dynamics. ICFRE through its institutions maintains a record of over 195 preservation plots across the country. IISc has been maintaining a large 50 hectare plot and 20 smaller plots in the Nilgiris where high resolution data are being collected. Such plots could form the core of long-term studies on a variety of subjects related to climate change. Some of the aspects to be studied could include: a) Physiological ecology (photosynthesis, respiration, water-use efficiency) of tree species in relation to climatic variables b) Sensitivity of plant performance (growth, mortality, etc) to climatic variability c) Forest/grassland community response to changing climate d) Long-term forest dynamics (recruitment, mortality, growth) in relation to climate e) Landscape-level changes in ecosystems and biomes to changing climate f) Carbon stock changes at various levels from communities to landscapes A network of such sites following international standards in data collection, analyses and interpretation would form the backbone of research efforts in several subjects.	10 Years	40 crore	ICFRE and Institutes, BSI, IISc.

2	**Determine sustainable harvest levels for non-timber forest products under changing climate** A variety of non-timber forest products are important sources of livelihoods of rural people in India. There are already fears that many of these are being harvested in a non-sustainable manner. Changing vegetation in response to changing climate could further exacerbate the situation for some of these products while it could also have positive outcomes for other products. Experiments and observations are needed to evaluate the likely impacts of climate change on NTFP species in order to determine sustainable levels of harvest under a changing climate.	10 years	10 crore	ICFRE, Universities, IISc, ATREE
3	Estimation and monitoring of carbon dynamics for different agro-ecological zones Long term studies are proposed in different forest types, plantations as well as other eco-systems such as grasslands for estimation of total biomass that includes above ground biomass (trees, shrubs and herbs), below ground biomass (roots), forest floor biomass, microbial biomass and soil organic carbon etc. Changes in carbon stocks with changes in land use will also be estimated. The study will give a total picture of biomass and carbon dynamics at the landscape scale and would be useful in suggesting manipulations for maintaining optimal carbon stocks.	10 Years	10 crore	ICFRE and institutes, IISc. IIRS, NRSA
4	Updating forest inventory data on regular basis The present inventory, mapping and assessment of forest and tree cover in the country being carried out by Forest Survey of India should continue and be strengthened in order to derive more useful information on species and communities in the climate change context. Other institutions with expertise in vegetation ecology should interface with this programme in order to derive the maximum benefits from the inventory and mapping. The budget provided is mainly for institutions other than FSI.	10 Years	10 crore	ICFRE Institutes, FSI
5	*Ex-Situ* conservation of valuable germplasm of forest and plantation species The possibility of extinction of significant numbers of species makes it imperative for the preservation of germplasm of at least the less common plant species found across the Indian forests, especially the endemics, as well as the commoner species from various latitudes and altitudes for future introduction and restoration programmes. At the same time the original germplasm of exotics such as Eucalypts, Poplars and Casuarinas etc. used in plantations is eroding due to neglect. There is need for maintaining repositories and conservation areas of genetic variability of indigenous and exotic plantation species.	5-10 Years	20 crore	NBRI, TBGRI, ICFRE and Institutes, SFRIs, FBIs
6	**Effect of climate change on tree growth and wood formation, possible physiological and anatomical changes** Changes in temperature and precipitation could alter the process of tree growth, in particular the formation of wood. This has implications for the quality of timber produced and its marketability. Research on these aspects could help develop improved methods of raising trees for wood products	5-10 Years	5 crore	ICFRE and Institutes
7	**Development of appropriate silviculture practices and determination of optimum stocking level.** Natural distribution range of many native species is likely to be altered by the projected climate change. Existing 150 year old silvicultural systems may no longer hold good for maintenance of these forests in a sustainable manner. There is need to undertake pilot studies on this important aspect of silvicultural research. The study will also contribute in selection of tree species best adapted to existing sites, i.e., matching species and site.	10 Years	10 crore	ICFRE and Institutes SFDs

8	Studies on longevity of harvested wood products (HWPs) A large range of products from paper and pulp to plywood, plyboards, particle boards and other durable wood products like door window frames and shutters, wooden flooring, furniture, wooden artefacts and other household items is produced from woody material. Studies on the longevity of these wood products have not been conducted, and only rough estimates about life of these products are quoted. The durability of HWP will be an important agenda of climate negotiations in the context of long-term carbon storage.	10 Years	10 crore	ICFRE and Institutes, (FRI and IWST) CPPRI Saharan Pur, IPRITI
9	Developing and using models to project vegetation dynamics including shift in forest types and carbon fluxes of forest types/ subgroup types as well as species distributions	10 Year	10 crore	ICFRE, IISc., IIRS
10	**Modern Forest Fire Management and Integrated Pest Management** Climate change is expected to cause changes in fire frequencies as well as incidence of pest and disease attacks in forest ecosystems. Investigations on risk of fire and attacks by pests and diseases in relation to climatic variability and change would help develop robust fie and integrated pest management plans for forests.	10 Years	10 crore	ICFRE and Institutes/ ISRO/NRSA/ Forestry Universities

(FOOTNOTES)

[1] Assimilation of atmospheric carbon, to the extent of approximately 10 tonnes CO2 per hectare, can be realized by Jatropha plantations!**Syamala Ariyanchira. 2005.** Biodiesel - Is Jatropha India's Solution? http://www.frost.com/prod/servlet/market-insight-top.pag?docid=36738184 (accessed on 22nd March 2010). However, availability and diversion of land for biodiesel plantation is a debatable question in India in view of the higher priority for ensuring food security.

[2] The additional carbon sequestration potential under the project scenario for 30 years is estimated to be 12.8 t C/ha/year inclusive of harvest regimes and carbon emissions due to biomass burning and fertilizer application. Considering carbon storage in harvested wood, an additional 45% carbon benefit can be accounted. P. Sudha, V. Ramprasad, M. D. V. Nagendra, H. D. Kulkarni and N. H. Ravindranath. 2007. Development of an agroforestry carbon sequestration project in Khammam district, India. Mitigation and Adaptation Strategies for Global Change 12(6): 1573-1596.

[3] The Mission document is not yet final. However, it is presumed that the strategies being outlined in this report would subsume the mitigation potential of the Mission.

Climate Change and Forests in India

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PART-1

Impact of Climate Change on Indian Forest

1. INTRODUCTION

Climate is one of the most important determinants of vegetation patterns globally and has significant influence on the distribution, structure and ecology of forests[1]. Several climate–vegetation studies have shown that certain climatic regimes are associated with particular plant communities or functional types[2]. It is therefore logical to assume that changes in climate would alter the distribution of forest ecosystems. Based on a range of vegetation modeling studies, the IPCC[3] suggests potential forest dieback towards the end of this century and beyond, especially in tropics, boreal and mountain areas[4,5]. The most recent report from International Union of Forest Research Organization[6] paints a rather gloomy picture about the future of the world forests in a changed climate as it suggests that in a warmer world the current carbon regulating services of forests (as carbon sinks) may be entirely lost as land ecosystems could turn into a net source of carbon dioxide later in the century.

India is a key country with respect to tropical forests, with around 20% of the geographic area classified as forests[7]. A recent study[8] has a detailed discussion on the current status of forests in India including the forest area, carbon stocks in Indian forests, and aforestation trends in India. Another study[9] using BIOME4 vegetation model concluded that 77% and 68% of the forested grids in India are likely to experience shift in forest types due to climate change under A2 and B2 scenarios, respectively. Impacts of climate change on forests have severe implications for the people who depend on forest resources for their livelihoods. India is a mega-biodiversity country. With nearly 173,000 villages classified as forest villages, there is a large dependence of communities on forest resources in India[10]. India has a large afforestation programme of over 1.32 Mha per annum[11], and more area is likely to be afforested under programmes such as 'Green India Mission' and 'Compensatory Afforestation Fund Management and Planning Authority' (CAMPA). Thus it is necessary to assess the likely impacts of projected climate change on existing forests and afforested areas, and develop and implement adaptation strategies to enhance the resilience of forests to climate change.

The present study investigates the projected impacts of climate change on Indian forests using a dynamic global vegetation model (DGVM) and for the short (2021-2050) and long (2071-2100) term periods. It specifically assesses the boundary shifts in vegetation types, changes in NPP (Net Primary Productivity) and soil carbon stocks, as well as the vulnerability of existing forests in different regions to future climate change.

2. METHODS

The impacts of climate change on forests in India are assessed based on the changes in area under different forest types, shifts in boundary of forest types and NPP. This assessment was based on: (i) spatial distribution of current climatic variables, (ii) future climate projected by relatively high-resolution regional climate models for two different periods for the A1B climate change scenario, and (iii) vegetation types, NPP and carbon stocks as simulated by the dynamic model IBIS v.2 (Integrated Biosphere Simulator)[12]

2.1 Vegetation model

The dynamic vegetation model IBIS is designed around a hierarchical, modular structure. The model is broken into four modules namely: 1) the land surface module, 2) Vegetation phenology module, 3) Carbon balance module and, 4) Vegetation dynamics module. These modules, though operating at different time steps, are integrated into a single physically consistent model. The state description of the model allows trees and grasses to experience different light and water regimes and competition for sunlight and soil moisture determines the geographic distribution of plant functional types and the relative dominance of trees and grasses, evergreen and deciduous phenologies, broad leaf and conifer leaf forms, and C3 and C4 photosynthetic pathways. IBIS was selected for the exercise as it is DGVM, and is well-validated for India[8].

2.2 Input data

IBIS requires a range of input parameters including climatology as well as soil parameters. The main climatology parameters required by IBIS are: monthly mean cloudiness (%), monthly mean precipitation rate (mm/day), monthly mean

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relative humidity (%), monthly minimum, maximum and mean temperature (⁰C) and wind speed (m/s). The main soil parameter required is the texture of soil (i.e., percentage of sand, silt and clay). The model also requires topography information.

Observed climatology is obtained from CRU (Climatic Research Unit, Univ. of East Anglia)[13], while soil data was obtained from IGBP[14]. For climate change projections, RCM outputs from Hadley centre model HadRM3 were used[15]. The climate variables for future scenarios were obtained using the method of anomalies. Briefly, this involved computing the difference between the projected values for a scenario and the control run of the HadRM3 model, and adding this difference to the value corresponding to the current climate as obtained from the CRU climatology. The Climate Data Analysis Tool (CDAT)[16] was used for data processing and generation of various maps and plots. All input data was re-gridded to a 0.5⁰ x 0.5⁰ (lat x lon) resolution, and used for the run.

2.3 Scenarios of climate change

In this study, we consider only SRES scenario A1B. Further, two future time-frames are considered: 1) Timeframe of 2021-2050 (atmospheric CO_2 concentration reaching 490ppm). This is also labeled as "2035", for brevity (which is the median of the period); 2) Timeframe of 2071-2100 (atmospheric CO_2 concentration reaching 680ppm) which is labeled as "2085". We compare the results of these with the 'baseline' scenario, which represents the simulation of vegetation using the 1961-91 observed climatology. 'Baseline' is also referred to as either 'reference' or 'control' case. The A2 and B2 scenario results for timeframe of 2071-2100 are detailed in another recent publication[8]

3. MODEL VALIDATION

We simulated the current vegetation pattern, NPP, biomass and soil carbon over India using the IBIS model driven by observed climatology.

4. IMPACTS OF CLIMATE CHANGE ON FOREST TYPES AND EXTENTS

4.1 Changes in the distribution of forests

The vegetation distribution simulated by IBIS for baseline, and A1B scenario in the simulation grids are shown in Figure 1. One can notice that there is an expansion of tropical evergreen forests (IBIS vegetation type 1) in eastern India plateau in the A1B scenario. The same trend can be seen in the Western Ghats. It is interesting to note that there is almost no vegetation type change in the north-east. Further, there is a slight expansion of forests into the western part of central India. One caveat to the expansion trend of forests (like tropical evergreen forests) is the assumption that forests are not fragmented, and there is no dearth of seed-dispersing agents. In the real world, forests are fragmented (vastly due to anthropogenic pressures), and seed dispersal may not be efficient in the view of loss or reduction in number of dispersal agents due to human habitation pressures and climate change[17]. As the population of seed-dispersing agents may decline, predicted forest expansion is not guaranteed.

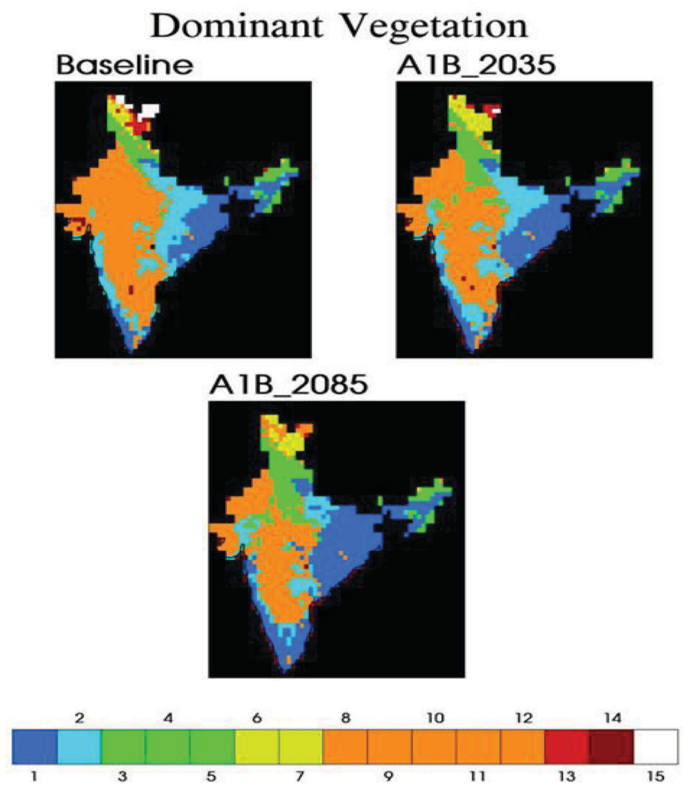

Figure 1: **Forest type distribution and extent simulated by IBIS for the baseline case and A1B (2035 and 2085) scenarios. (VT – refers to Vegetation Types. The numbers refer to the following vegetation types 1: tropical evergreen forest / woodland, 2: tropical deciduous forest / woodland, 3. temperate evergreen broadleaf forest / woodland, 4: temperate evergreen conifer forest / woodland, 5: temperate deciduous forest / woodland, 6: boreal evergreen forest / woodland, 7: boreal deciduous forest / woodland, 8: mixed forest / woodland, 9: savanna, 10: grassland/ steppe, 11: dense shrubland, 12: open shrubland, 13: tundra, 14: desert, 15. polar desert / rock / ice)**

Another interesting observation is the shrinkage in the polar desert / rock ice in the Himalayas to the (mostly) tundra type. This is consistent with higher projections of warming in high-altitude areas[3].

4.2 Vulnerability of Indian forests

Forests in India are already subjected to multiple stresses including over extraction, insect outbreaks, fuelwood collection, livestock grazing, forest fires and other anthropogenic pressures. Climate change will be an *additional* stress, which may have an over arching influence on forests though other stresses (insect and pest incidence, diseases, etc). Here, we develop a vulnerability map and assess the vulnerability of different forest types and regions, due to projected climate change. A grid is marked vulnerable if there is a change in vegetation, as simulated between the baseline and the future (both 2035 and 2085, and A1B SRES scenario, in this case) vegetation. This means that the future climate *may not be optimal to the present vegetation* in those grids. The distribution

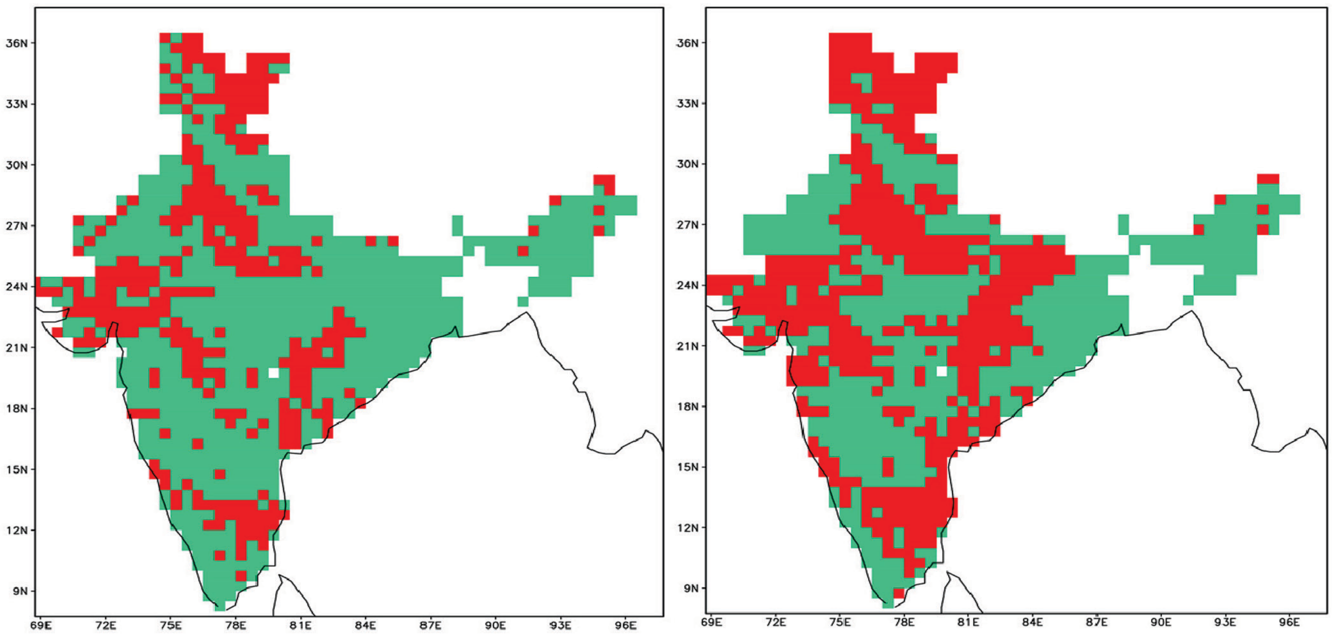

Figure 2: **Vulnerable grids (marked red) in the A1B scenario. Left panel is for timeframe of 2021-2050. Here, 326 (30.6%) out of a total number of 1064 grids are projected to be vulnerable. The right panel is for the timeframe of 2071-2100. In this case, 489 (45.9%) grids are projected to be vulnerable. In turn, all forest areas in such vulnerable grids are projected to be vulnerable to climate change**

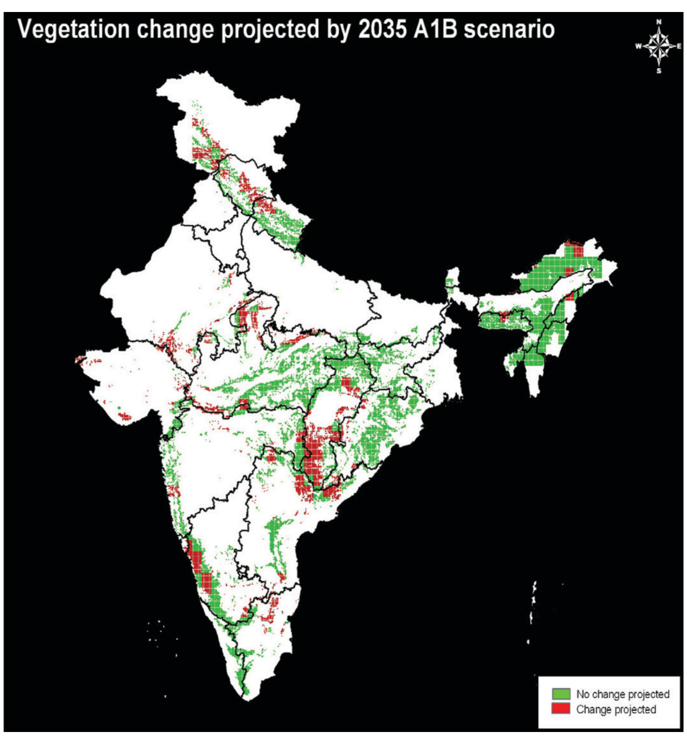

Figure 3: **All forested grids in India are shown in color (red or green): red indicates that a change in vegetation is projected at that grid in the time-period of 2021-2050, and green indicates that no change in vegetation is projected by that period. The black lines indicate state boundaries**

of this vulnerability the country is shown in Figure 2.

A digital forest map of India[7,8] was used to determine the spatial location of all forested areas. This map was based on a high-resolution mapping (2.5' by 2.5'), wherein the entire area of India was divided into over 165,000 grids. Out of these, 35,899 grids were marked as forested grids (along with the forest density and the forest type). The projected change in vegetation information was combined with the spatial location of FSI grids (Figures 3 and 4).

The figures 3 and 4 show the forested grids where a vegetation shift is projected by IBIS. For example, in 2035, one can see that most of the grids are projected to undergo change in the state of Chhattisgarh. Other forested areas that may be vulnerable to climate change are the northern parts of the Western Ghats (in the north part of Karnataka) and the northern parts of the forests of the Himalayas.

- The forests in the central part of India, especially the north-western part of India are highly vulnerable. There are regions of vulnerability surrounded by non-vulnerable regions in that area.
- There are relatively few areas in the northeastern part of India that have a high vulnerability. This low vulnerability in this region is because climate is predicted to get hotter and wetter there which is conducive to the existing vegetation types (such as tropical evergreen forests).
- A significant part of the Himalayan biodiversity hotspot that stretches along the north-western part of India along the states of Punjab, Jammu and Kashmir and Himachal Pradesh is projected to be highly vulnerable. This may be mostly

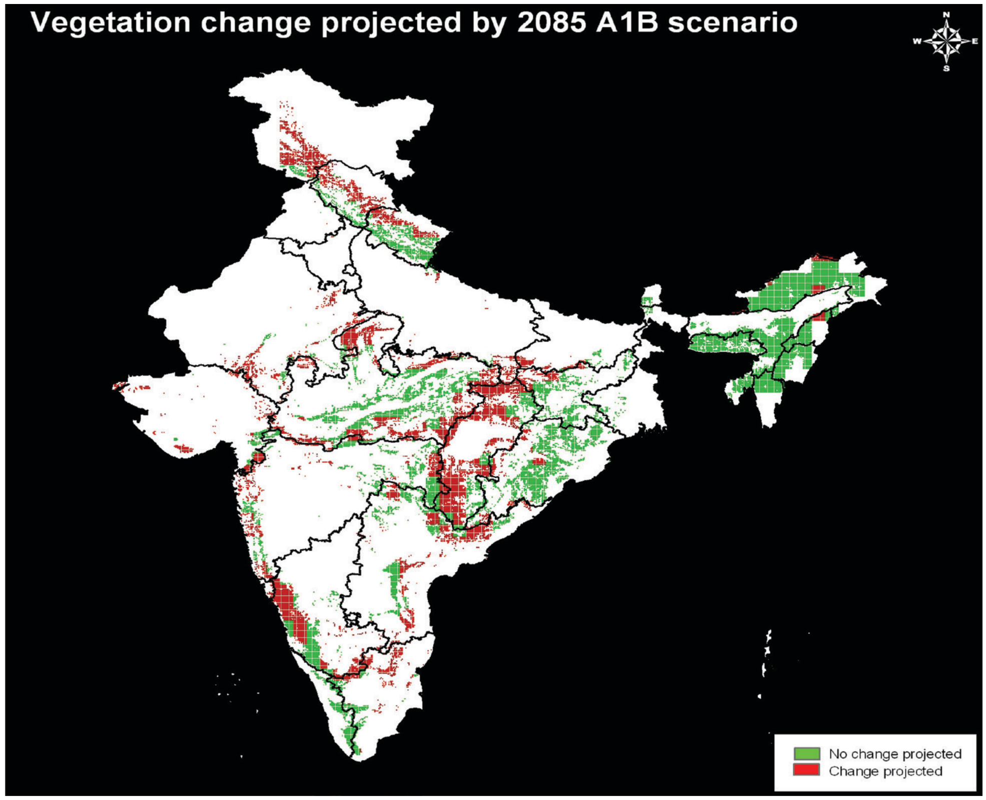

Figure 4: **All forested grids in India are depicted in color (red or green): red indicates that a change in vegetation is projected at that grid in the time-period of 2071-2100, and green indicates that no change in vegetation is projected by that period. The black lines indicate state boundaries**

attributed to the higher elevation of these regions. Our studies have shown that these regions will experience higher levels of warming.

- Northern and central parts of the Western Ghats seem to be vulnerable to climate change. Northern parts of the Western Ghats contain significant extent of open forests, which may drive up the vulnerability. Vulnerability in the central part of the Ghats is likely caused by the negligible precipitation increase over there (with more than 3ºC rise in temperature). The southern Western Ghats region appears to be quite resilient as IBIS simulates mostly tropical wet evergreen forests which, according to the simulations, are likely to remain stable.

5. IMPLICATIONS OF CLIMATE IMPACT ASSESSMENT

The assessment of climate impacts showed that at the national level, about 45% of the forested grids are likely to undergo change. Vulnerability assessment showed that the vulnerable forested grids are spread across India. However, their concentration is higher in the upper Himalayan stretches, parts of central India, northern Western Ghats and Eastern Ghats. In contrast, northeastern forests, southern Western Ghats and the forested regions of eastern India are estimated to be least vulnerable. Currently, within the forested area of 69 Mha only 8.35 Mha is categorized as very dense forest. More than 20 Mha of forest is monoculture and more than 28.8 Mha of forests are fragmented (open forest) and have low tree density (See FSI report of 2009[7]). Low tree density, low biodiversity status as well as higher levels of fragmentation contribute to the vulnerability of these forests.

Western Ghats, though a biodiversity hotspot, has fragmented forests in its northern parts. This makes these forests are additionally vulnerable to climate change as well as to increased risk of fire and pest attack. Similarly, forests in parts of western as well as central India are fragmented and are having low biodiversity. At the same time these are the regions which are likely to witness a high increase in temperature and either decline or marginal increase in rainfall.

We notice that most of the high-altitude mountainous forests (sub-alpine and alpine forest, the Himalayan dry temperate forest and the Himalayan moist temperate forests) are susceptible to the adverse effects of climate change (Figure 3 and 4). This is because climate change is predicted to be larger for regions that have higher elevations. There is a need to explore win-win adaptation practices in such regions such as anticipatory plantations, sanitary harvest, and pest and fire management.

Forests are likely to benefit to a large extent (in terms of NPP) in the northern parts of Western Ghats and the eastern parts of India, while they are relatively adversely affected in western and central India (Figure 3 and 4). This means that afforestation, reforestation and forest management in northern Western Ghats and eastern India may experience carbon sequestration benefits. Hence, in these regions, a species-mix that maximizes carbon sequestration should be planted. On the other hand, in the forests of western and central India, hardy species which are resilient to increased temperature and drought risk should be planted and care should be taken to further increase forest resilience.

Some of the potential recommendations with respect to climate change and forest sector include the following:

- There is a need for climate impact and vulnerability assessment using multiple global climate models as well as multiple dynamic global vegetation models. This may require generation of climate, vegetation, soil and water related data for different forest types of India.
- There is a need to develop tropical forest or India-specific dynamic global vegetation models which will require generation of a number of plant physiological parameters.
- India should initiate long-term monitoring of vegetation response to changing climate in the long-term.
- Since nearly half the forested grids are projected to experience changes in vegetation type, there is a need for serious consideration of incorporation of climate change in all forest conservation and development programmes, such as 'Greening India Mission'.
- There is a need for developing and implementing adaptation measures to enable forest ecosystems to cope with climate risks. Many "win-win" or "no-regret" adaptation practices could be considered for implementation. A few examples of adaptation practices include:
    - Modifying the forest working plan preparation process, incorporating the projected climate change and likely impacts
    - Initiating research on adaptation practices, covering both conservation and forest regeneration practices
    - Linking Protected Areas and forest fragments
    - Anticipatory planting of species along the altitudinal and latitudinal gradient
    - Adopting mixed species forestry in all afforestation programmes
    - Incorporating fire protection and management practices and implement advance fire warning systems
    - Adopting sanitary harvest practices and thinning.

PART-2

Carbon management in Indian forests: a policy analysis to assess mitigation potential

This study estimates the carbon mitigation and offset potential of a rapid afforestation policy, while a discussion of the impact of carbon pricing on the carbon-offset potential is outside the scope of this article. We analyze this policy under two scenarios: a rapid afforestation rate (i.e., achieving this goal by 2020) and moderate afforestation rate (i.e., achieving this goal by 2030).

1. METHODOLOGY FOR MITIGATION POTENTIAL ASSESSMENT

In this article, we estimate the mitigation potential of the afforestation policy of bringing approximately 33% of the total geographic area of India under forests. According to latest state wise estimates from the NRSA, India has 55.26 Mha of wasteland[18]. As opposed to the use of agricultural land, the use of wasteland does not threaten the food security and livelihood of agricultural communities. In addition, the opportunity cost of wasteland is less than, for example, an agricultural land. Hence, only wastelands are considered for afforestation activities in this study. The steps followed in this study have been enumerated below:

- Step 1: select a suitable mitigation-assessment model;
- Step 2: divide the geographic area into homogeneous zones, for mitigation assessment;
- Step 3: obtain latest area estimates for suitable wasteland categories, for each such zone;
- Step 4: identify land categories suitable for the mitigation activities appropriate for their biophysical and social characteristics – short rotation (SR) plantations (harvested within approximately 10 years of planting) and long rotation (LR) plantations (harvested in approximately 40 years of planting)
- Step 5: obtain the existing area under forest cover in each of the zones under each plantation/forest subcategories;
- Step 6: estimate the gap between India's forest cover target of 33% and the existing forest cover at the national level;
- Step 7: allocate the suitable land for annual afforestation in each of the zones under plantation subcategories under different afforestation policy scenarios;
- Step 8: obtain biomass and soil carbon stocks and growth rates for each of the zones and plantation subland categories from published literature and field ecological studies;
- Step 9: estimate the carbon stock estimates for different periods for the baseline as well as in different afforestation policy scenarios, and the net additional carbon stock changes;
- Step 10: compare and aggregate the carbon stock estimates of the different zones.

2. GCOMAP MODEL

The Generalized Comprehensive Mitigation Assessment Process is a set of models developed by Lawrence Berkeley National Laboratory (LBNL) aimed at estimating the quantity of carbon sequestration achieved for a given year or over a period of years, as well as the financial implications and cost effectiveness of forestry mitigation projects[19]. These models use linear growth rates for biomass and soil carbon increments. It establishes a baseline scenario of land used for potential mitigation activities for the specified time frame, with no additional afforestation. The model usually imposes a carbon price at different rates, and simulates the response of forest and wasteland managers to these price incentives, and estimates additional land brought under the mitigation activity above the baseline level. However, in this study no carbon price has been assumed in either of the scenarios. In the current simulation, the model provides the estimates of the additional carbon sequestration benefits in the alternate policy scenarios in the response to increased afforestation rates, while meeting the annual demand for timber and **nontimber** products.

3. LAND CATEGORIES & ACTIVITIES SELECTED FOR MITIGATION ASSESSMENT

The current assessment is limited to only wastelands, degraded or marginal lands. Wasteland categories are degraded lands that are often unsuitable for crop production. Mitigation activities considered for such land categories are short- and long-rotation (SR and LR, respectively) plantation forestry. As per the observed trend in Indian afforestation programs, two-thirds of the wasteland area was allocated to the SR option, while a third of wasteland was allocated to LR options in each of the AEZs[20]. Scenarios for mitigation potential assessment We have considered the following policy scenarios for this analysis:

Baseline scenario

This assumes that afforestation continues with the current baseline rate of 1.1 Mha/year until the total forested area reaches 108 Mha by 2047. Carbon stock under baseline changes over time in response to new land afforested.

Scenario-2020

This scenario analyses the mitigation potential over the 2010–2030 period. Here, approximately 33% of the geographic area is brought under forest cover by 2020. This scenario assumes rapid afforestation, so that the total forest cover reaches 108 Mha by 2020. The afforestation rate is 4.14 Mha/year, which is almost four-times higher than the baseline scenario

Scenario-2030

This scenario also analyses the mitigation potential over the 2010–2030 period. Here, approximately 33% geographic area is brought under forest cover by 2030. This scenario assumes slower afforestation rate compared with scenario-2020

4. MITIGATION POTENTIAL UNDER DIFFERENT POLICY SCENARIOS

The GCOMAP model was run for 19 zones and the mitigation potential was estimated. In Table 1, we outline the mitigation potential as per AEZ zones. It can be seen that the aggregate mitigation potential in scenario-2020 is estimated to be approximately 3.2 GtCO2 over the baseline, while in scenario-2030, the overall increase in mitigation potential is approximately 1.8 GtCO2. This shows that rapid afforestation under scenario-2020 will lead to an incremental 1.4 GtCO2 mitigation potential over scenario-2030. An aggressive afforestation policy brings an incremental area under plantation cover at an early date compared with the moderate scenario, which starts producing carbon benefits earlier. Thus, by 2030, the aggressive scenario ends up producing more carbon benefits than the moderate scenario. Furthermore, it can be observed that AEZ 4 has the highest mitigation potential of all the scenarios, since this AEZ has a high availability of the wasteland and good growing conditions. AEZ 4 coincides with the central Indian states of Madhya Pradesh and Maharashtra.

This is followed by the AEZs 14, 17 and 6

Figure 5 shows the cumulative mitigation potential for different scenarios. It suggests that the amount of carbon sequestered by afforestation is 5.3 GtCO2 in the period of 2010-2030 in the most aggressive afforestation scenario. A mitigation potential of 3.96 and 2.12 GtCO2 is estimated for scenario-2030 and the baseline scenario, respectively. Thus, rapid afforestation is able to create a sink of approximately 2.4 times more carbon compared with the baseline scenario and approximately 1.8 times higher than scenario-2030. The analysis further suggests that the incremental mitigation potential for scenario-2020 as well as for scenario-2030 will peak in 2030. Even after the incremental mitigation potential peaks and after the afforestation goal of a third of the geographic area is reached, these forests will continue to hold and expand the carbon sink, which could potentially be used to buy time to implement other greenhouse gas-reduction strategies. AEZ 4 has the highest mitigation potential under both the policy scenarios, followed by AEZ 14 and 17.

AEZ 4 coincides with the north India plains and central Indian highlands, while AEZ 14 coincides with Western Himalayan regions and AEZ 17 coincides with Eastern and N-E India.

Table 1: **Mitigation potential of different agro-ecological zones under different scenarios**

AEZ	Baseline scenario	Scenario-2020 (million tons of CO_2)		Scenario-2030 (million tons of CO2)	
	Total	Total	Incremental	Total	Incremental
1	22.22	55.37	33.15	41.71	19.49
2	132.24	327.63	195.39	248.82	116.58
3	30.87	53.78	22.91	40.05	9.18
4	271.08	684.42	413.34	508.47	237.39
5	116.76	294.77	178.01	219.02	102.26
6	138.04	347.63	209.59	258.78	120.74
7	91.27	230.04	138.77	171.09	79.82
8	99.44	244.67	145.23	186.27	86.83
9	41.84	104.62	62.79	78.51	36.68
10	132.58	332.35	199.77	248.98	116.40
11	42.79	108.16	65.38	80.64	37.85
12	137.18	347.98	210.80	257.56	120.38
13	58.38	146.38	87.99	109.70	51.32
14	236.93	599.52	362.59	444.72	207.79
15	64.73	160.76	96.03	121.37	56.64
16	136.87	340.02	203.15	256.71	119.84
17	220.74	548.65	327.91	414.26	193.51
18	75.13	190.14	115.00	141.30	66.17
19	72.44	182.96	110.52	135.88	63.44
Total	2121.53	5299.85	3178.32	3963.83	1842.29

Incremental mitigation potential denotes the additional potential realized in a particular scenario over the baseline scenario.

AEZ: Agro-ecological zone.

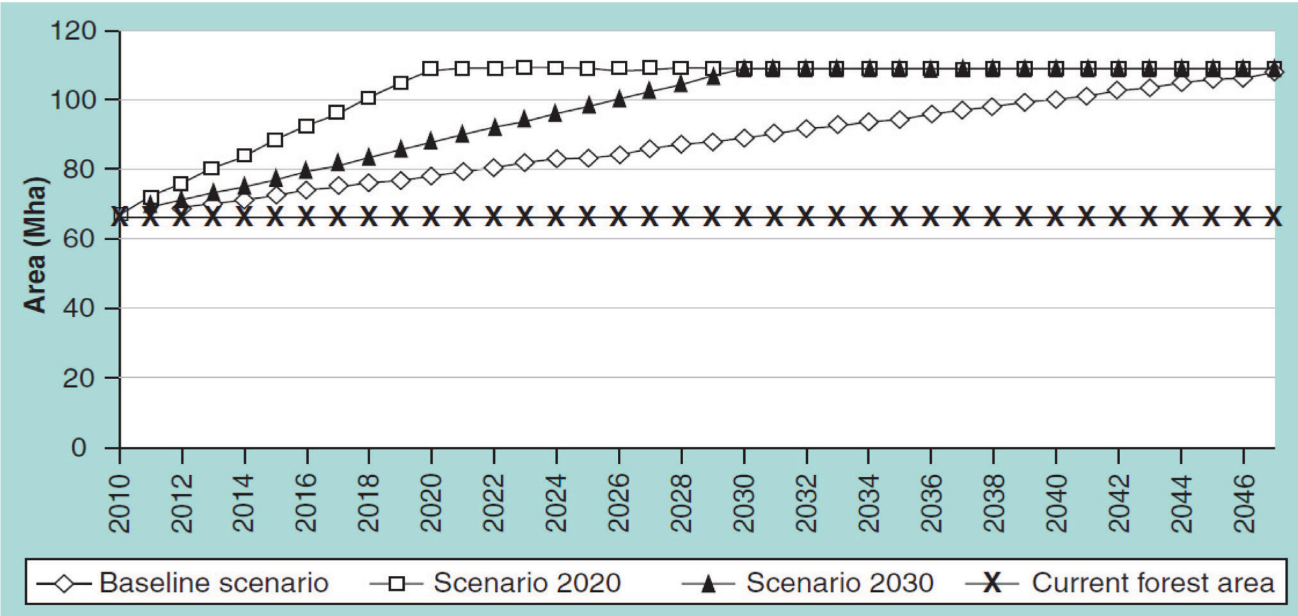

Figure5: **Change in total forest area with respect to time, in various scenarios considered.In this study, an attempt is made to estimate the mitigation potential of achieving a target of 33% of geographic area under forest cover by 2020 and 2030. The study has considered two afforestation scenarios: rapid (33% by 2020) and moderate (33% by 2030) afforestation rates. Furthermore, a baseline scenario consisting of afforestation continuing at the current rate of 1.1 Mha/year is also analyzed. We find that rapid afforestation (scenario- 2020) can sequester approximately 2.4-times more carbon than the baseline, while a more moderate afforestation rate (scenario-2030) sequesters 1.8-times more carbon during the period 2010–2030. We further estimate that such afforestation alone can mitigate 9 and 6.7% of the projected national emissions, under scenario-2020 and scenario-2030, respectively, for the period of 2010–2030.**

In the long term, it should be noted that these forests will continue to hold and expand the carbon sink, after the afforestation goal (of a third of the geographic area) is reached. This sink could be valuable in the future and could be used to buy time to implement other greenhouse gas-reduction strategies.

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Assessment of Indian Forest Carbon Cycle

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1. INTRODUCTION

The bioclimatic, topographic and socio economic fabric of India makes Indian forests unique in their distribution, diversity and ecosystem services and goods offered. The forest cover as per the satellite data of 2006 constitutes 69.08 Mha covering 21.02% the country's total geographical area (SFR,2009). The total growing stock of wood in the country has been estimated to be 6.22 billion m^3 of which 4.61 billion m^3 is in the forests, and 1.61 billion m^3 is in the tree outside the forests (SFR, 2009). Around 226 M populations depend on forest energy resources and over half of the live stock population (270 million) depends on forest for grazing resources. Still a gap of 184 Mt/annum of firewood and 125 Mt/annum of green fodder exists. 60.11% of the total forest cover of India exists in tribal districts whose lively hood support is met from forests (MOEF, 2006). There has been also continuous pressure on forest land for agriculture, commercial plantations and developmental activities. On the other side the impacts of grazing, fire and climate change are realized as the factors adding vulnerability to forest change.

This shows the degree of intricate relation of forest productivity with socioeconomic fabric, climate and associated flows of carbon (Sathaye et al., 2006). Forests store large quantities of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration, and act as sources of atmospheric carbon, if they are disturbed by certain human activities (e.g. harvesting, clear cutting for conversion to non-forest purposes, poor harvesting procedures) or natural causes (e.g., wildfires). However, they become atmospheric carbon sinks during land abandonment, re-growth after disturbance and due to afforestation and forest conservation. The net flux of carbon between the forest sector and the atmosphere determines whether forests are net sources or sinks of carbon (Bala et al., 2011) .

The reliable spatial and temporal accounting of carbon pools and fluxes is realized as important to assess and understand the trends in carbon fluxes and to facilitate the prediction of forest ecosystem response in the future scenario of changing socio economics and global climate. Such an exercise is also important in view of the obligation placed by the United Nations Framework Convention on Climate Change (UNFCCC) on the signatory nations to provide a periodic update of carbon flows and stocks in the atmosphere.

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2. FOREST CARBON ASSESSMENT – DATA REQUIREMENTS AND UNCERTAINTIES

There are different components of forest ecosystem which need to be better parameterized, quantified and interrelated for the precise estimates of forest carbon pools. These include accounting of spatial heterogeneity in forest condition (Crown density), types and standing biomass, mortality of trees, area subjected to processes like disturbances, reforestation and afforestation, proportion of carbon transferred to various pools due to these processes, precision in estimation of above and below ground biomass, biomass expansion factors, biomass density and carbon fraction estimates, litter fall, soil carbon, decay rate of soils and wood products (Kaul et al.,2009) .

These uncertainties could be grouped into three classes viz. spatial characterization, temporal characterization of forest cover and standing biomass and use of precise ground based forest allometric databases. Because of high degree of spatial and temporal variability in rainfall, topography and biotic disturbances, both forest type and standing biomass differs appreciably across space. Any national level estimates at times suffer due to in accuracy because of the inadequacy in accounting the spatial heterogeneities in terms of both forest condition (Crown Density), type and standing biomass. The main carbon pools in tropical forest ecosystems like India are the living biomass of trees and understory vegetation along with the dead mass of litter, woody debris and soil organic matter. Living biomass of tropical forest vegetation is generally considered to be more than 80% above-ground biomass (AGB), as opposed to below-ground biomass mainly represented by root systems (Brown et al., 1991). Estimating forest AGB is therefore one of the most critical steps in quantifying carbon stocks and fluxes (Rai, 1984; Bhatt and Ravindranath, 2011)

On the other hand, due to thinning, increment, afforestation and mortality etc., there could be changes in the biomass. The temporal quantification of such changes in biomass assumes greater importance in view of the forest degradation and also the afforestation activities (Haripriya, 2002a, Haripriya, 2002b). Estimates of CO_2 emissions due to land-use change vary considerably because humans interact with the land in a myriad of ways. Estimates vary due to uncertainties in annual forest clearing rates, the fate of the land that is cleared, the amounts of biomass (and hence carbon) contained in different ecosystems, the modes by which CO_2 is released (e.g., burning or decay) and the carbon released when soils are disturbed. The net impact of these processes effecting carbon cycle depends on local and region specific standing biomass levels and net annual increment. The ground based data on biomass expansion factors, specific gravity of wood, annual increment, wood extraction in terms of fuel wood, thinning, logging etc are other important variables which induce larger uncertainty in forest carbon stock assessment (Rai, 1983).

In this context the present paper brings out a review on different availability of different national databases, studies conducted on forest carbon pools assessment, Land Cover and Land Use Change and forest carbon fluxes, emerging areas of research and challenges in forest Carbon assessment and monitoring

3. NATIONAL DATABASES AND FOREST CARBON ASSESSMENT

3.1 Forest Crown Density

The area under different forest crown density levels is used as one of the critical parameter in growing stock estimation in India (Kaul, 2009). Forest Survey of India undertakes satellite remote sensing based national biennial forest crown density mapping and so far 11 cycles of assessment has been completed (SFR, 2009). With the increasing spatial resolution of the sensors and the advancement in satellite data processing, the crown density mapping has progressed from two crown density classes viz 10-40% and >40% to three crown density classes 10-40%, 40-70% and >70%. Based on the satellite data of 2006, national forest cover is estimated at 69.08 Mha covering 21.02% of the total geographical area of the country(SFR, 2009). Since 2002, three biennial assessments were made using digital analysis techniques and spatial forest change statistics were prepared providing information on forest land remaining as forest, forest land changing to others and other lands becoming forests. These databases provide both spatial and temporal characterization of forest change and are critically important for estimation forest carbon fluxes as per the IPCC guidelines (1996).

3.2. Forest type distribution

Champion & Seth's forest type classification (1968) scheme followed in the country offers hierarchical approach where in climatically driven forest ecosystems systems with distinct physiognomy and phenology are primarily classified as 16 type groups, 45 subgroups based on region specific climate and topographic controls and 227 types based on microclimatic, topographic, geomorphologic, edaphic and floristic patterns. The scale of requirement of such spatial explicit information on these forest types varies based on the degree of details required in the growing stock estimates. The forest types differ significantly in terms of ratio of below and above ground biomass, annual increment and biomass density determining the standing biomass levels. Precise delineation of boundaries of the different type groups, single species formations and mixed species formations offers a unique opportunity for developing spatially balanced sampling designs, improving the precision of the field sampling and attributing appropriate BEF at national, state or bioclimatic zones to improve the precision of the estimates. Forest type mapping using IRS–LISS III satellite data was taken up by Forest Survey of India addressing the classification scheme and principles of Champion and Seth. The details of statistics for 16 type groups are published in SFR, 2009. Kaul (2009) have described how the forest type information was used in different studies related to assessment of forest carbon pools of India. National level vegetation type mapping was carried out by NRSC/IIRS using IRS LISS-III satellite data. The classification scheme followed in this exercise is focused towards assessing plant diversity across mixed, gregarious, locale specific and degradation stages and it has the scope to remap into Champion and Seth Classification scheme.

3.3 Forest Sampling and Growing Stock Estimation

In forested ecosystems selected features are typically identified by their location. Consequently, any quantitative assessment needs spatial perspective: sampling in space. There are two scientifically defensible approaches for sampling and extrapolating from a sample to an entire population i.e. design and model based methods. The principle difference between the design and model-based approaches lies in the source of randomness they utilize. Both these approaches are effectively used in the development of different quantitative database on growing stock biomass and species diversity. However most of the growing stock assessments in the country follow design based approaches and very few studies were reported on model based methods.

National forest growing stock estimates are made by FSI for every two years based on systematic sampling (2 sample points of 0.1 ha at 2.5x2.5 grid interval) done over remote sensing based forest cover area. The survey is done over 10% of the 600 districts randomly selected without replacement per one year over different bioclimatic regions of the country. The survey provides growing stock over the country against ten dominant species. As part of National Carbon Project of ISRO-GBP Programme, biomass specific field data was collected at around 2000 sites chosen based on forest crown density and type specific stratified random sampling approach. The each site with a size of 250x250m consists of 4 plots at each corner with a size of 0.1 ha. The sites were distributed proportionately across the homogeneous zones identified using physiography, climate and river basin to capture natural variability across space. This spatially balanced sampling design with large size sites having nested plots will be useful to reduce the variance in the estimates and also in up scaling using remote sensing based modelling approaches.

3.4 Forest Allometry

It is necessary to have information on volume equations, biomass expansion factors, specific gravity of wood for estimation of above and below ground biomass, assessing commercial and non commercial part of biomass etc. Forest Survey of India (FSI) and Forest Research Institute (FSI) have been bringing extensive information on these parameters in the form of reports. As part of National Carbon Project under ISRO-GBP programme, an effort was made to develop database on 753 Regional species specific volume equations and general equations based on FRI and FSI publications. Specific gravity data of 16,400 species of the Asia has been collected. Specific gravity of 86 fire wood trees and shrub growing in wasteland/degraded sites has been added. Biomass expansion factors were used to convert stand volume to aboveground biomass and account for the non-commercial components such as branches, twigs, bark, stumps and foliage. Brown et al., (1989) and Hall and Uhlig (1991) report these factors to be in the range 1.14 to 1.6. However, Brown et al., (1989) related biomass expansion factors to volume and density and the same approach was used in Chhabra et al., (2002a), to convert growing stock in three density classes to an estimate for the forest C-pool. Haripriya (2000) used regression equations for species such as teak (*Tectona gandis Linn f.*), sal (*Shorea robusta Gaertn. f.*) and chir pine (*Pinus roxburghii*). The biomass expansion factors used were 1.59 for broad-leaved species, 1.51 for conifers and 1.55 for hardwoods mixed with conifers, similar to Hall and Uhlig (1991) and Brown et al., (1989). Biomass expansion factors were also estimated using the ratio of biomass density and growing stock volume for three crown density classes of forest cover in each state as published in Chhabra et al., (2002a). The latter is based on log relation between growing stock volume density and biomass expansion factor (Brown et al., 1999). The approach of using density dependent biomass expansion factors from (Chhabra et al., 2002a) provided conversion factors in range of 1.1-2.4 for dense forests and 1.15-4.6 for open forests. Allometric equations for both above and below ground components were developed for three tree species *Dalbergia sissoo Roxb., Acacia catechu Willd.*, and *Albizia lebbeck Benth.* growing in Terai region (a level area of superabundant water) of central Himalaya. Five diameter classes were defined for D. sissoo and A. catechu and 3 for A. lebbeck. 5 trees were harvested in each diameter class. Individual tree allometry was exercised for developing the allometric equations relating tree component (low and above ground) biomass to dbh .Post analysis equations were highly significant (P > 0.001) for each component of all species (Visha et al., 2011).

3.5 Forest Soil Databases

Currently national level soil maps are available at 1:5000, 000 scale which forms the basis for stratification, filed data collection and up scaling of the estimates for regional and national scales. The field based soil databases are limited at national scale and recently efforts are being put FSI, Indian Council of Forest Research & Education (ICFRE) and ISRO in developing national level soil databases. Recently efforts are made to collect 1650 sample points as part of National Carbon Project of ISRO-GBP.

3.6 Forest Wood extractions

In India, the volume of reported extraction of timber and fuel wood from forests in much lower than the actual consumption (Haripriya, 2003). There are different estimates of fuel wood such as 235 million m3 per year (Ravindranath et al., 1997), 303 million m3 for 1996 (FSI, 1997), 297 million m3 for 2000 (FAO, 2002). Similar to variation on estimates on fuel wood consumption, considerable difference of opinion on what fraction comes from forests exists. The National Sample Survey Organisation (NSSO) of the Ministry of Statistics and Programme Implementation estimated that annual requirement of fuel wood is 201 Tg or 251 million m3, out of which approximately 51% (103 Tg) comes from forests (including plantation) and rest 49% (98 Tg) from farm forestry and other wooded lands outside forests. Most of the fuel wood studies conducted in India focused on the consumption aspect rather than the supply and source aspect. Since no reliable information is available on production and consumption of wood from forests, the total annual demand of wood is between 324-434 million m3, where as the total sustainable availability of wood from all sources (public and private) is only 127 million m3 per year (http://enfor.nic.in/nfap/Unff2.pdf). The databases on quantity and source of wood extraction are found very limited and the availability at least state level would help to reduce the uncertainty in assessments.

4. FOREST CARBON POOLS ASSESSMENT

A number of studies have been published on forest carbon pool of India (Table-1). The studies used the remote sensing derived forest areas, growing stock inventory and BEF values at different levels of aggregation. Based on the inputs and methodologies used, the assessments were grouped into four categories. The comparative analysis reveals that national carbon pools estimates based standard BEF values and limited stratification results in under estimation as in category-1. The estimates from category-1 were found in the range of 2398- 4504 Tg of biomass as against 5321-8372 Tg of biomass estimated with improved stratification and BEF as found in other categories. The estimates made by Kaul et al., (2009) with 5253-6359 Tg of biomass lies in between estimates made between national and state level aggregation. Kaul et al., (2009) have used state wise RS based forest areas, field inventory based growing stock, state wise mean wood density and 2 different values of mean BEFs from earlier studies. Chhabra and Dadhwal (2004) have also reported how the district level areas as inputs would improve the estimates in of carbon pool assessment. However their estimates are found on lower side compared to closet year of estimate of Chhabra et al., (2002). Recent estimates found that conservation policies have resulted in increase of the country's forest carbon stocks from 6244.8 to 6621.6 Mt with an annual increment of 37.7 Mt of the carbon from 1995 to 2005(Kishwan et al., 2011).

The comparison reveals that with improved stratification and BEF, the estimates are increasing compared national level aggregated estimations. However further down scaling and increasing BEF and wood density information has resulted in lower side estimates compared to state level aggregations. It is also evident from the studies conducted on two time periods that estimates have shown increase in the quantity of pools irrespective of the methodology adopted. The comparative analysis shows that there is a need to understand the spatial scale at which the estimation could be made. This requires suitable error budgeting of the different processes involved in the biomass estimation and analyze for optimal scale at which precise estimates could be made. In this context local scale field intensive sampling studies would provide useful inputs and a few representative studies from different regions is presented. The standing volume, above ground biomass and carbon storage of Dry deciduous forest mainly teak dominated of Raipur district of Central Indian region is estimated as, 35.59 to 64.31 m3·ha-1, 45.94 to 78.31 Mg·ha-1, and 22.97 to 33.27 Mg·ha-1, respectively (Bijalwan et al., 2010). Gairola et al., (2011) reported. The total live tree biomass varied from 215.5 to 468.2 Mg ha–1 and total carbon varied from 107.8 to 234.1 Mg C ha–1 in Moist temperate Himalaya forests of Garhwal Himalayas. While total biomass ranged from 129 to 533 Mgha−1, the total carbon storage ranged between 59 and 245 Mgha−1 in subtropical to temperate Himalayan forest OF Solan forest division. (Sharma, 2009).

The studies from temperate regions of Garhwal Himalaya reported that TCD ranged between 77.3 CMg ha−1 on SE aspect and 2916 CMg ha−1 on NE aspect. SOC varied between 40.3 CMg ha−1 on SW aspect and 177.5 CMg ha−1 on NE aspect. Total C density (SOC+TCD) ranged between 118.1 CMg ha−1 on SW aspect and 469.1 CMg ha−1 on NE aspect(Sharma et al.,2011).Singh et al., (2011) have analysed the biomass of central Himalayan Terai region and reported that the total forest vegetation biomass was 10.86 Mg ha−1 in 2008 which increased to 19.49 Mg ha−1 in 2009 with forest sequestering carbon at the rate of 4.32 Mg ha−1 yr−1. Baisya et al., (2009) reported from the humid forests of North East Himalayas that the natural forest had lower AGB (323.9 Mg ha-1) than the plantation forest (406.4 Mg ha-1).Ray et al., (2011) have analysed the mangrove forest of Sunderbans and reported that the above ground biomass (AGB) and live below ground biomass (LBGB) held different biomass (39.93 ± 14.05 t C ha−1 versus 9.61 ± 3.37 t C ha−1). Carbon accrual to live biomass (4.71–6.54 Mg C ha−1 a−1) is more than offset by losses from litter fall (4.85 Mg C ha−1 a−1), and carbon sequestration differs significantly between live biomass (1.69 Mg C ha−1 a−1) and sediment (0.012 Mg C ha−1 a−1).

5 LAND USE LAND COVER CHANGE AND FORESTRY - CARBON FLUXES

In accordance with Article 12 of the climate convention, the signatory countries are required to submit on a continuous basis information on green house gas emissions by sources and removals by sinks using agreed methodologies, as outlined in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The IPCC section dealing with Land Use Land Cover Change and Forestry (LULUCF) accounts for changes in terrestrial carbon(C) storage. The estimates from the LULUCF sector include emission by sources and /or removal by sinks from changes in forest land, crop land, grassland, and settlements. The sources of the C pool are the above and below ground biomass, dead organic matter such as dead wood and litter, and organic matter in soils.

Estimation of GHG emission inventories in India started on a limited scale in 1991. These estimates were further revised using the updated methodologies, country specific emission factors and activity data and several papers and reports published (Mitra, 1992; ALGAS, 1998; Garg et al., 2001). Each study adopted a different approach based on different methods, different sources of data, different carbon pools and for different years, resulting in a net forest carbon flux that ranges from 0.4 Tg C per year (ALGAS, 1999) to sink a value of 5 Tg C per year (Ravindranath et al., 1997). Chhabra et al., (2002) computed district level forests phytomass C for 1988 and 1994 and concluded that district level changes in the forest cover resulted in better estimates than the results from the aggregated national estimates. Hairpriya(2003) estimated that during 1993-94,disturbances released 11.5 Tg C into the atmosphere (of which fires accounted for 10.6 Tg C ,0.02 Tg C was due to mortality and 0.7 Tg C was due to clear cut logging and slash burning). Chhabra and Dadhwal, 2004 estimated terrestrial carbon storage using a simple book-keeping 'Marine Biological Laboratory Terrestrial Carbon' model (Houghton et al., 1983). Assuming initial phytomass carbon density estimates of 75 and 100 tha^{-1} in national and regional scenario of the model, the cumulative net carbon flux to the atmosphere (1880–1996) due to deforestation were estimated at 2.34 and 3.24 Pg C, respectively. The net annual carbon flux over the period (1880–1996) for both the scenarios of the model was estimated at 39 ± 1.0 and 54 ± 2.0 Tg C, respectively.

As part of India's National communication to the UNFCCC, the most comprehensive GHG inventory was reported for the year 1994 based on IPCC 1996 guidelines (NATCOM, 2004). According to this inventory the net emissions from the LULUCF sector were estimated to be 3.86 Tg C for the inventory year 1994. It is pertinent to mention that LULUCF sector in India contributed only 1.78% of the CO_2 emissions according to the NATCOM. Kaul et al., (2009) estimated the net carbon flux caused by deforestation and afforestation in India over the period from 1982 to 2002, separately for two time periods, 1982–1992 (PI) and 1992–2002 (PII), using the IPCC 2006 guidelines for greenhouse gas inventories. The net C emissions from the forest land conversion to another land use (deforestation) resulted in annual emissions of 9.9 and 3.2 Tg C during PI and PII, respectively. The total annual increase in biomass C stocks due to biomass growth was estimated at 0.28 and 0.62 Tg C for PI and PII, respectively. The cumulative net carbon flux from Indian forests due to land use change between 1982 and 2002 was estimated at 45.9 Tg C. Subodh et al., 2011 as part of greenhouse gas inventory of India for 2007 estimated that the LULUCF sector was a net sink in 2007 and sequestered 177.03 Tg of CO_2.

The forest carbon flux estimates suffer from uncertainties associated with types of input data and methodology adopted. Due to the land use change, an area can change from source to sink or vice versa, and hence precise information on dynamic change areas such as plantation, re growth in shifting cultivation areas, degradation due to thinning, illicit felling and fuel wood extraction is very essential. Many studies have indicated uncertainty over actual area of the plantations and fuel wood extraction levels (Ravindranath et al., 1987; Pande, 2002; Haripriya 2003). Estimating the net C balance from the harvest requires accurate information on the available biomass before the harvest, the fraction of biomass harvested or damaged, and the fraction removed from the forests and used as fuel and wood products.

6. FOREST SOIL CARBON

Soil Organic Carbon (SOC) is the largest terrestrial carbon pool. Soil can be a source of (CO2,CH4, and N2O) or sink (CO2 and CH4) of greenhouse gases depending on land use and management (Lal,1999).The total SOC pools in Indian forests have been estimated as 4.13 Pg C(top 50 cm) to 6.81 Pg C (top 1 m soil depths) for the period 1980-82 (Chhabra et al.,2002) .Based on the national and regional soil carbon densities, Indian forest SOC pool estimates are in the range 6.7 to 9.8 Pg C (Dadhwal, 1998;

Table 1 **: Summary of estimated forest biomass and C-Pool for Indian Forests**

Methodology adopted	Year	Estimated Biomass (Tg)	Carbon Pool (Pg C)	Carbon density (Mg C ha^{-1})	Re
Category I (National level Forest areas and BEF)					
Field inventory of Growing stock and using single conversion	1985	4432	1.99	31	[1]
Species wise forest inventory data, mean wood density of various strata and BEF ranging from 1.51 to 1.59 for different forest composition.	1993	4313	2.16	34	[5]
Strata wise estimation of GS based on forest inventories, thematic maps and vegetation maps for different density class. Wood biomass was further estimated using specific gravity and calculated GS for each state.	1984 & 1994	2398 2395	1.085 1.083	17 17	[6]
Stratum wise field inventory of growing stock as reported by FSI and standard conversion factor as per IPCC guidelines.	1995	4504	2.03	32	[8]
Category II (RS based National level areas, Strata level BEF at National level)					
RS based forest area, biomass densities from literature for five crown cover levels for some of the forest types and extrapolating the same for entire India.	1986	8372	4.18	65	[2]
RS based forest area biomass density national level improved estimates on branches and twig.	1999 & 2005	6244 6622	--	--	[10]
Category III (State wise RS based areas & State wise, Strata wise BEF)					
State wise RS based forest area, field inventory based GS, Biomass Expansion Factors (BEF) for 2 crown density classes.	1982 & 1991	7690 8142	3.98 4.07	62 64	[3]
State wise field inventory based data on growing stock, Biomass Expansion Factors (BEF) for 3 crown density classes and 4 forest categories.	1993	8685	4.34	68	[4]
State-wise RS based forest area; field inventory based GS; state wise mean wood density and 2 different values of Mean BEFs calculated from earlier studies.	1992 & 2002	5253 / 6151 & 5321 / 6359	2.6 / 3.1 & 2.7 / 3.2	41 / 48 & 39 / 47	[9]
Category IV (District wise areas, State wise, Strata wise BEF)					
District based RS based forest area, field inventory based GS, BEF for 2 crown density classes.	1988 & 1994	7742 7748	3.871 3.874	60.5 61	[7]

[1] Dadhwal & Nayak (1993); [2] Ravindranath et al., (1997); [3] Dadhwal and Shah (197); [4] Chhabra et al. (2002a). [5] Haripriya (2000); [6] Manhas et al., (2006); [7] Chhabra et al. (2002b); [8] Lal & Singh (2002); [9] Kaul et al., 2009,[10].Kishwan et al.,2011

Jha et al., 2003). Based on different forest types in India ,the national average of soil carbon per ha in forest soil was estimated as 183 Mg /ha (Jha et al., 2003). As part of Second national communication of India, forest soil pool estimates of 3.51 Pg and 3.75 Pg for 1995 and 2005, respectively, were reported by ICFRE and IIRS using 657 soil samples (Kishwan et al., 2011).

Land use can have a large effect on the size of soil pool through activities like conversion from forest land to cropland or grassland, where 20-40% of original soil carbon stock can be lost. Within a land use type, a variety of management practices also can influence soil organic C storage, particularly in cropland and grassland (Ogle et al., 2005). The time dependence (D) (i.e., default as 20 years) determines the number of years over which the majority of soil organic C stock change occurs, following a management regime. It is possible to use the default time dependence (D) for land use sector,(e.g. 20 years for cropland) but the dependence can be changed if sufficient data are available to justify a different time period. Kaul et al.,(2009) reported as part of their Indian forest C flux studies that with a 30 year(T) time dependence(where T exceeds D) for soil organic carbon to reach equilibrium, the carbon uptake could be reduced from 0.5 to 0.3 Mg C per ha during 1982-92 and from 0.2 to 0.1 Mg C per ha during 1992-2002.

7. FLUX TOWER BASED BIOPHYSICAL MEASUREMENTS - MODELING OF FOREST C FLUXES

Micrometeorological approaches for estimating CO_2/H_2O fluxes, including the eddy covariance technique method, provide a means to estimate CO_2/H_2O flux at specific tower sites. The tower based flux measurements alone can lead to unbiased regional estimates of CO_2 fluxes (Baldochi et al., 001). Initial efforts were made to identify the needs and approach for developing flux net work over India (Sundareshwar et al., 2007). As part of National Carbon Project (NCP) initiative of ISRO-GBP programme nationwide network of carbon towers in major forests taken up. Three towers at forest sites of 15-20 m height at Barkot, Uttarakhand; Haldwani, Uttarakhand and Betul, MP, were established. Betul tower is recently initiated to record flux measurements. A new tower in mangrove forests of Sunderabans is being established. Site specific studies were also conducted for measurement and modeling of soil respiration and /emission fluxes using automatic soil $C0_2$ exchange system at Haldwani tower site

The biophysical data generated is being analysed to understand diurnal, seasonal variation in carbon and water fluxes and NPP modeling using RS based models. Half-hourly CO_2 flux measurements corresponding to dry period (18-28 Jan, 2009) and flush stage (April, 2009) were processed to study the diurnal variation in net ecosystem exchange and its response to environmental variables. Light-response curves were derived for quantifying quantum photosynthetic efficiency. Efficiency worked out to be 0.021 μmol CO_2 μmol photon-1 during flush stage. Respiration-temperature response was also evaluated to derive Q10 coefficients. In order to quantify CO_2 fluxes over large region, it is necessary to upscale site-specific data using process based ecosystem models. The model could include site specific SVAT models for NPP assessments and biospheric models like CASA, PJ and IBM etc. Efforts will be made to develop better climate and vegetation specific forcing variables from flux tower data for adoption in forest ecosystem models and study biospheric carbon dynamics over longer time scales.

There have been a few studies on assessing spatial and temporal patterns of satellite based biophysical parameters and NPP over India using process based biophysical models.. Estimates of monthly net C fixation and net primary productivity over India and its eight regions, using SPOT-VEGETATION 10-day NPP composites, and comparing the monthly patterns of NPP and NDVI was made (Chhabra and Dadhwal, 2004).The total net C fixation of India was estimated as 2.18 PgC, which amounts to area-weighted terrestrial NPP of 6.66 tCha–1 yr–1 for the period June 1998–May 1999. An analysis of monthly fAPAR dataset derived from NOAA–AVHRR data covering the period from July 1981 to May 2001 over the Indian land mass was carried out (Pandya et al., 2004). Significant positive trends of decadal increase of about 2.9% and 2% were observed in pre-peak (June–October; P-I) and post-peak (November–May; P-II) seasons respectively. The Carnegie–Ames–Stanford Approach (CASA), a terrestrial biosphere model, has been used to investigate spatiotemporal pattern of net primary productivity (NPP) during 2003 over the Indian subcontinent. Sensitivity analysis suggest that the difference could be due to inclusion of variable light use efficiency (LUE) across different land cover types and environment stress scalars as down regulator of NPP in the present CASA model study (Nayak et al., 2011a).

Seasonal and inter-annual variability of NPP and NEP and their control by the climate has been extensively analyzed using CASA model based monthly simulations of NPP, NEP and etc., for the period of past 25 years 1981-2006(Nayak et al., 2011 b). Results suggest that both NPP and NEP have exhibited large seasonal and inter-annual variability. In the national scale, average annual NPP is estimated to be 1.5 Pg C Yr-1 and is increasing at the rate of 0.005 Pg C Yr-2 during past 25 years from 1981-2006. This trend is equivalent to 8.5% over the country during past 25 years. Spatial distribution of NPP trend is different in different places and in different periods. In the recent time (1995 onwards), large decline of NPP over the Indo-Gangetic plane is observed owing to decline of rain over the regions. Estimated NEP budget for the country suggest that, on an average India is the region of net sink of atmospheric CO2 with total annual uptake of 9.5 Tg C yr-1. Estimated long term linear growth rate of NEP over the country was 1.8 Tg C Yr-2 (8.5%) which is small but significant. There exists strong inter-annual variability of NEP over the country. Except early period (1981-1985), most of the years India is net sink of atmospheric CO2.

8. EMERGING RESEARCH AREAS AND CHALLENGES

The challenges in carbon pools and flux estimates lie in the extent to which the degree uncertainty could be reduced. The stages where errors accumulate include i)Measurement errors at plot level ii) Errors due to allometric relationships, iii) Sampling errors, and, iv) Model prediction errors. Currently C pool estimates rely on field measurements and subject to measurements uncertainties. A shift towards multi sensor remote sensing based biomass estimations with optimal field sampling is an urgent need. Remote sensing and ground based LIDAR systems helps in intensive site characterization to develop models for biomass estimation and validation. These approaches would facilitate to produce periodic biomass assessments using satellite data and limited ground information and reduce uncertainties.

Additional primary field data on forest increment, allometric relationships and wood extractions would help to reduce uncertainties due to stand/forest type specific inputs. With the advent of availability of geospatial tools and digital databases, spatially balanced field sampling designs could be evolved using multiple layers of information to reduce errors in sampling. Currently design based models are used to develop regional and national estimates. The spatial disaggregated model based estimation methods would help in optimizing the errors during up scaling. Regular remote sensing based LULUCF monitoring, calibration of biospheric models based on India specific biophysical coefficients would further strengthen the understanding intra and inter annual C fluxes over India.

The main factors acting on soil organic matter evolution concern the vegetation (residue input, plant composition), then climatic factors (temperature/moisture conditions) and soil properties (texture, clay content and mineralogy, acidity). Soil respiration is the second largest terrestrial carbon flux and is sensitive to climate, vegetation type, and soil properties. Soil respiration affects the soil carbon stock primarily by the long-term balance between soil respiration output and vegetation carbon input in terms of roots, litter and residue. In view of this it is important to understand the variations in soil carbon flux as a function of chronosequence, vertical distribution of SOM as a function of age and soil carbon loss as a function of soil erosion / processes.

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India and REDD+: Opportunities and Challenges of Implementation

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INTRODUCTION

Forests are increasingly occupying centre stage in climate change mitigation debates in view of their 638 Gt of carbon storage (FAO 2010), and 17.4% of global green house gas (GHG) emissions from deforestation activities (IPCC 2007). Developing countries are being encouraged to increase their participation in global climate change mitigation efforts by implementing REDD+ mechanism, a forest-based mitigation strategy under the United Nations Framework Convention on Climate Change (UNFCCC). It is estimated that 40% mitigation potential of developing countries could be harnessed through the REDD+ mechanism (Parker et al 2009).

India is actively participating in REDD + negotiations under the UNFCCC, and contributing towards the development of REDD+ architecture especially '+' activities. While international community continues to work with several emerging and complex issues in order to provide a firm shape to REDD+ UNFCCC policy framework, the intricacies of designing a national strategy and implementing REDD+ activities pose important questions and challenges that require innovative approaches in the Indian context. This paper focuses on the development of the national REDD+ system in India under the given UNFCCC policy framework of REDD+. It explains and analyses the opportunities available in the national forest policy framework of India for implementation of REDD+ activities. This paper examines the associated challenges, and attempts to identify the critical issues that require attention to effectively establish and implement REDD+ actions.

REDD+ ARCHITECTURE UNDER UNFCCC

Noting high deforestation rates in developing countries like Brazil, Indonesia, and Bolivia, a new agenda item on 'Reducing emissions from deforestation in developing countries', known as RED, was proposed by Papua New Guinea and Costa Rica at the 11th Conference of the Parties (COP) to the UNFCCC held in Montreal in 2005. The COP 11 invited Parties to submit their view on the agenda item, and forests were brought back to the debates of climate change mitigation. The agenda item was referred to the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC for further elaboration on technical and methodological issues within a period of two years. During this process of discussion, Parties agreed to address the emissions resulting from forest degradation noting its significance in many developing countries. Thus one more 'D' got added to RED, and the agenda item was expanded to 'Reducing emissions from deforestation in developing countries' (REDD).

In the UNFCCC forums, nations with heavy deforestation rates like Brazil strongly advocated the policy approach of positive incentives and compensation in return of their commitment to reducing current deforestation rates. On the other hand, countries like India and China who achieved increment in forest carbon stocks following conservation oriented policy framework resulting in increase in forest cover and sustainable management of forests put forth the case of getting compensation for conservation efforts. Countries like Cameroon and Gabon with low rate of deforestation also argued for financial incentives for stabilizing their forest cover as a result of protection and sustainable management measures.

India stressed the view that efforts to reduce emissions from deforestation in developing countries should accommodate diverse national circumstances while developing a framework for positive incentives comprising technological, methodological, monitoring, validation, and disbursement issues. India's submissions to the UNFCCC consistently reiterated its position to get recognition and encouragement for conservation, sustainable management of forests, and increase in forest cover as a potential policy approach under REDD. India maintained that all countries engaged in efforts to maintain and increase forest carbon stocks in their broader national policy framework of conservation and sustainable management of forests should also be rewarded.

THE MILESTONE OF BALI CONFERENCE: REDD TO REDD+

The discussions in COP 13 of the UNFCCC, which was held in 2007 at Bali, focused on inclusion of conservation and enhancement of forest carbon stocks as potential policy approach under the umbrella of REDD. The concept of 'compensated conservation' was strongly put forward by India and supported by China, Columbia, Bhutan, Pakistan, Bangladesh, Congo Basin countries, and Philippines. This proposal of India, however, did not go well with Brazil, Japan, the EU, and some of the Latin American

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countries experiencing high deforestation rate.

After a series of lengthy discussions and negotiations, based on the recommendations of SBSTA, the Bali conference adopted Decision 2/CP.13: "Reducing emissions from deforestation in developing countries: approaches to stimulate action" (UNFCCC 2008a). "Acknowledging the contribution of the emissions from deforestation to global anthropogenic greenhouse gas emissions," the Decision 2/CP.13 recognized the "efforts and actions to reduce deforestation and *to maintain and conserve forest carbon stocks in developing countries*… in helping to meet the ultimate objective of the Convention (emphasis added)". The Decision 2/CP.13 also initiated a programme of work on "methodological issues including, inter alia, *assessments of changes in forest cover and associated carbon stocks and greenhouse gas emissions, incremental changes due to sustainable management of the forest*, demonstration of reductions in emissions from deforestation, [and] forest degradation (emphasis added)". Thus, the conservation policy approach of India was finally recognized and given a place in the Bali Decision 2/CP.13 alongwith deforestation and forest degradation.

COP 13 also focused on long term cooperative action and post-2012 issues in order to enhance implementation of the Convention; and, Parties agreed on initiating a two year process, popularly known as 'Bali Action Plan', to finalize a post-2012 regime. The Bali Action Plan (UNFCCC 2008b) identified the scope of REDD instrument, and launched a comprehensive process to address "Policy approaches and positive incentives on issues 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 (emphasis added)". With this inclusion of sustainable management of forests, conservation, and enhancement of forest carbon stocks in developing countries, the agenda of REDD began to be referred to as REDD+.

THE COPENHAGEN ACCORD AND COP 15 DECISION ON REDD+

After the Bali conference, countries continued to work on various REDD+ issues under SBSTA and Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA). COP 15 in Copenhagen adopted the decision 4/CP.15 (UNFCCC 2010a) on REDD+ providing methodological guidance on activities based on work undertaken by SBSTA in follow-up of Bali decision 2/CP.13. The Copenhagen decision 4/CP.15 requested developing countries to identify drivers of deforestation and forest degradation. Developing countries were also requested to identify activities that result in reduced emissions and increased removals, and stabilization of forest carbon stocks; and use the most recent Intergovernmental Panel on Climate Change as a basis for estimating anthropogenic forest related GHG emissions by sources and removals by sinks, forest carbon stocks and forest area changes.

The decision also desired developing countries to establish, according to national circumstances and capabilities, robust and transparent national forest monitoring systems by using a combination of remote sensing and ground-based forest carbon inventory approaches. In the decision, the COP encourages capacity building in developing countries, and effective engagement of indigenous peoples and local communities.

The Copenhagen Accord (UNFCCC 2010b), which was not the legally binding outcome of the Copenhagen conference, recognized the crucial role of reducing emission from deforestation and forest degradation, and the need to enhance removals of greenhouse gas emission by forests.

In the Accord, developed countries agreed to the need to provide positive incentives to such actions through REDD+ mechanism. Developed countries also committed to provide USD 30 billion for the period 2010–2012 and mobilizing jointly USD 100 billion a year by 2020 to address the needs of developing countries including forestry through establishing the Copenhagen Green Climate Fund.

THE CANCUN AGREEMENTS

REDD+ Scope and Phased Implementation

The decision 1/CP.16 adopted by COP 16 in Cancun defines the REDD+ strategy from the policy perspective for the first time (UNFCCC 2011). The Cancun decision on REDD+ has reaffirmed the scope of the strategy, and identifies the eligible activities that developing countries can undertake according to their respective capabilities and national circumstances: reducing emissions from deforestation, reducing emissions from forest degradation, conservation of forest carbon stocks, sustainable management of forest, and enhancement of forest carbon stocks.

Considering the different capacities and national circumstances of developing countries, the decision supports a phased approach to REDD+. The first phase would begin with development of national strategies, policies and measures, capacity-building, and economic assessment of finance needed. This would be followed by implementation of national policies and action plans, technology development and transfer, and results based demonstration activities.

The third phase would evolve into results-based actions that should be fully measured, reported, and verified. It is further recognized that the implementation of various REDD+ activities including the choice of a starting phase would depend on the specific national circumstances, capacities and capabilities of each developing country, and the level of support received.

Methodological Issues

The decision states that developing countries willing to participate in REDD+ mechanism should prepare a national strategy or action plan, and determine a national (interim measure- subnational) forest reference emission level and/or forest reference level against which emissions reduction and/or enhancement of carbon storage respectively could be monitored, reported and verified through a robust and transparent national forest monitoring system.

A national monitoring, reporting, and verification (MRV) system is also required to be put in place in accordance with the national circumstances. The MRV system is going to be a key element in generating confidence in REDD+ actions. The SBSTA is initiating a work programme to provide guidance on modalities for MRV system.

Guidance and Safeguards

Recognizing the socio-economic concerns and possible political ramifications voiced by various indigenous and forest dwellers groups, representatives of civil society, researchers, and critiques of REDD+ agenda; the Cancun decision requires countries to address the land tenure and forest governance issues along with effective participation of all relevant stakeholders and ensuring gender considerations during implementation of REDD+ activities. The decision also underlines that REDD+ activities should be consistent with the objective of environmental integrity taking into account the multiple functions of forests and other ecosystems, and should be implemented in the context of national sustainable development goals and reducing poverty. Furthermore, the decision puts safeguards for conservation of natural forests and biological diversity, non conversion of natural forests, and consistency with the objectives of national forest programmes during implementation of REDD+ actions. Countries are also expected to develop a system for providing information on these safeguards.

Unresolved Issues of Finance and Further Work

The REDD+ framework under the Cancun decision though clearly identifies the eligible activities and safeguards required to be promoted during implementation, lacks guidance on financial issues- scale, nature, and distribution of incentives and benefits among countries and within country.

It is yet not clear whether there would be same basket of money for all REDD+ activities or there would be different compartments attaching different values to different activities. However, there is remote possibility of keeping different compartments for different activities as countries like China and India are supporting the same basket approach. Countries are also discussing the quantum of incentives for incremental stocks under conservation/ sustainable management of forests/ enhancement of forest carbon stocks approach v/s reducing decremental stocks under reduced deforestation and degradation approach, and majority is in favour of payments at the same rates.

India is arguing for the provision of same incentives for one unit of carbon saved following reduced deforestation and degradation approach, and one unit of carbon added by undertaking conservation/ sustainable management of forests/ enhancement of forest carbon stocks activities. There is also uncertainty about the possibility of incentivizing maintenance of baseline forest carbon stocks. India has mooted the proposal of incentives for baseline stocks as well arguing that it will work as the insurance for keeping baseline stocks intact. Although, the Cancun decision urges developed countries to support developing countries in terms of finance, technology, and capacity building to develop national strategies or action plans and implementation of REDD+ activities, there is no dedicated fund or mechanism yet available under UNFCCC to make REDD+ action a reality on ground. Currently, REDD+ readiness and demonstration activities pilot projects in more than 50 countries are being supported by Forest Carbon Partnership Facility for REDD, UN REDD Programme, and some multilateral and bilateral programmes outside the framework of UNFCCC. There have been some discussions of linking REDD+ to Clean Development Mechanism (CDM) of Kyoto Protocol but developing country Parties have not bought the idea in view of negative experience with cumbersome CDM technical modalities and procedures. However, countries have been considering the plausible nature of funding mechanism under UNFCCC for REDD+. Countries have been discussing the market based mechanism for REDD+ finance yet no agreement has been arrived at. It is important to note that implementation of REDD+ activities would require large scale financial support. It has been estimated that US$17-33 billion per year are required for implementation of this mechanism. In this scenario, integration or linking REDD+ mechanism to carbon market appears to be one way to generate additional finance. At this point, usual market, social and environmental risks associated with carbon markets needs to be taken into account as REDD+ mechanism is looking at forests beyond their carbon value; and, requires ensuring safeguards for conservation of natural forests and co-benefits like biodiversity conservation with the involvement of local communities and relevant stakeholders. The careful architecture of REDD+ mechanism involving market based options has significant potential to raise sufficient finance and enable developing countries to commit for full implementation of REDD+ activities beyond demonstration activities and pilot projects. At the same time, capacity building of developing countries and access to technological knowhow related to developing inventories of forest carbon stocks and systems of monitoring, reporting, and verification would pave the way for effective implementation of REDD+ mechanism. The Ad Hoc Working Group on Long-term Cooperative Action under the UNFCCC has been given the task to explore financial options for the full implementation of REDD+ actions.

INDIA'S FOREST CLIMATE ALLIANCE AND REDD+ OPPORTUNITIES

Forests of India

The total forest and tree cover of India is estimated to be 78.37 million ha covering approximately 24% of the country (FSI 2009). Out of the estimated forest cover of 69.09% constituting 21% of the geographical area, only 8.35 million ha (2.54%) is very dense forest. About 31.90 million ha is moderately dense forest, and 28.84 million ha (8.77%) is open or degraded forest (ibid). India has the world's tenth largest area of forests, and occupies third position among countries which have registered annual net gain in forest area from 1990 to 2010 (FAO 2010). According to FSI (2009) report, the increase in the forest cover between 1997 and 2007 is 3.13 million ha (4.75%).

As per the observation of ITTO (2006), only 39.1 million ha of India' forests fall under the category of natural forests. FAO (2010) estimates that out of 68.43 million ha of total forest area, 15.70 million ha is primary forest, 42.52 million ha constitutes other naturally regenerated forest and 10.21 million ha comprises of planted forest area.

In terms of biodiversity, India is one of the world's 17 "mega-diverse" countries with four global biodiversity hot spots accounting for 7-8% of the recorded species of the world spread over 45,500 species of plants and 91,000 species of animals. Approximately 4.75% of the total geographical area of the country is under in situ conservation through a 'Protected Area' network of National Parks (96), Wildlife Sanctuaries (509), and Conservation Reserves (3) (MoEF 2008).

Forestry has contributed 1.2% of gross domestic product over the years, and annual value of direst contribution of non timber forest products (NTFP) is about US$27 billion and that of wood products is US$ 17 billion (MoEF n.d.).

Carbon Storage and Sequestration Potential

Carbon stock is an important indicator of the state of forests in the context of climate change. There are varying estimates of carbon stock in biomass and mineral soils in India. Haripriya (2003) conducted a comprehensive study taking into account the carbon stored in both above and below ground biomass as well as in the soil. The total carbon stock in biomass and mineral soils were estimated to be 2,934 MT C and 5,109 MT C, respectively, for the year 1994 and 1995. The average biomass carbon of the forest ecosystem in India for the year 1994 was reported to be 46 T C/ha, of which 76 % was in above ground biomass and the rest in fine and coarse root biomass. The average mineral soil carbon was found to be 80 T C/has.

Increase in annual productivity directly indicates an increase in forest biomass and hence higher carbon sequestration potential. Noting the annual productivity increase in India's forests from 0.7 m3 per ha in 1985 to 1.37 m3 per ha in 1995, Lal and Singh (2000) estimated the carbon pool for the Indian forests to be 2026.72 Mt for the year 1995, and concluded that India's forests and plantations had been able to remove at least 0.125 Gt of CO2 from the atmosphere in the year 1995. Assuming that the natural forest cover in India will sustain itself at an annual productivity of 1.37 m3 per ha while the plantations would have an annual productivity of 3.2 t/ha, the total annual carbon uptake of 55.48 Mt and 73.48 Mt for the years 2020 and 2045 respectively was also projected.

Kaul, Dadhwal, and Mohren (2009) observed that Indian forest sector acted as a small source of carbon during the period 1982–1992, and as a small carbon sink during the period 1992–2002. The cumulative net carbon flux from Indian forests due to land use change between 1982 and 2002 was estimated as 45.6 Tg C.

On the basis of analysis of forest cover, afforestation and reforestation, and other conservation measures, Ravindranath, Chaturvedi, and Murthy (2008) have projected an increase in Indian forests during the period 2006-2030, and occupation of 72 m ha of land under forests by 2030 under the current trend scenario of the afforestation rate of 1.32 mha/annum. The model based projection of carbon stocks in India's forests and tree cover reflects an increase in the carbon stocks from 8.79 GtC in 2005 to 9.75 GtC in 2030 (ibid).

According to GoI (2009), India's forests are a major sink of CO2, and serving an important role in GHG mitigation for India. From 1995 to 2005, the carbon stocks stored in forests and trees have increased from 6,245 Mt to 6,662 Mt with an annual increment of 38 Mt of carbon. The annual CO2 removals by India's forest and tree cover is enough to neutralize 11.25% of India's total GHG emissions at 1994 levels, which is equivalent to offsetting 100% emissions from all energy in residential and transport sectors; or 40% of total emissions from the agriculture sector.

Ravindranath et al. (2007) estimated the national mitigation potential in forestry sector and noted that during the period 2005 to 2035, at a carbon price of US$100 per tC, India's forests have the potential to sequester an additional 260 MtC through afforestation and reforestation activities. Another study by Ravindranath et al (2011) projects that the cumulative mitigation potential of India's forests is to increase by up to 14% to 21% between the years 2008 and 2108 using BIOME4 vegetation model. However, estimates obtained from IBIS, a dynamic global vegetation model, suggest mitigation potential increases by only 5% to 6% during the period 2008 to 2108.

The Dynamics of Resource Use and Degradation

Although deforestation is not a significant issue noting the stabilization and marginal increase in forest cover, the dynamics of forest degradation need careful examination in the context of REDD+ implementation in India. The parameters of growing stock, productivity, and changes within canopy density of forest cover are important pointers to understand the status and health of forest cover.

The report of FSI (2009) shows that there is a net loss of 936 km2 of moderately dense forest and net increase of 1,626 km2 of open forest between 2005 and 2007. While India's forests have the average potential productivity of 6 cum per ha per year (Paterson cited in FSI 1987), the forest productivity is only 0.7 cum per ha per year, and significantly low against the world average of 2.1 cum per ha per year (MoEF 2010a). This low productivity has resulted in a demand supply gap in various forest products leading to overharvesting and forest degradation. To obtain national level estimates of growing stock of forest and 'Trees Outside Forests' (TOF- trees growing outside recorded forest areas), Forest Survey of India (FSI)-a GoI organization mandated to publish 'India State of Forest Report' every two years-modified its sampling design in 2001. On the basis of 2002 data period, FSI reported growing stock of the country to be 6414 million cum (FSI 2003) which came down to 6218 million cum for 2004 data period (FSI 2005), and further declined to 6098 million cum for 2006 data period (FSI 2009) indicating the degradation of country's growing stock. However, India's country report for Global Forest Resources Assessment 2010 conducted by FAO, wherein data provided by FSI is used, shows an increase in growing stocks from 4,363 million cum in 1990 to 4,662 million cum in 2000, and from 5,129 million cum in 2005 to 5,489 million cum in 2010 (FAO 2010). It is important to note here that the estimate of growing stocks for 2005 also includes estimates of growing stock in TOF, and estimates for 2010 were calculated on the basis of per ha growing stock of 2000 and 2005. This discrepancy in figures related to growing stock needs clarification, and questions the authenticity of data. More reliable and sophisticated methodologies will be required to build confidence of international community in country data for providing performance-based incentives under REDD+.

Forests of India are under huge pressure of meeting the demand for a variety of goods and services from increasing human and livestock population. With 2.5% of world's geographic area and 1.8% of world's forests, India sustains 16% of global human population and 18% of livestock population. Per capita availability of forest area is only 0.07 ha against the world average of 0.62 ha (FAO 2010). Around 70 million tribal and 200 million non-tribal rural people have been defined as forest-dependent (MoEF n.d.).

In the Indian context, forests are multipurpose resources, and work not only as a "savings account for people living in and around them, but they also provide a range of products for subsistence" (FAO 2006). Several studies have attempted to highlight the important role of forestry in rural livelihoods. While Vedeld et al (2004) noted that forest products contribute between 20 to 40% of the total household income in forest areas others observed a range between 10 to 54% (Bhattacharya and Hayat 2004, Prasad 2006, Saxena 1999). It is estimated that nearly 400 million people living in and around forests depend on NTFPs for sustenance and supplemental income (MoEF n.d.). In rural areas, about 50% of the total fuel consumption is met from fuelwood (FSI 2002). According to MoEF (n. d.) estimates, the annual fuelwood consumption is in the range of 250 to 300 million m3, which is mainly collected from forests in an unorganized way as only about 17 million m3 is recorded to be supplied from forests. It is estimated that fuelwood consumption would go up to 400 million m3 along with increase in industrial demand of wood from 58 in the year 2000 to 153 million m3 in the year 2020 (ibid).

Further, India's 78% forest area is under grazing pressure (FSI 1995) with 270 million cattle grazing inside forests (MoEF 2006a). Additionally 175 to 200 million tonnes of green fodder is also collected from forests through lopping and harvesting of grasses. Man-caused forest fire, predominantly for collection of certain NTFPs and land preparation for shifting cultivation, is adversely affecting 35 million ha of forest area annually (ibid). Around 26 million people in the north eastern states are involved in shifting cultivation on 10 million ha leading to deforestation. According to Manhas et al (2006) shifting cultivation accounts for 23% of the total deforestation in India leading to an annual loss of 0.93 MtC per year.

Thus, understanding the dynamics of forest degradation and their linkages to the nature and extent of existing pressures on forests is crucial to inform the policy process to support REDD+ implementation in the country.

ENABLING FOREST POLICIES: OPPORTUNITIES FOR REDD+ IMPLEMENTATION

The country framework of forest policies is critical to assess the available opportunities and fill the gaps to implement REDD+ actions. Flexible forest policies are required to support the '3E (effectiveness, efficiency, and equity) criteria' (Stern 2008) of REDD+.

The status of forest resources and forest carbon stocks, tenure rights, conservation and co-benefits of biodiversity, quality of communities participation, institutional arrangements are all governed by policies which influence preparedness and possibilities of successful implementation of REDD+. Thus, it is imperative to analyze India's forest policy and practice in order to identify associated challenges and to design appropriate measures and mechanism to overcome them.

India has several conservation oriented forest policies and legislations which shape forest management practice in the country. In the context of REDD+, key policy instruments are Indian Forest Acts, Wildlife (Protection) Act 1972, Forest (Conservation) Act 1980, National Forest Policy 1988, June 1990 Guidelines for Joint Forest Management, Biological Diversity Act 2002, National Environment Policy 2006, Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006, National Biodiversity Action Plan (NBAP) 2008, and Green India Mission 2010.

Indian Forest Acts (1865, 1978, and 1927)

In 1864, forest department was created to manage forests; and, to provide a legal framework for its working, the first Indian Forest Act was enacted in 1865. This Act created state monopoly in the forests for the first time in the Indian history (Guha 1990). The Forest Act of 1865 was later replaced with a comprehensive Indian Forest Act in 1878. The Indian Forest Act of 1878 introduced the concept of 'reserved' forests, 'protected' forests, and 'village' forests. The Act of 1878 is considered as watershed in the history of the evolution of forestry regulations in India, as many of its provisions are still in force in the country even after a century (Guha 1996).

The Act of 1878 was replaced in 1927 by a more comprehensive piece of legislation. While retaining most of the provision of the Forest Act of 1878, the Act of 1927 also brought private forests and wastelands under its purview. The Act also provided to regulate shifting cultivation - a practice used by the tribals to raise agricultural crops by clearfelling forests. Under the Act, strict provisions were also made to empower forest officers in matter of controlling forest offences. The state governments were advised to devise their own rules under the Act. This Act is still in force, and provides basis for forest administration in the country through state forest departments.

Many state governments have incorporated amendments in the Act to make it more stringent mainly to control illicit removal of timber from the forests. Concerned with the increase in deforestation and consequent environmental degradation in the 1980s, state forest departments suggested further hardening of the rules in the form of draft Forest Act of 1981. The draft Act, however, was abandoned in view of sustained opposition from many corners seeking increased participation of local communities in forest management (Guha 1983; Jeffrey and Sundar 1999; Kulkarni, 1982).

Wildlife (Protection) Act, 1972

The Wildlife (Protection) Act, 1972 and its amendment in 2002 provides for the protection of wild animals and plants, and creation of a network of protected areas such as national parks, wildlife sanctuaries, conservation reserves, and community reserves.

Forest (Conservation) Act, 1980

The Forest (Conservation) Act of 1980 was borne out of concerns raised about alarmingly high rate of deforestation; between 1951-1980, 4.328 million-ha of forestland was diverted to non-forestry purposes mainly to agriculture, river valley projects, and industrial purposes (Lal 1992). The Act forbade de-reservation and deforestation of forestland by the states for non-forestry purposes without prior concurrence of the central government thus bringing forests effectively under the Central control (Arnold and Stewart 1991). The Act was further amended in 1988 to bring a ban on clearfelling, and brought commercial crops such as coffee, tea, and rubber plantations also under its purview. The Act has been successful in reducing the rate of deforestation of forestland from 0.15 million ha per year to about 1,600 ha per year (FSI 1997).

National Forest Policy, 1988

In the 1980s, growing concerns related to deforestation and the intensification of social conflicts over forest resource use increased pressure on the government to reorient its forest policy towards the needs of forest-dependent communities. The result was promulgation of a new forest policy by the Government of India in 1988.

The policy of 1988 aims to combine the objectives of environmental stability and bio-diversity conservation with those of social justice (Sarin et al 1998). The policy explicitly prohibits clearfelling of natural forests and introduction of exotics, and desires that no forest should be worked without government approved working plans. The policy recognizes that forests in the country have suffered serious depletion owing to "relentless pressure arising from ever-increasing demand for fuelwood, fodder and timber, inadequacy of protection measures, diversion of forest lands to non-forest uses without ensuring compensatory afforestation and essential environmental safeguards, and the tendency to look upon forests as revenue earning resource" (GoI 1988).

The policy subordinates revenue considerations to the needs of forest conservation. It also discourages: (1) the diversion of forests for non-forestry purposes; (2) allotment of forestlands to industries for raising plantations; and, (3) supply of forest products to the industries at concessional rates. While maintaining its target to have one-third area of the country under forest cover, the policy desired to have massive afforestation programme for fuelwood and fodder development, especially on all denuded, degraded, and unproductive lands. The policy also desired to modify laws to encourage individuals, institutions, and especially the weaker sections to undertake tree plantation.

The policy recognized the rights and concessions of the rural communities by considering the domestic requirements of poor forest-dwellers and tribals for fuel-wood, fodder, minor forest products, and construction timber as the first charge on the forests. Moreover, for the first time, the policy envisaged creation of "a massive people's movement with the involvement of women" (GoI 1988) to achieve its objectives and to reduce pressure on forests.

The June 1990 Guidelines: Joint Forest Management

In the background of emerging consensus among policy planners and increased advocacy about the need to involve people in forest management, the Ministry of Environment and Forests (MoEF), Government of India in June 1990 issued executive instructions to all the state governments paving the way for peoples' involvement in forest management. The instructions envisaged involvement of village communities, suitably interfaced with voluntary agencies wherever possible, with the state forestry departments for protection, afforestation, and development of degraded forestlands especially in the vicinity of habitations. It also provided guiding principles for joint management and usufruct sharing between the village communities and the state forest departments (MoEF 1990).

The policy became successful in prompting various state governments to devise operational frameworks for participatory forest management. In 2000, the Ministry of Environment and Forests, Government of India, issued another set of guidelines to the state governments to strengthen the JFM process in the country. Its major provisions include legal backup for JFM committees, extension of JFM in good forest areas, and provisions for enhanced participation of women in the process (MoEF 2000).

Biological Diversity Act, 2002

The Act has a reference to the Convention on Biological Diversity (CBD) which recognizes the sovereign rights of States over their natural resources. The Act regulates access to genetic resources and associated sharing arrangements along with development of policies and programmes for long term conservation and protection of biological resources of the country.

National Environment Policy, 2006

The policy recommends formulation of an innovative strategy for increase of forest and tree cover to 33 percent in 2012, through afforestation of degraded forest land, wastelands, and tree cover on private or revenue lands. One of the key elements of the strategy is "implementation of multi-stakeholder partnerships involving state forest departments, land owning agencies, local communities, and investors, with clearly defined obligations and entitlements for each partner, following good governance principles, to derive environmental, livelihood, and financial benefits" (MoEF 2006c). The policy also calls for enhancing the density of natural forests, and universalization of community based practices.

Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006

Considering the past anomalies that resulted from the declaration of tribal and other lands as state forests without proper settlement of rights, the Act, also referred as Forest Rights Act, was formulated. The Act has provisions of settling tenure and other rights to forest dwelling communities and individuals. Although there are several complex issues which are to be addressed under the Act, it would incentivize forest dwelling communities to participate in REDD+ actions.

National Biodiversity Action Plan (NBAP), 2008

Drawing upon the fundamental principal of the National Environment Policy, 2006 that human beings are at the centre of concerns of sustainable development, and attempting to provide a focus and impetus to the country's efforts towards biological conservation, the NBAP is central to achieving the objectives of the CBD. The NBAP takes into account ecosystem approach, and describes the major threats and constraints facing biodiversity conservation.

Various objectives and provision of NBAP are relevant and in consonance with the safeguards of 'conservation of natural forests and biological diversity' for REDD+ actions as noted in decision 1/CP.16 (UNFCCC 2011a). The NBAP considers the global threat of climate change, and promotes holistic approach to conservation, enhancement, and sustainable utilization of biodiversity. The action plan calls for protecting and strengthening *in situ* as well as *ex situ* conservation measures. The recommendation of NBAP to integrate biodiversity concerns into different policies, plans, programmes, and projects ensures safeguarding the 'conservation of natural forests and biological diversity' under REDD+ implementation in the country. The NBAP also aims at developing and integrating biodiversity information from diverse sources into a national database, and inventorization of country's floristic, faunal, and microbial resources with special attention to endangered and endemic species. This requirement of NBAP would be helpful in developing systems under REDD+ for providing information on safeguards related to biodiversity and natural forests conditions.

Further the action plan emphasizes to assign appropriate market value to the goods and services provided by various ecosystems and incorporation of these costs into decision making, management, and sustainable utilization of biological resources to encourage more efficient allocation of resources while making country level investment decisions.

The Green India Mission, 2010

The Green India Mission (GIM), one of the eight Missions under the National Action Plan on Climate Change (NAPCC), recognizes that climate change will seriously affect the forest resources of the country, and the associated livelihoods of the people. The Mission puts the "greening" in the context of climate change adaptation and mitigation, and aims at addressing climate change by enhancing carbon sinks in sustainably managed forests and other ecosystems; enhancing the resilience and ability of vulnerable species/ecosystems to adapt to the changing climate; and, enabling adaptation of forest dependant local communities in the face of climatic variability (MoEF 2010b).

Taking a holistic view of forestry, the GIM proposes not only to increase the quantity of forest and tree cover on 5 million ha of lands but also the quality of forest cover on another 5 million ha of lands with involvement of revamped JFM committees and decentralized governance. The GIM aims and objectives of improving ecosystem services including biodiversity, hydrological services, and enhanced annual CO2 sequestration by 50 to 60 million tonnes in the year 2020 with increased forest-based livelihood income of about 3 million households living in and around the forests (ibid) aligns well with the REDD+ activities and safeguards.

The GIM is the manifestation of India's support for the policy of conservation, sustainable management of forests, and increase in forest cover as important instrument of mitigating climate change. Various Mission activities would result in conservation and enhancement of forest carbon stocks, thus, helping in improving the mitigation potential of forests.

ESTABLISHING NATIONAL REDD + ARCHITECTURE: CHALLENGES OF IMPLEMENTATION

The concept of REDD+ developed as a global initiative and until recently much of the debate has been focusing on its global architecture. Although the incentives for participation in REDD+ are being set at the international level under UNFCCC negotiations, implementation of REDD+ needs action at national, regional, and local levels.

The global architecture as defined under the Cancun Agreements provides direction and guidance to REDD+ participating countries for establishing their national REDD+ architecture. Establishing REDD+ involves a national architecture or structure that facilitates comprehensive planning and actions to deliver efficient, effective, and equitable forest based carbon mitigation along with co-benefits of biodiversity, conservation of natural forests and environmental services, and poverty alleviation.

Globally more than 60 countries are developing national REDD+ strategies and frameworks, and hundreds of REDD+ demonstration/pilot projects financed through bilateral, multilateral, and international donor agencies like UN-REDD+ Programme, and the Forest Carbon Partnership Facility (FCPF) managed by the World Bank outside the UNFCCC REDD+ mechanism are being implemented in order to build capacity and gain experience within countries for full implementation of REDD+ actions, and to inform the policy process of REDD+ under the UNFCCC. Currently India do not have a firm national REDD+ architecture or REDD+ strategy and institutions for implementation nor any demonstration/pilot REDD+ project. Nevertheless, India's keen participation in REDD+ negotiations under the UNFCCC, reference of implementation of REDD+ actions within country in submission to UNFCCC (UNFCCC 2011b), and country's ambitious programme in forestry sector - 'GIM' indicate the intent and commitment of the GoI to implement the REDD+ actions in the country.

Any efficient and effective national REDD+ architecture is required to meet the challenges of establishing a national coordination mechanism, MRV systems, finance and equitable benefit sharing, and communities participation. The following sub sections will outline and examine some of the important issues and debates relevant to these challenges of REDD+ implementation.

NATIONAL COORDINATION MECHANISM

The mandate of developing a national strategy or action plan in accordance with national circumstances has been assigned to the national governments under the Cancun agreements decision 1/CP.16 (UNFCCC 2011a). Accordingly national government has to own the REDD+ process and implementation in the country. The Ministry of Environment and Forests (MoEF) is the coordination unit for implementation of NAPCC that addresses climate mitigation and adaptation programmes in the country through eight National missions. The MoEF also deals with the environment and forests administration in the country. The overall responsibility for REDD+ process and implementation lies with the MoEF.

At the international level, the GoI is actively engaged in REDD+ discussions, and has been successful in expanding REDD to REDD+ with inclusion of plus activities. At the national level, however, the related processes are still at a very early stage. In many developing countries willing to participate in REDD+ mechanism, steps towards development of national REDD+ strategy and pilot projects were initiated as early as 2008, any such initiative in a concrete way is yet to be taken by the MoEF. One of the reasons towards slow progress on REDD+ in the country is the non availability of external funding in India for pilot REDD+ projects. Until recently agencies like UN REDD Programme and FCPF of the World Bank were supporting only REDD pilot and demonstration projects in tropics, and plus activities in countries like India that practice conservation oriented forest management were not considered suitable for financial and technical support. Now when FCPF and UN REDD Programme have started funding support to plus countries, India is yet to express its interest to join these agencies and receive external funds for pilot REDD+ projects.

The MoEF has established a 'Coordinating Committee' in its forestry wing in January 2011 to deal with issues related to climate change and forests. In its very first meeting, the 'Coordinating Committee' considered the need for setting up a small unit of REDD+ Cell in the MoEF to provide an institutional forum to deliberate upon the policy, technical and methodological related to REDD+ under the guidance of the 'Coordinating Committee'. Noting that a majority of interventions under the Mission have potential to qualify under the REDD/REDD+, the flagship programme of GIM mentions that a REDD+ Cell would be set up within the Mission directorate under the overall guidance. It is envisaged that the Cell will have the task of creating awareness and capacity building on the REDD+ process for all stakeholders, including the community institutions, and a comprehensive REDD+ strategy would be worked out through an inclusive process. Although the need to establish a REDD+ Cell under the guidance of MoEF has been agreed upon in principle to coordinate REDD+ activities at the national level, and the GoI submission to the UNFCCC states that India has established a REDD+ Cell in the MoEF (UNFCCC 2011b), the REDD+ Cell is yet to take shape on ground and initiate dialogue with relevant stakeholders and take up the task of coordinating REDD+ activities within the country. To step forward, engagement of REDD+ Cell in the following tasks is the urgent need of the hour:

1. Developing a national REDD+ strategy and action plan including a legal framework of REDD+ implementation linking existing policies and legislations
2. Identifying and analyzing the scope of REDD+ activities for national implementation in the current status of forest resources and socio-economic pressures
3. Aligning the strategy with other development strategies of the country like NAPCC and GIM
4. Identifying stakeholder groups, and initiating consultations with state governments, technical institutions, JFM committees, forest dependent communities and local farmers, the private sector, civil society, political leaders, and other relevant stakeholders
5. Specifying the rights and responsibilities of different levels of governments; and, developing equitable benefit sharing mechanism from national to local level
6. Identifying plausible sources of finance for REDD+ activities including international ones specifically for phase one and two, i.e., capacity building and demonstration/pilot projects
7. Identifying and establishing the network of technical institutions to put in place MRV of REDD+ actions
8. Coordination, monitoring, and reviewing the implementation at national level
9. Interaction and reporting to relevant international bodies.

INSTITUTIONALIZATION OF MRV SYSTEMS

Participation in REDD+ mechanism requires countries to put in place a national reliable and credible system of measuring, reporting, and verifying changes in forest carbon stocks. It is well recognized that capacity building of developing countries is the most fundamental issue to move towards fulfilling various technical aspects of a REDD+ methodology including development and administration of the MRV system (Peskett and Brockhaus 2009). India along with China and Brazil is one of the few developing countries which has institutional and infrastructural capacity while others need more concrete efforts and support to build scientific and technical capacity and expertise for establishment of institutions to meet the technical requirements of REDD+ (Singh and Rawat 2009).

Globally, India is among very few countries which have an operational system for wall-to- wall mapping of forest cover biannually. In India, Forest Survey of India (FSI) has been undertaking a regular systematic programme of monitoring country's forest cover since 1987 using remote sensing techniques. FSI has also been carrying out a national project for forest type mapping to map forest types of India according to Champion and Seth classification that divides India's forests into 16 forest groups/major types and 221 sub-group types. The project has resulted into a series of forest maps showing different sub group types of the country on 1:50,000 scale. Recently considerable technological advancement has been made in FSI methodology related to forest resource mapping. It is now possible to measure increase/decrease in forest cover with a fair degree of accuracy at national level and hence GHG capture or emissions respectively. India has the capacity to develop a national level 'Forest Carbon Accounts' every five years on the basis of the assessment of forest cover in three categories of crown density (10-40%, 40-70%, >70%), above and below ground biomass in different forest types, and soil organic carbon (SOC) in different forest types (UNFCCC 2009).

Under Second National Communication (SNC) of India to UNFCCC, an estimation of biomass carbon and SOC of the country's forests has already been made. FSI has assessed India's forest carbon stocks for the years 2005 and 2007 following a GIS approach and using forest types maps based on Champion and Seth classification. It is observed that forest carbon stocks have increased from 7,289 million tonnes in 2005 to 7,326 million tonnes in 2007, and 135.7 tonnes of CO_2 has been removed from the atmosphere (Ashutosh 2010).

Under SNC, estimation of SOC in India's forests was also taken up by Indian Council of Forestry Research and Education (ICFRE). As per Champion and Seth classification, all 16 forest groups divided into forest sub-group types were identified on ground as basic unit for soil sampling; and, standard method of Walkley and Black (Jackson, 1973) was used for SOC estimation. SOC was aggregated for each major forest type, and finally at country level. ICFRE (2010) study on SOC showed that due to increase in forest cover during 1995-2005, soil in Indian forests acted as a net sink of 203.3 mt of carbon.

The procedure followed under the SNC for estimation of biomass carbon and SOC has the potential of being developed and adopted as a REDD+ methodology for assessing and monitoring changes in forest carbon stocks over a stipulated period. FSI with a network of national institutes - ICFRE, Indian institute of Remote Sensing (IIRS), Indian institute of Science (IISc), and Wildlif Institute of India (WII) - has been identified as the lead institution in the country for national forest carbon stocks accounting and monitoring (UNFCCC 2011b). It is also envisaged that in future state forest departments (SFDs) would undertake the responsibility of carrying out the assessment and estimation of forest carbon stocks in conjunction with the biennial exercise of assessment of forest and tree cover (ibid).

FINANCING REDD+ IN INDIA

A number of donors are making initial investments to support the national and local capacity, and demonstration projects in many REDD+ countries. In India, however, none of these donor supported REDD+ activities have been initiated.

India seeks REDD+ funds for its flagship forestry programme of GIM in the interest of global climate protection (Sharma 2010). The GoI submission to UNFCCC notes that its initiatives like GIM and National Afforestation Programme together with programmes in sectors like agriculture and rural development would annually add or improve 2 million ha of forest and tree cover leading to an annual incremental addition of 2 million tonnes of carbon. This would require an investment of USD 2 billion every year for 10 years; and, a substantial part is expected to be met from REDD+ financial support from UNFCCC (UNFCCC 2011b). Thus, India intends to make initial investments for REDD+ activities on its own but expects UNFCCC funds in future to support its domestic initiatives. However, it is important to note that any REDD+ specific fund allocation for developing or upgrading capacity of national institutions and multiple actors intended to be involved in full implementation of REDD+ as per UNFCCC requirements is yet to be done along with establishing the mechanism to link current policy and legal framework, and programmes to REDD+.

COMMUNITY PARTICIPATION

Finance and technology are not the only important factors when implementation of REDD+ actions is considered. As livelihood of communities living in and around forests is highly influenced by the availability of a number of forest products and ecosystem services of forests, REDD+ actions are required to integrate local communities' concerns and participation as well. Although the international architecture for REDD+ is providing the framework for implementation, several issues related to social implications are linked to national implementation strategy and policy.

In India, REDD+ is considered "an additional co-benefit" (MoEF n.d.) to communities who are already enjoying a number of goods and services from forests under current legislative framework of the country. It is argued that "REDD+ will not adversely impact on the traditional and legal rights of the local communities over forests, but … will ensure more monetary benefits flowing to them" (ibid). Further it is suggested that passing REDD+ incentives to local communities will ensure sustained forest protection against deforestation.

According to GoI, the existing policy framework and institution of JFM encouraging participation of local communities in forest management and protection will be linked to the implementation of REDD+ action in India. JFM is an incentive-based strategy in which benefits, accruing from successful resource management, are shared between the state forestry departments and the local communities and within the communities. Incentives to local communities in JFM arise from economic gains in the form of a share in the final produce that ranges from 25-80% in different states (Sarin *et al.* 1998), usufructs sharing from intermediate yield, collection of NTFPs, and wage employment. Several authors have carried out economic analyses of JFM under various conditions and found that JFM, in the long run, is economically attractive to communities (Hill and Shields 1998; Kant and Nautiyal 1994; Tewari 1996). While ensuring all existing benefits of JFM, REDD+ has the opportunity to add monetary carbon benefits to communities.

Nevertheless, the debate around equitable distribution of benefits in JFM is also critical to successfully involve and protect interests of all forest user groups in REDD+ actions as well. Different user groups in a community may have different reasons for participating in REDD+. Therefore, the incentives in REDD+ require the needs of these groups to be assessed and addressed. Furthermore, "different classes will require different degree of assurance… and classes that are more vulnerable will want assurance of alternative means of subsistence in the short run and high degree of long-term assurance about the sustained supply of resources" (Gupta 1985) beyond monetary benefits under REDD+ mechanism.

As implementation occurs in "settings that are extraordinarily diverse, useful generalizations about implementation are not easy" (Khan 1989), aligning REDD+ implementation to JFM policy and practice needs careful consideration, especially benefit distribution from REDD+ to forest communities. Equity is a difficult proposition to achieve. REDD+ needs to take care of equity issues and efforts should be made to ensure that it does not engender further inequality in already unequal rural communities.

CONCLUSIONS

Though international REDD+ architecture defines the design and implementation of national REDD+ activities, the social, economic, and political national context is critical to its success and outcome. The article has identified the available opportunities and enabling policies which have the potential to successfully implement REDD+ actions in the country. However, effective set up of institutional REDD+ arrangements, benefit sharing, wider participation and engagement of multiple actors including local communities, and high level government commitments will be crucial in providing a conducive national REDD+ implementation framework.

Besides attaining the technical capabilities for robust MRV systems, considerations of social impacts of REDD+ will be one of the biggest challenges. Generating confidence and incentivizing forest dependent communities, especially the poor who are heavily dependent on forest resources for livelihoods will be essential to make REDD+ a success story in the country. While international REDD+ architecture is evolving and financial support mechanism is still to be explored, finding innovative ways and research taking into account national realities will help in moving ahead with REDD+ implementation at the National level.

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Eco Clubs Make a Difference in Green India Mission - A Case Study of Subarnapur District of Odisha

Dr Satyanarayan Hota *

INDIA lives in her villages; 80% of total population resides in rural India. Rich environmental resources are still now at our reach. Development is the key of Society. Development can't subsist upon a deteriorating environmental resource base. Environment can't be protected when growth ignores the social and economic costs of environmental destruction. The problems can't be treated separately by fragmented policies and institutions. Environment and Development can't be seen as separate challenges; they are linked in a complex system of cause and effect. Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Development paths of industrialized nations are clearly unsustainable

- Choice of technology
- Patterns of resource use
- Consumption
- Life styles
- Outcome

Taking measures to move towards sustainable choices

"For countries like India the challenge of development is not how to get there but how not to get there." (*India's Report to UNCED 1992)*

CHALLENGES TO SUSTAINABLE DEVELOPMENT

- Policy
- Laws
- Systems
- Technology
- Financial Mechanisms
- Enforcement
- Education & Communication

GLOBAL WARMING IS THE CAUSE OF CLIMATE CHANGE

Global warming does not only mean that the air is too hot. There are many other problems that are linked to

- Agricultural Production level decrease – affect availability of food.
- Climate change is natural.
- Some activities by humans are speeding up the process of climate change

CUTTING TREES AND FOREST

- Creating agricultural fields & cities
- Building dams & road
- Loss of Biodiversity – Plants and animals would be forced to keep up with climate shits.
- Those that can't migrate would disappear in the course of time.

SCHOOL AS A CHANGE AGENT

- Schools are the social institution where thoughts are nurtured and practiced.
- Tender age students are guided by resourceful teachers
- Awareness, knowledge, attitude, skills, actions are streamlined
- Education of students is essential in 'Climate Change' topic in different subjects like geography, literature, mathematics, general Science, etc.

Eco Clubs make a difference

- Schools are runs with different students clubs - Eco Clubs, Consumer Clubs, Science Clubs, Legal Aid Clubs, etc.
- Eco club activities can make a difference by knowing 'Climate Change'.
- Project works makes the children aware and develop culture.

Strength of Eco Club

In India now we have

* 1.20 lakh schools (UP, Secondary, Higher Secondary Level)
* 35 lakh students (Registered Members)

Odisha State

- 30 Revenue districts
- 7,500 Eco clubs in THE STATE
- 30-50 student members in each Eco club

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SUBARNAPUR DISTRICT

- 250 Eco clubs in the district
- 10,000 students registered members in the district

Knowledge of the students

- Students of rural schools are aware of Climate Change.
- Plantation in the school campus reduced GHGs.

SMALL STEP VISIBLE

- Polythene free zone-School Campus
- Use of dustbin
- Creation of separate pit for Bio-degradable and Non Bio-degradable substances
- Replace Polythene – Use of Paper 'Thunga'
- Use of Sal Leaf Hand made Container “DANA” at snacks time (Long Recess)

CONTRIBUTING TO RURAL LIVELIHOODS

Subarnapur District is under KBK region of Odisha.

* Tribal dominated
* Forest product cottage industry based livelihood of tribal family.
* Low income group.
* Daily labour type work culture

CONSEQUENCES

- The livelihood of tribal household is under risk.
- Due to climate change, Sal Tree became less available.
- Traditional bread earning is in danger.
- Cultural needs can be hamper in the coming days.

Carbon Sequestration Potential of Soil under Different Agroforestry Land Use Systems in Poanta Area of Himachal Pradesh

Bilal Ali Khaki* and Akhlaq A. Wani**

INTRODUCTION

The debate on atmospheric build up of GHGs and their role in global warming by conference of the parties to the United Nations Frame work Convention of Climate Change (UNFCCC) in 1997, in Kyoto, Japan, culminated in urging the participating countries to find ways of reducing GHGs concentration in the atmosphere. Carbon reduction targets could be achieved through two major processes viz. reducing anthropogenic emissions of CO_2 and Creating and/or enhancing carbon sinks in the biosphere.

Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter and root residues into the soil. There is a large potential of sequestering carbon in soil and vegetation by adopting suitable agroforestry systems on salt affected soils (Singh and Singh 1997). In Haryana India, Bhojvaid & Timmer (1996) reported a large increase in soil organic carbon content by reclamation of sodic soils through growing *Prosopis juliflora*.

The soil organic carbon pool in the top 1 m depth of world soils ranges between 1,462 and 1,576 Pg. It is nearly three times that in the above ground biomass and approximately doubles that in the atmosphere; 32% of this is contributed by soils in the tropics. (Eswaran *et al*., 1993). Kern and Johnson (1993) reviewed data from 17 fields comparing no tillage with conventional tillage plots in USA and observed that soil organic carbon gains were 27 per cent for the 0-8 cm layer, 16% for the 8-15 cm layer and no gains for depth > 15 cm. In tropical zones a significant impact on soil organic concentration has been observed for 0-10 cm layer (Bayer *et al*., 2000 & Lal, 1996). In western Nigeria, Lal (1996) observed that the soil organic carbon (SOC) of the surface 10 cm layer declined by about 50% within 10 years after deforestation and cultivation. In the Ivory Coast, (Traore & Harris, 1995) reported that the soil organic carbon content declined steadily with duration of cultivation, In Australia, (Dalal & Carter, 2000) reported that the SOC pool in the 10 cm layer decreased with cultivation duration from 7.5-22.1 to 4.4-10.2 Mg C ha^{-1}. The rate of loss was lower in coarse textured soils. In Argentina, Rosell & Galantini (1998) reported decrease in soil organic carbon content from 2.71-1.54% after 11 years of cultivation.

Lal (1995) estimated the SOC loss from the tropical ecosystem caused by a wide range of agricultural activities. Estimates of the historic SOC loss included 2-13 Pg C by deforestation. The current rate of SOC loss was 90-219 Tg C yr^{-1} because of tropical deforestation, 3.8 -9.2 Tg C yr^{-1} by shifting cultivation, 112-276 Tg C yr^{-1} by annual burning of grass lands, 38-92 Tg C yr^{-1} by plowing of cropland, 55-133 Tg C yr^{-1} from pastures and 2-3 Tg C yr^{-1} from cultivation of peat soils.

In Nigeria (Jaiyeoba (1998) monitored changes in soil properties following conversion of Savannah woodland into *Pinus oocarpa* and *Eucalyptus camaldulensis* plantations. The SOC content of 0-0.15 m depth declined during initial stages of tree establishment and increased thereafter to a steady equilibrium value, attained in about 16 years. The initial decline was apparently due to the near absence of ground cover and low biomass production. According to Ball *et al*. (1999); Low or zero CO_2 fluxes under no tillage are associated with reduced gas diffusivity and air filled porosity, while increased CO_2 emission with ploughing is due to degassing of soil CO_2.

STUDY AREA

The present investigation was conducted during January-June 2007. Poanta valley is located at an elevation of 350 mts a.m. s. l. It is on the western extreme of the Doon Valley distance of about 55 km from Dehradun representing 30º 26'N latitude and 77º 37' E longitude. It has a sub-tropical continental monsoon climate characterized by a seasonal rhythm, hot summers, slightly cold winters unreliable rainfall and great variation in temperature (0^0C to 40^0C). In winters, frost sometime occurs during December and January. It also receives occasional winter rains from the western disturbance.

MATERIAL AND METHODS

Six agroforestry systems were selected viz. Hortipastoral system (HP) (Mango + natural grasses), Silvi-pastoral system (SP) (*Dalbergia sissoo* + natural grasses), Agri-silviculture system (AS) (Sal + wheat), Horti-silvi-pastoral system (HSP) (Mango

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Table 1: **Agroforestry Systems and Tree Combinations in the study area**

Agroforestry system type	Code	Tree crop combination	Net cropped area m^2	Area under trees m^2	Area under grasses m^2	No. of trees/ hectare	Age of the land use system
Hortipastoral	HP	Mango+ Litchi + natural grasses	-	1000	9000	100	12
Silvi-pastoral	SP	Dalbergia+ natural grasses	-	1300	8700	400	12
Agri-silviculture	AS	Sal + wheat	9000	1000	-	60	12
Horti-silvi-pastoral	HSP	Mango+ Litchi+poplar+Natural grasses	-	1400	8600	144	12
Pure forest	PF	Sal	-	10000	-	200	40
Natural grassland	NG	-	-	-	10000	-	-

+ Poplar + natural grasses), Pure Fores (F) (Sal), Natural grass land (NG) (Pure grasses).Two soil depths have been taken as D1 (0-20) cm and D2 (20-40) cm and three replications of each with Randomised Block Design (RBD) were taken for analysis. Six agroforestry systems formed main plot treatment and sampling depth as sub plots. Various tree crop combinations have been taken as given in table 1.

Soil samples were collected by dividing each main plot area into five sub areas each 10 x 10m. Soil samples for each sub area were obtained by digging five profiles of (20 x 20) cm (sub-surface area) up to 50 cm deep. Composite samples from all sub area were obtained for each depth. Samples were air dried in shade, ground with wooden pestle, passed through 2mm sieve and stored in cloth bags for further laboratory analysis. The physico-chemical attributes of soil were calculated. Bulk density (g cm^{-3}) was calculated using specific gravity method and soil organic Carbon (%) using (Walkley & Black, 1934). The soil organic carbon pool inventory expressed as Mega grams ha^{-1} (Mg ha^{-1}) for a specific depth was computed by multiplying the soil organic carbon (g kg^{-1}) with bulk density (g cm^{-3}) and depth (cm) (Joao Carlos *et al*., 2001).

RESULTS AND DISCUSSION

The data obtained were subjected to statistical analysis using RBD of experimentation as per the procedure suggested by (Gomez & Gomez, 1984). Wherever, the effects exhibited significance at 5 per cent level of probability, the critical difference (CD) was calculated. Analysis was carried out on computer using the package "STATISTICS".

Different land use system due to their structure, function and tree species included and the management to which each system is put reflects wide variability both in production potential and the carbon stored in the defined agroclimatic region. The Soil status levels obtained and the carbon stored in the soil through different land use systems have been described in this chapter under the following heads:

Soil physico-chemical properties of different land uses

Soil physico-chemical properties viz., bulk density, percent soil organic carbon (SOC) and soil organic carbon stock in total were determined land uses wise and the same were depicted as below:

Bulk density (g cm^{-3})

A critical examination of the data presented in Table 2 evinced significant variations in the bulk density (BD) values for different land use systems. Under 0-20 cm depth, Natural grass land showed the significantly higher value of 1.28 g cm^{-3} among all the systems. It was followed by Hortipastoral system (1.26 g cm^{-1}), Silvipastoral (1.24 gm cm^{-3}) and Agrisiliviculture system (1.24 g cm^{-3}) and then Hortisilvipastoral system (1.23 g cm^{-3}). The lowest bulk density value of (1.16 g cm^{-3}) was found in Pure Forest system.

In 20-40 cm depth, the results also showed significant variation. Natural grassland and Agrisilviculture showed the significantly higher value of 1.32 g cm^{-3} among all the systems. It was followed by Pure Forest system (1.31 g cm^{-3}), Silvipastoral system (1.30 g cm^{-3}) and Hortipastoral system (1.29 g cm^{-3}). The lowest density of 1.28 g cm^{-3} was found in Horti-Silvipastoral system.

Table 2: **Effect of land use systems on bulk Density (g cm^{-3}) at different soil depths**

Land use systems	Bulk density		Mean
	0-20 cm	20-40	
Hortipastoral system (HP)	1.26	1.29	1.275
Silvipastoral system (SP)	1.24	1.30	1.270
Agrisiliviculture system (AS)	1.24	1.32	1.28
Hortisilvipastoral system (HSP)	1.23	1.28	1.260

Pure forest (F)	1.16	1.31	1.240
Natural grassland (NG)	1.28	1.32	1.30
SE ±	0.0018	0.0019	
$CD_{0.05}$	0.0042	0.00437	

Percent Organic Carbon

Soil organic carbon (SOC) was influenced significantly due to various Agroforestry systems. Data in Table 3 revealed that soil organic carbon under soil depth 0-20 cm was highest under Pure Forest system (3.64%) which was followed by Hortisilvipastoral system (1.85%) and Agrisilviculture system (1.69%). The Silvipastoral system showed lowest (1.30%) soil organic carbon.

In soil depth of 20-40 cm, soil organic carbon was higher under Pure forest system (2.03%) which was followed by natural grass land (1.26%) and Hortipastoral system (1.12%), respectively. The Horti-Silvipastoral system showed lowest (1.04%) soil organic carbon.

Soil organic carbon in 0-40 cm soil range was significantly highest in Pure forest (2.84%) followed by Horti-Silvipastoral (1.45%), Agrisilviculture (1.38%), Natural Grassland (1.35%) and Hortipastoral system respectively in the descending order.

Table 3: **Effect of agroforestry systems on soil organic carbon (g cm^{-3}) at different soil depths**

Land use system	Soil organic carbon (%)		Average
	0-20 cm	20-40 cm	0-40 cm
Hortipastoral system (HP)	1.42	1.12	1.27
Silvipastoral system (SP)	1.30	1.07	1.19
Agrisiliviculture system (AS)	1.69	1.06	1.38
Hortisilvipastoral system (HSP)	1.85	1.04	1.45
Pure forest (F)	3.64	2.03	2.84
Natural grassland (NG)	1.43	1.26	1.35
SE ±	0.063	0.018	0.0405
$CD_{0.05}$	0.148	0.041	0.094

Soil Organic Carbon stock (tonnes ha^{-1})

Soil organic carbon stocks were calculated by multiplying the organic carbon with weight of the soil for a particular depth and expressed as tonnes ha^{-1}. The various land use systems influenced SOC stocks significantly. A critical examination of the data in Table 6 indicated that in 0-20 cm depth, pure forest system showed significantly higher (84.31 tonnes/ha) SOC stock.

Hortisilvipastoral system exhibited (45.409 tonnes/ha) SOC stock on a par with that of Agrisilvicultural system (41.816 tonnes/ha). The Silvipastoral system shows that lowest SOC stock of (32.175 tonnes/ha) Data in Table 4 also indicated that in 20-40 cm soil depth Pure Forest showed significantly higher (53.07 tonnes/ha) SOC stock. It was followed by Natural grass land system with a value of 33.13 tonnes/ha. Silvipastoral system and Agrisilvicultural system did not show much variation. Agrisilvicultural system shows SOC stock value of 27.92 followed by Silvipastoral system which show SOC stock value of 27.74 tonnes/ha.

The Horti-Silvipastoral system under soil depth 20-40 cm showed the lowest SOC stock value of 26.566 tonnes ha^{-1}. The total soil organic carbon stock i.e. carbon stock in soil depth 0-20 cm plus carbon stock in soil depth 20-40 cm for different Agroforestry systems followed the followings order: PF> HSP>AS>NG>HP>SP. In general, Soil Organic Carbon (SOC) in the 0-20 cm layer was quite higher than that of 20-40 cm layer.

Table 4: **Soil Organic Carbon stock (SOC) under different land use systems at different soil depths (tonnes/ha).**

Land use systems	Total carbon stocks		
	0-20 cm	20-40	Total
Hortipastoral system (HP)	35.70	28.90	64.6
Silvipastoral system (SP)	32.175	27.74	59.91
Agrisiliviculture system (AS)	41.816	27.92	69.73
Hortisilvipastoral system (HSP)	45.409	26.56	71.96
Pure forest (F)	84.31	53.07	137.38
Natural grassland (NG)	36.52	33.13	69.65
Mean	45.98	32.88	78.87

Soil organic carbon inventory

Soil organic carbon pool inventory for a particular system was determined by multiplying bulk density (g cm^{-3}), organic carbon (g kg^{-1}) and depth (cm), which was expressed as Mg ha^{-1}. Data in Table 5 reveals that the soil organic carbon pool under pure forest system was maximum (843.0 Mg/ha) in soil depth 0-20 cm and significantly higher than all other systems. Under soil depth 0-20 cm, Pure Forest system was followed by Horti-Silvipastoral system (454.0 Mg/ha), Agrisilviculture system (418.1 Mg/ha) and the Silvipastoral system showed lowest (321.7 Mg/ha) value of SOC pool. Under the soil depth of 20-40 cm, Pure forest system showed again the maximum SOC pool value of (530.7 Mgha^{-1}). This is followed by Natural grassland system (331.3 Mgha^{-1}). The Hortisilvipastoral showed the minimum SOC pool value of (265.6 Mg/ha) under the soil depth of 20-40cm. The total SOC pool for different Agroforestry system followed the following decreasing order: PF (1373.7 Mg/ha) > HSP (719.6 Mg/ha) > AS (697.3 Mg/ha) > NG (696.5 Mg/ha) > HP (646 Mg/ha) > SP (599.1 Mg/ha).

Table-5: **Effect of different land use systems on soil organic carbon pool (Mg/ha)**

Land use systems	Carbon inventory		Total
	Depth 0-20 cm	Depth 20-40 cm	
Hortipastoral system (HP)	357.0	289.0	646
Silvipastoral system (SP)	321.7	277.4	599.1
Agrisiliviculture system (AS)	418.1	279.2	697.3
Hortisilvipastoral system (HSP)	454.0	265.6	719.6
Pure forest (F)	843.0	530.7	1373.7
Natural grassland (NG)	365.2	331.3	696.5
Mean	459.83	328.86	788.7
SE±	15.742	5.848	
$CD_{0.05}$	35.075	13.031	

CONCLUSIONS

Various agroforestry systems and natural grassland showed significantly higher value (1.23-1.28) than the pure forest land. The high value of bulk density in the soils is ascribed to the lower soil organic carbon content. Findings are in line with Karan *et al.* 1991, who reported higher values of bulk density in cultivated soils due to low organic carbon content. Bulk density in general increased with the increase in soil depth. Deeper depth shown in Table 2 has higher values than the shallower ones. The lower bulk density value in upper layer of soils profile may have resulted from the dilution of soil matrix (mineral matter) with lesser denser material (organic matter) and improvement in soil aggregation.

Data on SOC reveal that soil organic carbon in 0-20 cm layer was higher under Pure forest (3.64%) which was followed by Hortisilvipastoral (1.85), Agrisilviculture system (1.69) and then Natural grasslands. The increased organic carbon content in soils under Pure forest may be ascribed to more leaf litter accumulation and root turn over from trees (Zegeye, 1999). The greater accumulation of soil organic carbon on the surface is due the incorporation of leaf litter and addition of decayed roots to the upper layers. The higher soil organic carbon under natural forest can be attributed to increased mineralization under forest than other land use systems.

The soil: plant ratio of total carbon stock for different agroforestry systems was highest (34.63) in natural grassland whereas minimum (1.68) in pure forest system. Soil organic carbon pool was also maximum in pure forest systems followed by Horti-silvipastoral system and Agrisilviculture system. The minimum soil organic carbon pool was in silvipastoral system.

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Carbon Sequestration Potential of Biomass under Different Agroforestry Land Use Systems in Poanta Area of Himachal Pradesh

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INTRODUCTION

Global climate change, caused by increased emission of greenhouse gases (GHGs) is likely to affect the agro ecosystems. The concentration of major contributing gases viz., Carbon dioxide, Nitrous oxide and Methane (CO_2, N_2O and CH_4) has considerably increased over the last century and is set to rise further. Among these, continuous increase in CO_2 levels of atmosphere has serious implications for agriculture, forests as well as environment. Current terrestrial (plant and soil) carbon is estimated at 2000 ± 500 Pg, which represents 25% of global carbon stocks (DOC, 1999). The sink option for CO_2 mitigation is based on the assumption that this figure can be significantly increased if various biomes are judiciously managed and/or manipulated.

In agroforestry systems carbon sequestration is a dynamic process and can be divided into phases. At establishment, many systems are likely to be source of GHGs. These follow a quick accumulation phase and a maturation period when tonnes of carbon are stored in boles, stems, and roots of trees and in soils. At the end of rotation period, when the trees are harvested and land returned to cropping (sequential systems), part of carbon will be released back to atmosphere (Dixon, 1995). In case of simultaneous systems like hedgerow inter-cropping, silvi-pasture systems and agri-silviculture systems fate of carbon will be different. Therefore, effective sequestration can only be considered if there is a positive net carbon balance from an initial stock after a few decades (Feller *et al*., 2001).

In India agroforestry is being promoted as an alternate land use system to deal with the problems related to land use sustainability and environmental amelioration yet its real potential needs scientific evidences. Numerous agroforestry systems both natural as well as planted developed in different agro climatic regions of the country have been found highly productive and environmentally suitable. North-West Himalayan region also have variety of land management practices and systems of agroforestry nature. Promising among these have been modified and planted on farm lands of Poanta valley of Himachal Pradesh. Therefore, present study on carbon stock under different land use systems of Poanta valley of Himachal Pradesh is a maiden attempt in this direction.

CARBON SEQUESTRATION AND ITS MITIGATIONS THROUGH PLANT BIOMASS

Kotto-Same-J *et al*. (1997) identified three alternatives to slash and burn agriculture and evaluated them in terms of carbon sequestration. The alternatives were: Commercial cassava cultivation, improved forest conversion and stratified agroforestry. These alternative landuse had the potential to reduce carbon losses over slash and burn practices by 10, 55 and 75 Mg C ha^{-1}, respectively, and also differs greatly in potential to alleviate rural poverty, protect biodiversity and reduce deforestation. Singh *et al*. (2000) found that farm forestry plantations have sequestered nearly 20 million tonnes of carbon. Therefore, farm forestry is the major instrument for increasing carbon sequestration while supplying wood and non-wood products to meet both domestic and market requirements.

Cannel and Milne (1995) reported that carbon storage in the trees, products, litter and soil can be evaluated in terms of long term equilibrium storage or short term rate of storage. These two components vary among forest types in Britain and globally. Plantations harvested at the time of maximum mean annual increment (MAI) will not store as much carbon as mature old growth forests on the same site unless they have long lasting products and/or are very fast growing. Maximum equilibrium carbon storage is generally achieved by harvesting at the time of maximum MAI when the life time of products exceeds the time of maximum MAI.

The amount of carbon sequestered largely depends on the agroforestry system put in place the structure, and function of which are, to a great extent, determined by environmental and socio-economic factors. Other factors influencing carbon storage in agroforestry systems includes tree species and system management (Albrecht & Kandji, 2003). The carbon storage potential of agroforestry systems was estimated between 12 and 228 Mg ha^{-1} with a median value of 95 Mg ha^{-1} (Albrecht

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& Kandji, 2003).Growing trees can improve soil quality, albeit at a slow rate, and sequester carbon in soil and biomass. Kair (*Capparis deciduas*), one such tree is adaptable to the dry lands of North-West India (Gupta *et al*., 1989).

Farm forestry plantations raised on farmer's fields are mainly on marginal lands with low levels of soil carbon. However, the soil carbon in such area rises quite rapidly and can reach levels of normal forest soils in a period of 15 to 25 years (Sampson & Sedja, 1997). Planted forests are known to take up and store carbon at high rate compared to other world land covers, storage rates commonly range from 1 to 8 Mg C ha^{-1} other world land covers, storage rates, commonly range from 1 to 8 Mg C ha^{-1} $^{yr-1}$ and typical mean carbon storage over a rotation period is from 50 to 80 Mg C ha^{-1} (Winjum & Sehroeder, 1995).

STUDY AREA

The present investigation was conducted during January-June 2007. Poanta valley is located at an elevation of 350 m asl. It is on the western extreme of the Doon Valley distance of about 55 km from Dehradun representing 30° 26'N latitude and 77° 37' E longitude. It has a sub-tropical continental monsoon climate characterized by a seasonal rhythm, hot summers, slightly cold winters unreliable rainfall and great variation in temperature (0°C to 40°C). In winters, frost sometime occurs during December and January. It also receives occasional winter rains from the western disturbance.

MATERIAL AND METHODS

Six agroforestry systems were selected viz. Hortipastoral system (HP) (Mango + natural grasses), Silvi-pastoral system (SP) (*Dalbergia sissoo* + natural grasses), Agri-silviculture system (AS) (Sal + wheat), Horti-silvipastoral system (HSP) (Mango + Poplar + natural grasses), Pure Forest (F) (Sal), Natural grass land (NG) (Pure grasses). Six agroforestry systems formed main plot treatment and sampling depth as sub plots. Various tree crop combinations have been taken as given in Table 1.

Stem biomass

To estimate stem biomass of all the trees falling in the plot (10 x 10 m) were enumerated. The diameter at breast height was measured with caliper and height with Ravi's multimeter. Form factor was calculated with Spiegel Relaskope to find out the tree volume using the formula given by (Pressler, 1865; Bitlerlich, 1984).

$$F = 2h_1 /3h$$

Where, F - Form factor, h_1 – height at which diameter is half of dbh, h- Total height

Volume was calculated by Pressler formula (1865) v= f x h x g. Where, v- volume, f- Form factor, h- Total height, g- Basal area, $g = \pi r^2$ or $\pi (dbh/2)^2$, r-radius, dbh-diameter at breast height

Specific gravity

The stem cores were taken to find out specific gravity which was used further to determine the biomass of the stem using maximum moisture method (Smith, 1954)

$$G_f = \frac{1}{\frac{M_n - M_o}{M_o} + \frac{1}{G_{so}}}$$

Where, G_f specific gravity based on gross volume, M_n weight of saturated volume sample, M_o weight of oven dried sample, G_{so} average density of wood substances equal to 1.53. Thus, the weight of the wood was estimated using the formula i.e. mass per unit volume. Mass = average specific gravity of stem wood x volume.

Branch Biomass

Total numbers of branches irrespective of size were counted on each of the sample tree, then these branches were categorized on the basis of basal diameter into three groups viz < 6 cm, 6-10 cm, and > 10 cm. Fresh weight of two sampled branches from each group was recorded separately. The following formula

Table-1: **Agroforestry Systems and Tree Combinations in the study area**

Agroforestry system type	Code	Tree crop combination	Net cropped area m^2	Area under trees m^2	Area under grasses m^2	No. of trees/ hectare	Age of the land use system
Hortipastoral	HP	Mango+ Litchi + natural grasses	-	1000	9000	100	12
Silvi-pastoral	SP	Dalbergia+ natural grasses	-	1300	8700	400	12
Agri-silviculture	AS	Sal + wheat	9000	1000	-	60	12
Horti-silvi-pastoral	HSP	Mango+ Litchi+poplar+ Natural grasses	-	1400	8600	144	12
Pure forest	PF	Sal	-	10000	-	200	40
Natural grassland	NG	-	-	-	10000	-	-

Above ground biomass was estimated by non-destructive method for different plant parts viz., stem, branches, leaf & roots.

Table 2: **Biomass production levels of different land use systems (tonnes/ha).**

Biomass / Systems	Above ground biomass (Tonnes ha^{-1})	Below ground biomass (Tonnes ha^{-1})	Total biomass (Tonnes ha^{-1})	Rate of biomass production (Tonnes $ha^{-1}yr^{-1}$)
Hortipastoral system (HP)	15.26	5.37	20.63	2.06
Silvipastoral system (SP)	32.72	11.50	44.22	3.68
Agrisiliviculture system AS)	34.05	11.97	46.02	3.83
Hortisilvipastoral system HSP)	18.20	6.40	24.60	2.46
Pure forest (F)	134.18	47.16	181.34	4.53
Natural grassland (NG)	3.44	1.03	4.47	4.43
SE ±	5.97	2.0	5.95	
$CD_{0.05}$	13.31	4.45	13.26	

The data presented in table 2 evinced that the maximum above ground biomass (134.18 tonnes ha^{-1}) was produced by pure forest (Sal) which was found to be significantly higher than the all other land use systems.

(Chidumaya, 1990) was used to determine the dry weight of branches:

$$B_{dwi} = B_{fwi}/1 + M_{cbdi}$$

Where B_{dwi} - oven dry weight of branch, B_{fwi}- fresh/green weight of branches, M_{cbdi}- moisture content of branch on dry weight basis

Total branch biomass (fresh/dry) per sample tree was determined as given by:

$$B_{bt} = n_1bw_1 + n_2bw_2 + n_3bw_3 = \sum_{i=1}^{n} nibwi$$

Where B_{bt} – branch biomass (fresh/dry) per tree, Ni- number of branches in the i th branch group, Bwi-average weight of branch of i th group, i = 1, 2, 3, average refers to branch group

Leaf biomass

Leaves from the branches were removed, weighed and oven dried separately to a constant weigh at 80 ± 5°C (Chidumaya, 1990).

Tree biomass

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The tree biomass was converted into carbon by a factor of 0.45 (Woomer, 1999).

Crop, Grass and Underground Biomass

Crop biomass was estimated using 1 m x 1m quadrates. All the crop plants occurring within the borders of the quadrant were cut at ground level and collected samples were weighted, sub sampled and oven dried at 65 ± 5°C to a constant weight. The crop biomass was converted into carbon by multiplying with a factor of 0.45 (Woomer, 1999). Grass biomass was estimated using 1m x 1m quadrates. The total grass biomass occurring within the borders of the quadrat were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 ± 5°C to a constant weight. The grass biomass was converted into carbon by multiplying with a factor of 0.45 (Woomer, 1999). Underground biomass of roots was calculated by multiplying the above ground biomass by a factor of 0.26.

The data obtained were subjected to statistical analysis using RBD of experimentation as per the procedure suggested by Gomez and Gomez (1984). Wherever, the effects exhibited significance at 5 per cent level of probability, the critical difference (CD) was calculated. Analysis was carried out on computer using the package “STATISTICS”.

RESULTS AND DISCUSSION

Different land use system due to their structure, function and tree species included and the management to which each system is put reflects wide variability both in production potential and the carbon stored in the defined agroclimatic region.

Biomass production potential of different land use system

Six different land use systems have shown significant variation in their total biomass production levels. The biomass production level has been divided into above and below ground biomass and the same have been tabulated in Table 2.

Carbon stock under different land use systems

Whole tree carbon stock was significantly higher in pure forest (81.60 tonnes/ha) followed by agrisilvicultural system (20.70 tonnes/ha), Silvipastoral system (19.89 tonnes/ha), Hortisilvipastoral system (11.07 tonnes/ha), Hortipastoral system (9.28 tonnes/ha) and natural grassland system (2.0115 tonnes/ha), in descending order respectively as given in Table 3.

Table 3: **Carbon stock under different land use systems (Tonnes ha^{-1})**

Land use systems	Above ground carbon (Tonnes ha^{-1})	Below ground carbon (Tonnes ha^{-1})	Total carbon (Tonnes ha^{-1})
Hortipastoral system (HP)	6.86	2.41	9.28
Silvipastoral system (SP)	14.72	5.17	19.89
Agrisiliviculture system (AS)	15.32	5.38	20.70
Hortisilvipastoral system (HSP)	8.19	2.88	11.07
Pure forest (F)	60.38	21.22	81.60
Natural grassland (NG)	1.54	0.46	2.01
SE ±	0.02	2.69	2.67
$CD_{0.05}$	0.03	5.99	5.96

CO_2 mitigation potential of different land uses

A critical examination of the data presented in table 4 exhibited significant variations in CO_2 mitigation. The carbon mitigation obtained from a particular agroforestry system type through both above and below ground components has been termed as CO_2 mitigation of the system. The variability in CO_2 mitigation, among the different systems has been described land use system wise in both above and below ground components separately.

Among the six agroforestry system types studied, the data in Table 4 shows the variation in above ground and below ground CO_2 mitigation in different systems. The above ground CO_2 mitigation level was found highest in case of pure forest (220.38 tonnes/ha) and was lowest in grassland system (5.621 tonnes/ha).

Table 4: **CO_2 mitigation levels of different land use systems (Tonnes ha^{-1})**

Land use systems	CO_2 mitigation levels		Total
	Above ground	Below ground)	
Hortipastoral system (HP)	25.03	8.79	33.87
Silvipastoral system (SP)	53.7	18.87	72.59
Agrisiliviculture system (AS)	55.91	19.63	75.55
Hortisilvipastoral system (HSP)	29.89	10.51	40.40
Pure forest (F)	220.38	77.44	297.84
Natural grassland (NG)	5.621	1.67	7.34
SE ±	5.45	3.10	5.30
$CD_{0.05}$	12.13	6.90	12.0

Biomass carbon stocks and carbon mitigation potential

The biomass carbon stock in a particular land use system depends upon it age, structure, functional components and the management. As revealed in table 3 the carbon stored under Pure forest was found to be highest, which is due to the more age of this land use system. Among the four agroforestry system under the present study the Agrisilviculture system stored highest quantity of carbon followed by silvipastoral, Hortisilvipastoral and Hortipastoral system. The carbon storage capacity of natural grassland was least. This is because in natural grassland the biomass in removed from the system every year leaving only the biomass in the underground parts (roots), which has got limited storage capacity. The carbon mitigation potential of different land uses as shown in table 4 followed the same trend as that of carbon stocks.

It is deduced from the above discussion that variability in the carbon stocks of different land use system types depends primarily on its complexity. (Albrecht & Kandji, 2003) have also reported that carbon variability in plant biomass can be high within complex agroforestry systems and productivity depends on several factors including the age, the structure and the way system in managed.

CONCLUSIONS

The results obtained revealed the biomass production level both below and above ground was highest (181.34 tonnes ha^{-1}) in Pure forest system whereas minimum (4.47 tonnes ha^{-1}) in natural grassland. Agrisilviculture system produced the second highest biomass level among the different systems despite having less number of trees (60 tonnes ha^{-1}) over silvi-pastoral system which contained 400 numbers of trees per hectare. The CO2 mitigation was highest in siliv-pastoral system (297.84 tonnes ha^{-1}) followed by Agri-silviculture system, Silvipastoral system, Horti-silvipastoral, Hortipastoral, Natural grassland. The minimum value was in natural grassland system.

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Impact of Insect Disturbance on Forest Carbon Stock Potential: A Case Study on Casuarina

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INTRODUCTION

Increased rate of tree planting is felt very much needful now a days to reclaim waste lands, prevent further ecological degradation and to meet the needs of local communities providing fuel wood through Tree Cultivation in Private Land (TCPL) and Tree Outside Forests (TOF). Plantation forestry has grown phenomenally, accelerated by government departments and farmers as a commercial activity incorporating tree species of industrial value. *Casuarina equistifolia* is an important multipurpose tree species used for fuel wood, wind break and shelterbelt along coasts in several tropical countries including India and plays a crucial role in the rural economy. It is being extensively planted commercially by farmers and paper based industries as well as in many other afforestation programmes by the government. The species is highly susceptible to bark feeding caterpillar *Indarbela quadrinotata* Walk. (Lepidoptera: Metarbelidae). Sasidharan (2004) reported that 40 species of insects are associated with *C. equisetifolia* in Tamil Nadu. One among them is the bark eating caterpillar, *Indarbela quadrinotata* was found to be the most economically important pest. *I. quadrinotata* is a polyphagous insect attacking a variety of trees like *Casuarina equisetifolia, Prunus domestica, Acacia* spp. and *Anacardium occidentale* (Mathew, 1997). The larvae tunnel into the wood through the axils of side shoots and come out to feed on the bark through a sleeve made of frass and excreta webbed together extending from the tunnel mouth. Larval duration lasts for about 8 months. The larvae may attack the same tree at different locations in heavy infestations and this may result in serious injury to the bark. The holes left on the trunk facilitates the secondary infestation by pathogenic organisms and the trees suffer from die-back and break at the points of attack. Data generated from plantations at different sites under different agroclimatic zones of Tamil Nadu affected by *I. quadrinotata* indicate considerable reduction in the yield. The impact of the borer *I. quadrinotata* on biomass/timber yield and in turn loss of carbon sequestration potential in C. *equisetifolia* plantations is discussed.

MATERIAL AND METHODS

C. equisetifolia plantations in different parts of the state under five different Agroclimatic zones lies between 8° 04´ N lat. and 11°43´E long. were selected for the study. Care was taken to select the plantation in such a way that they are in the age class of 7 yrs. Each plantation in each location was divided into as many quadrats of 50 x 50 m^2 area. Further each quadrat was divided into quadrats of 10x10 m^2 area and 5 such quadrats were selected at random. Height and diameter at breast height (DBH) of all the trees in the quadrats and the intensity of infestation of *I. quadrinotata* was scored based on a modified Wellendorf (1989) and compared with Rohrmoser severity scale (Mac Dicken *et al*., 1991) in the month of November, 2008 when the infestation of *I. quadrinotata* was found maximum. Height and diameter at breast height (DBH) of all the trees in the same quadrats were recorded in the month of July, 2009 when the infestation was very low. Data for the calculation of above ground biomass was recorded from allometric methods (FAO, 1997) (http://www.fao.org/docrep/007/y5490e/y5490e07.htm).

CALCULATION OF ABOVEGROUND BIOMASS FROM ALLOMETRIC METHODS

The aboveground biomass was estimated from the field measurements at each site and each plantations (quadrats) as described by Rajput *et al*. (1996) and Negi *et al*. (2003).

Biomass (g) = Volume of biomass (m3) X Specific gravity (SG)

Where; SG = Oven dry weight / Green volume

Carbon = Biomass X carbon %

Here, the procedural steps for the calculation of aboveground biomass from such field data are as follows.

With the allometric method, the basal area (*Ab*) of the trunk was estimated by:

$A_b = \text{P} \times r^2$

where: P= 3.1415927; and *r* is the radius of the tree at breast height (0.5 DBH).

With A_b, the volume (*V*) in cubic metres was calculated from:

$V = A_b \times H \, x \, BEF$

where: A_b is the basal area; *H* is the height BEF Biomass expansion factor for a country (India 1.575 - Kishwan *et al*.,2009 http://envfor.nic.in/mef/Technical_Paper.pdf; 130 ICFRE BL - 23 2009).

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Using the calculated volume of the trunk, total trunk biomass in kilograms was calculated by multiplying by the wood density (*WD*) corresponding to the Casuarina tree species (FAO, 1997):

$$\text{Biomass} = V \times WD \times 1000$$

$$\text{Carbon (C)} = \text{Biomass X carbon \%}$$

$$\text{Carbon sequestration} = C*3.666$$

RESULTS AND DISCUSSION

The infestation details of *I. quadrinotata* in different location under different Agroclimatic zones followed by above ground biomass details of *C. equisetifolia* before and after infestation of *I. quadrinotata* are given in table 1-3. The maximum biomass of 202.34 t ha^{-1} was observed from 7 yrs old *C. equisetifolia* in Cuddalore under North Eastern Zone (Table 1). However, minimum biomass of 43.75 t ha^{-1} and 74.08 t ha^{-1} were recorded in Karur under Western Zone with an interval of eight months (Table 2). Rana *et al*. (2001) recorded 137 to 205 t ha^{-1} of biomass from 7 yrs old *C. equisetifolia* in Kumarganj near Faziabad. Mathew (1997) recorded the annual yield of timber from affected plantations of *Paraserianthes falcataria* by *I. quadrinotata* in Kerala was only 4.38 cum per hectare while yield ranging from 1040 cum/ha/annum has been recorded from healthy plantations. Koul and Panwar (2008) recorded 393.15 t ha^{-1} biomass in *Dalbergia sissoo;* 251.46 t ha^{-1} in *Terminalia arjuna;* and 1980.04 t ha^{-1} in *Shorea robusta*. The percent infestation of *I. quadrinotata* was recorded between 14.4 and 70% in Salem (North Western Zone) and Kanyakumari (High rainfall zone), respectively. Sasidharan *et al*. (2010) observed 96.55% of *I. quadrinotata* infestation in Cauvery Delta zone. Correspondingly the Co2 sequestration loss due to insect infestation is between 13.25 t ha^{-1} and 64.40 t ha^{-1} in Salem (North Western Zone) and Kanyakumari (High rainfall zone), respectively (Table 3). The biomass loss and the carbon sequestration potential loss in all the sites in six agrocliamtic zones studied gave us 1.55 to 13.5% (Fig. 1). Biomass loss in *Tectona grandis* due to teak defoliator, *Hyblaea puera* was estimated to be 31% in Kerala. However, in protected area it was estimated to be 4 % (KFRI, 2003). Annual forest carbon sequestration loss due to insects was 1.7 and 4.5 in USA and Canada, respectively (Ravindranath *et al*., 2001). Bhatt *et al*. (2001) reported the annual carbon loss in plantation forests was 1.11 t ha^{-1} whereas in Managed forest it was estimated to be 0.15 t ha^{-1}. In the present study rate of accumulation of carbon stock ranges between 46.48 t ha^{-1} and 271.70 t ha^{-1} annually. Koul and Panwar (2008) reported the rate of accumulation of carbon stock in *Dalbergia sissoo, Terminalia arjuna* and *Shorea robusta* was 19.66, 13.66, 29.75 t ha^{-1}, respectively. Results from this study revealed that the infestation of *I. quadrinotata* was found to be high in high rainfall zone followed by Northeastern, Western Cauvery delta, Southern and finally in Northwestern zone and carbon stock potential was also reduced correspondingly. The present study is an indicator to select sites for large scale plantation of *C. equisetifolia* since some of the zones are less susceptible to *I. quadrinotata*. It is also clear from this study that in high rainfall area the cultivation of Casuarina is poor and also susceptible to *I. quadrinotata*. Further study would be conducted in clonal plantations in various sites under different agroclimatic zones to identify sites for large scale plantation of clonal material with less susceptible to *I. quadrinotata* with high biomass yield and carbon sequestration potential.

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Fig.1: **Loss of carbon sequestration potential of *C. equisetifoliain* response to infestation of *I. quadrinotata***

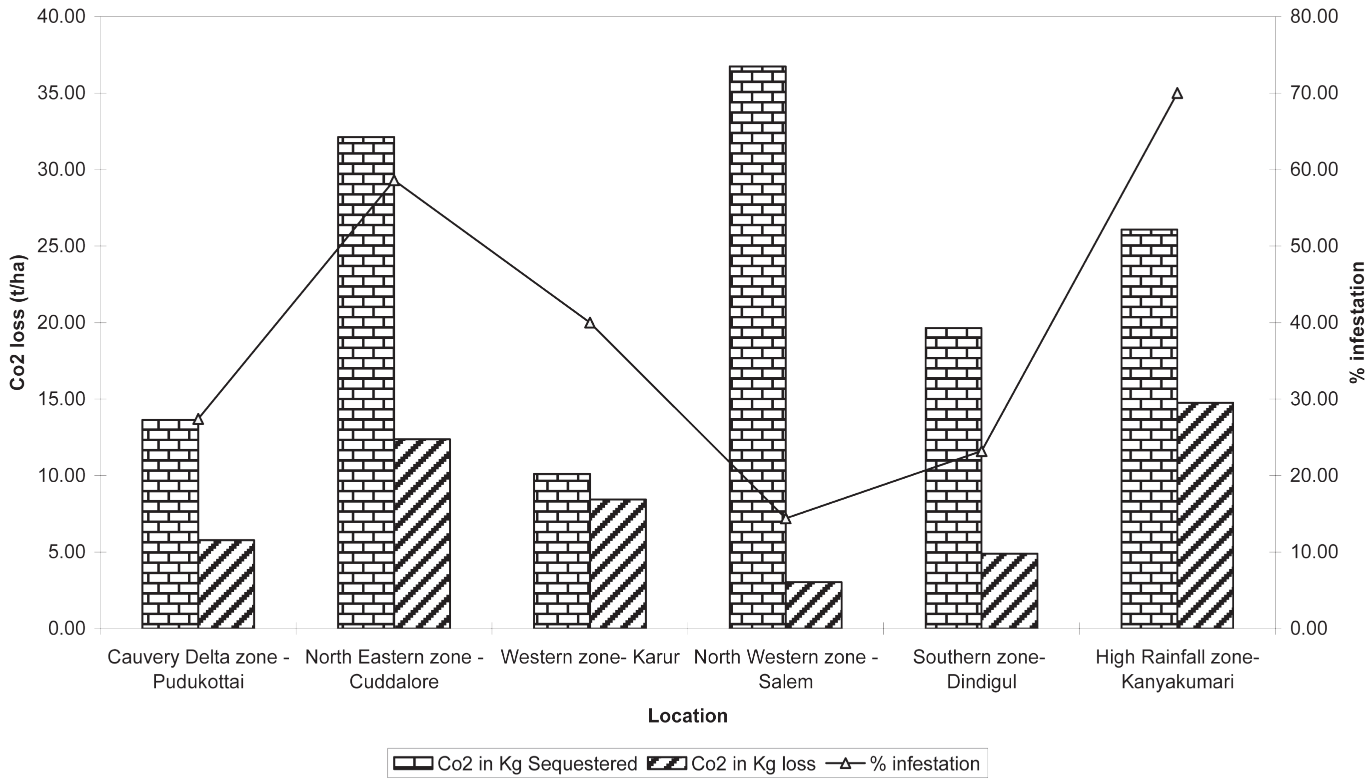

Table 1: **Biomass changes before infestation of *I. quadrinotata* on *C. equisetifolia***

Location	Before infestation						
	DBH (cm)	Height (m)	Wt in lbs	Green Wt. Root included	Dry Wt. (t/ha)	Carbon (t/ha)	Co2 Sequst. (t/ha)
Cauvery Delta zone - Pudukottai	6.58	9.03	24.45	29.34	53.18	26.59	44.22
North Eastern zone -Cuddalore	10.38	13.83	93.03	111.63	202.34	101.17	168.24
Western zone- Karur	6.09	8.67	20.12	24.14	43.75	21.88	36.38
North Western zone -Salem	9.80	12.59	75.61	90.73	164.46	82.23	136.74
Southern zone- Dindigul	7.50	9.95	34.98	41.98	76.08	38.04	63.26
High Rainfall zone- Kanyakumari	8.51	10.69	48.39	58.07	105.25	52.63	87.52

Table 2: **Biomass changes after infestation of *I. quadrinotata* on *C. equisetifolia***

Location	After infestation							
	DBH (cm)	Ht (m)	Wt in lbs	Green. Wt. Root included	Dry wt. (lbs)	Dry Wt. (t/ha)	Carbon (t/ha)	Co2 Sequst. (t/ha)
Cauvery Delta zone - Pudukottai	8.48	9.62	43.30	51.95	37.67	94.17	47.08	78.30
North Eastern zone -Cud-dalore	12.36	14.39	137.43	164.92	119.56	298.91	149.46	248.55
Western zone- Karur	7.80	8.95	34.06	40.87	29.63	74.08	37.04	61.60
North Western zone -Salem	12.46	13.03	126.40	151.67	109.96	274.91	137.45	228.59
Southern zone- Dindigul	9.76	10.44	62.13	74.56	54.05	135.13	67.57	112.36
High Rainfall zone- Kan-yakumari	11.02	11.12	84.45	101.34	73.47	183.68	91.84	152.73

Table 3: **Biomass changes and loss of carbon sequestration potential of *C. equisetifolia* due to infestation of *I. quadrinotata***

Location	Initial	Final					
	Dry wt. (t/ha)	Dry wt. (t/ha)	Increment	Carbon (t/ha)	Co2 Sequest. (t/ha)	% infestation	Co2 loss (t/ha)
Cauvery Delta zone - Pudukottai	53.18	94.17	40.98	20.49	75.13	27.40	25.21
North Eastern zone -Cuddalore	202.34	298.91	96.58	48.29	177.04	58.60	53.91
Western zone- Karur	43.75	74.08	30.33	15.17	55.60	40.00	36.80
North Western zone -Salem	164.46	274.91	110.45	55.23	202.48	14.40	13.25
Southern zone- Dindigul	76.08	135.13	59.05	29.52	108.25	23.20	21.34
High Rainfall zone- Kanyakumari	105.25	183.68	78.42	39.21	143.76	70.00	64.40

Outbreak of a New Nursery Disease of Teak in Madhya Pradesh Due to Climate Change

R.K. Verma *

INTRODUCTION

Climate change is linked to forest sector and is likely to adversely affect forest ecosystems and biodiversity. Climate change is dramatically altering the growing patterns of mushrooms, toadstools and other fungi. The study found that the alteration in fungal fruiting was due to mirrors changes in temperatures. The increase in late summer temperatures and autumnal rains has caused early season species to fruit earlier and late season species to continue to fruit later. Furthermore, climate warming seems to have caused significant numbers of species to begin fruiting in spring as well as autumn (Cardiff University, 2007). Forest plant diseases are strongly influenced by weather and climate. Warming, changes in precipitation, and weather extremes are already influencing forest plant diseases in western North America (Frankel, 2008; Hepting, 1963). For examples Alaska yellow-cedar (*Chamaecyparis nootkatensis)* decline and drought-related decline caused by a weak native pathogen, *Dothistroma septosporum* and an aggressive non-native pathogen *Phytophthora ramorum*. Red band needle blight caused by *Dothistroma septosporum* in British Columbia is another example. The disease outbreak is driven by increases in summer precipitation that are beyond the range of previously recorded weather patterns (Woods et al., 2005). Sudden oak death-related tree mortality is driven by extreme weather events. In California and Oregon, sudden oak death mortality rates abruptly increase and then subside. The pattern is driven by heavy rains and extended wet weather during warm periods which create optimal infection conditions. Forests that are already stressed by overstocking, pathogens, or climatic conditions such as drought may not survive additional climatic stress (Winnett, 1998).

Teak (*Tectona grandis* Linn. f.) is one of the most important timber species of Asian and some African countries. Young plantations of teak (2-10 years) were reported to damage by root rot disease caused by *Helicobasidium* spp. in India and Africa (Bakshi, 1976; Hocking and Jaffar, 1967; Soni and Verma, 2010; Verma et al., 2008; Vidal Hal and Williams, 1956; Waheed Khan, 1964) but it was never reported to cause damage of teak saplings in nursery.

The present study reports occurrence of a new disease syndrome of teak saplings caused by *Helicobasidium compactum* Boedijn and *Tritirachium roseum* J.F.H. Beyma only under water stressed conditions. Details symptoms and extent of damage caused by the disease syndrome in central India is given. The occurrence of disease is also correlated with warm conditions (due to climate change) and soil moisture stress during the year.

MATERIALS AND METHODS

The disease was observed in a commercial nursery raised by Madhya Pradesh Forest Development Corporation at Belkund, Dhimerkheda, Katni. The total area of nursery is 21ha and the total numbers of teak beds raised during 2009-2010 were 5000. The nursery was visited in June 2010 and nursery beds were critically observed. The disease occurs in patches in the beds situated at ridges and slopes and was noticed in 102 beds. The total number and number of dead saplings were counted in five beds of 3 different patches and range of disease occurrence was calculated. Diseased (dead and partially dead) saplings attached with fruiting bodies of fungus, *H. compactum* were carried to laboratory for identification of fungi. Soil samples from diseased and healthy beds were also collected and carried to laboratory and soil moisture contents were determined by oven drying the samples at 100°C for 24 hrs. The fungi associated with the disease syndrome were identified after microscopic study and consulting relevant literature. Data on temperature, humidity and rainfall for the year 2010 and 2011 were taken from the internet.

RESULTS

Temperatures regimes

On perusal of climate data for the year 2010 and 2011 it was revealed that the summer of the year 2010 experiences more drier climate than 2011. The average temperature for the months March to June was 8.3% more in 2010. Similarly maximum and minimum temperatures were also 8.7% and 6.4% more in the year 2010. Whereas average humidity and rain fall were 33.9% and 319.1%, respectively, less in the year as compared to proceeding year, 2011 (Table 1). Year 2010 also experience high and prolong summer due to delayed monsoon. For example in May 2010 maximum temperature was gone up to 45°C for 2 days, 44°C for 4 days and 43°C for 10 days as compared to May 2011, where the maximum temp was 44°C for one day, 43°C for 5 days and 42°C for 7 days. The minimum temperatures were also follows the same trends. Other months, March, April and June were also follows the same pattern during the study year (Table 2).

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Table 1: **Comparative average climatic conditions during March to June during 2010 and 2011**

Months	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Average Humidity	Rain fall (mm)
Mar 2010	28.2	36.1	20.3	33.0	3.05
April 2010	32.8	40.7	25.0	20.1	0.00
May 2010	36.0	42.8	29.1	25.3	0.00
June 2010	33.0	39.5	27.3	45.7	78.49
Average	**32.50**	**39.78**	**25.43**	**31.03**	**20.38**
Mar 2011	26.8	34.3	19.3	33.2	0.00
April 2011	30.2	37.6	23.3	32.3	3.05
May 2011	34.4	41.5	28.2	30.1	44.96
June 2011	28.6	33.1	24.8	70.6	293.62
Average	**30.00**	**36.63**	**23.90**	**41.55**	**85.41**

Table 2: **Variation in temperatures (5 maximum and minimum) in summer during 2010 and 2011 at experiment site**

Months	Maximum temperature (°C) and Frequency 2010		Maximum temperature (°C) and Frequency 2011		Minimum Temperature (°C) 2010		Minimum Temperature (°C) 2010	
	Temp.	Frequency	Temp	Frequency	Temp.	Frequency	Temp.	Frequency
March	40	2	38	1	25	3	24	1
	39	3	37	3	24	3	23	3
	38	6	36	7	22	4	22	3
	37	2	35	4	21	1	21	1
	36	5	34	3	20	2	20	3
April	44	1	41	1	29	4	28	1
	43	2	40	3	28	1	26	3
	42	3	39	4	27	2	25	3
	41	8	38	4	26	4	24	5
	40	6	37	7	25	5	23	6
May	45	2	44	1	33	2	31	2
	44	4	43	5	31	4	30	3
	43	10	42	7	30	5	29	8
	42	9	41	6	29	3	28	8
	41	2	40	9	28	6	27	4
June	44	1	41	1	32	1	28	3
	43	3	40	3	31	2	27	3
	42	2	39	4	30	2	26	1
	41	5	38	1	29	5	25	4
	40	5	35	1	27	7	24	5

Soil moisture level

The soil moisture level of nursery beds faces disease problem was comparatively low as compared to beds with no mortality. The sick soil has 20.9% less moisture level as compared to healthy soil, where there was no disease (Table 3)

Table 3: **Weight loss (moisture content) after two days of drying the soil in an oven**

Soil sample	Average weight loss in soil samples (%)
Diseased beds	1.96
Healthy beds	2.35

Disease syndrome and associated fungi

Two fungi namely, *Helicobasidium compactum* and *Tritirachium roseum* were found associated with disease syndrome. *H. compactum* and its anomorph *Rhizoctonia crocorum* caused root rot due to excessive development of silky dark brown to violet rhizomorphs. The fungus also forms an easily distinguishable fruit body in the form of thick band around the main stem at the collar region (just above the ground). The another fungus, *T. roseum* was found associated with rotten roots (Figs. 2-8)

Disease development

The disease was observed for the first time during June, 2010. The fungus, *Helicobasidium compactum* caused root rot and also produce fruit bodies on collar region of the teak saplings. The seedlings remained live even after colonization of fungus. The saplings start dying after passing through extreme dry condition with low level of moisture in the soil, particularly of beds situated on ridges and slopes of undulating nursery site (Fig. 1). Disease appeared in 3 patches spread over the entire nursery. The range of disease occurrence varied in different patches from 14.7 to 61.1% (Table 4). The stumps of partially dead seedlings were planted in polyethylene bags and irrigated. After watering the all stumps of partially dead seedlings were sprouted and recovered from the disease.

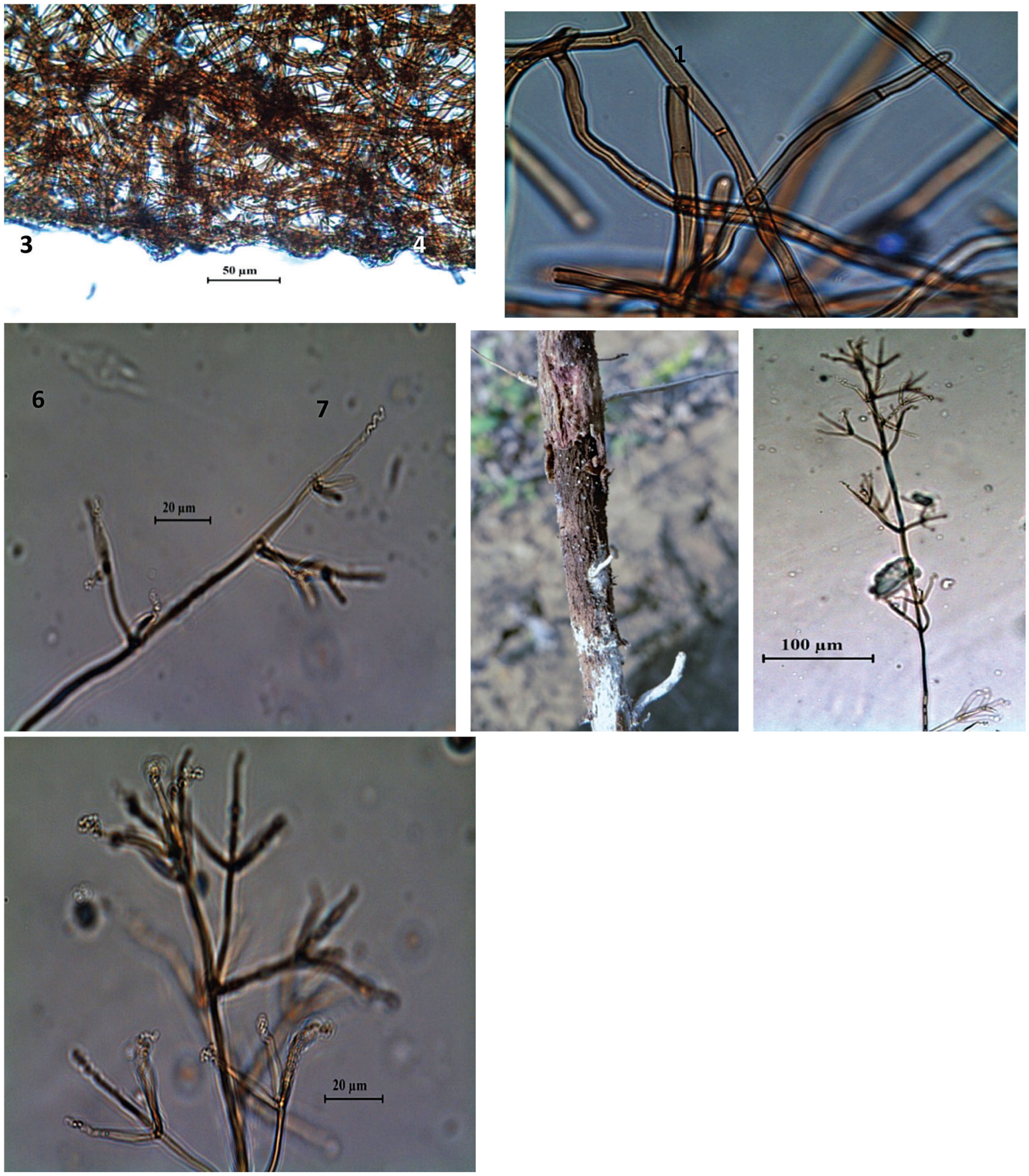
Table 4: **Occurrence of root rots disease in teak nursery (average of 5 beds)**

Situation	Total seedlings per bed	Number of dead seedlings	Average disease occurrence (%)
Patch 1	825	502.6	61.1
Patch 2	784	187.8	24.2
Patch 3	748	111.4	14.7

DISCUSSION

From the above results it can be predicted that occurrence of disease in the year 2010 is correlated to prolong summer experience during the year couple with high temperature, particularly during May and June and delayed rain. The soils of nursery beds especially of those made on ridges and slopes of uneven nursery site contains very less moisture content are the main cause of appearance of the disease in teak saplings. The nursery site with less moisture suffered more losses due to disease also indicate the view that the disease appeared due to water stress. Further it was confirmed when the partially disease affected saplings planted in polyethylene bags and after regular irrigation recovered from the disease and

Figures 1-8: **Root rot disease of teak. 1 mortality of teak seedlings due to disease syndrome, 2-4 *Helicobasidium compactum*, 2-3 mycelium mat and mycelium, 5-8 *Tritirachium roseum*, 5,7 and 8 branched conidiophores with zig-zag tips, 6 symptom on dead root.**



grow normally. The disease didn't recur in the next proceeding year, 2011, because of comparatively lower temperature during summer and precipitation in the months of June. It is reported in the literature that warming, change in precipitation and weather extremes influenced forest plant diseases (Frankel, 2006).

Climatic change dramatically alters the growing pattern and development of fruiting bodies of fungi (Cardiff University report, 2007). In the present study change in temperature and soil moisture stress induces disease development and production of fruit bodies of fungus, *H. compactum* which was not appeared in the year with normal weather conditions.

Earlier it was reported that *Helicobasidium compactum* affects the young plantations (Bakshi, 1976, Hocking and Jaffar, 1966) but recently it was found that the fungus causes serious damage to plantations at age of 5 years raised on poor sites (Soni and Verma, 2010). In the present study the pathogen, *H. compactum* for the first time reported causing disease due to extreme weather conditions and soil moisture stress.

CONCLUSION

It is concluded that the disease syndrome (by fungi, *Helicobasidium compactum* and *Tritirachium roseum*) of teak saplings was developed due to water stressed condition in nursery soil because of high temperature sustained for a comparatively longer duration during summer.

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Climate Vulnerability Index for Mountainous Rural Communities: A tool for Adaptation Strategy

Shashidhar Kumar Jha and Rajiv Pandey *

INTRODUCTION

The climate change impact assessment explore the vulnerability status of resource-reliant poor (Mearns and Norton 2010), established socioeconomic inequalities within communities, and discussed about the destitution of the poorest (Ahmed *et al.* 2009) however, some concluded that environmental change may catalyze rural communities' latent adaptive capacities (Pelling and High 2005, Nelson *et al.* 2007) and stimulate systemic improvements (Adger *et al.* 2005, Folke 2006). The climate adaptation and mitigation policy is devised based on these assessment and deals with coping strategies of rural communities in the face of increasingly frequent and extreme weather events (Paavola and Adger 2006, Eriksen and O'Brien 2007).

The traditional science addresses the climate change assessment through scenario driven approach based on models. This top down approaches does not account the differential vulnerabilities of human populations to these environmental risks, thus not suitable for policies. Thus, the likely impacts of climate change may be adjudged through bottom up approach as social vulnerability is inextricably linked with the climate change processes (Vincent and Cull 2010).

The vulnerability science is based on the logic that human populations mediate environmental change to produce impacts. Therefore, the bottom up approach may be used for key policy and other practical applications with focus of society-nature relations (Adger 2006, Füssel 2007). The 'vulnerability' assessment suggests a key role for targeted assistance in helping the rural poor to adapt to climate change (Lemos *et al.* 2007).

Context-specific methods of assessment are required to assess the levels of vulnerability to human societies due to multiple driving forces in relation to specific outcomes (Adger and Vincent 2005). The sustainable livelihoods framework may be suitable for assessing local level vulnerability and adaptive capacity through analysing the status of five 'capital assets' – financial, human, social, physical and natural (Chambers and Conway 1992). This framework has been applied to investigate the contextual and multi-dimensional nature of vulnerability (O'Brien *et al.* 2009).

Climate change and extreme events has adversely impacted on the functioning of the ecosystems and provisions of critical goods and services to mankind. This impact is much more pronounced to the resource poor mountainous communities (Parmesan and Yohe 2003) because they have limited livelihood options due to remoteness and fragile mountainous settings and less incentive to stay in balance with surrounding ecosystems. Mountainous ecosystems are also the key resources of water, energy, minerals and forest products to lowland community and most vulnerable due to the unsustainable use of existing ecological resources resulted into the vulnerability to human livelihood (ICIMOD 2010).

The globalised world threatened the reciprocal relationship between human and mountain. The livelihood vulnerability of mountainous ecosystems and intrinsic environmental fragility has brought the issues of global sustainability outline. However spatio-temporal assessment for smaller region is lacking across the region. The aim of present research is therefore to fill an academic and policy demand for the assessment of mountainous social vulnerability to climate change in the Himalayan region India. Evaluations of these impacts aim to identify preferred measures. One of the evaluation criteria revolves around the development of vulnerability indices. These indices seek to provide relative vulnerability scores at spatial or community level and to identify adaptation strategies that are feasible and practical in communities (Smit and Wandel 2006). The developed social vulnerability for mountainous region may be added to the existing biophysical vulnerability assessments to create holistic and integrated studies of the potential impacts of climate change in the mountainous settings.

The Hindu Kush-Himalayas, a highly heterogeneous in geographical features with a rich biodiversity depository (Schickhoff 2005) is not an exception in this respect and investigation is underway to understand the nexus between climate change and mountain vulnerability (ICIMOD 2010). The present study also assesses the community vulnerability through defining an index.

DESCRIPTION ABOUT THE INDEX

In the present study, a Climate Vulnerability Index (CVI) specific to mountainous settings has been proposed. The CVI will provide a realistic approach to recognize climate change vulnerability role on social and natural factors at the village or community level in the mountainous settings in light of various interacting fabrics of social and economic relationships. The multidimensional issues

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may be quantified by using indicators as proxies and these are often combined into a composite index allowing diverse variables to be integrated (Hahn *et al.* 2009). The proposed climate vulnerability comprises various dimensions of vulnerability by including eight major components such as: socio-demographic profile, livelihood strategies, social network, health, food, water, natural disaster and climate variability.

CVI uses primary data from household surveys to construct the index and presents a framework for grouping and aggregating indicators on the spatial level, which leads to development and adaptation planning. The desired information of the vulnerability due to climate change revolves around the various dimensions such as Exposure, Sensitivity, and Adaptive capacity. These all are dynamic and system specific (Smit and Wandel 2006) and explained as follows.

Vulnerability = *f* (Exposure, Sensitivity, Adaptive capacity)

The relationship between all three independent endogenous elements is not specified, and governed by local circumstances. However, vulnerability is a positive function of the system's exposure and sensitivity and a negative function of the system's adaptive capacity (Ford and Smit 2004). The relevant parameters to address the issue under consideration has been selected based on the literature across the world on similar issues (IPCC 2001, Patnaik *et al.* 2005, Hahn *et al.* 2009, Urothody *et al.* 2010), interactions with the peers as well as prominent people of the region and pilot study including local socio-economic studies directly or indirectly addressing the impact of stress on resources (ICIMOD 2010, Pandey 2010).

The details of such parameters has been collected from households as per defined methodology and reported in Table 1. The index has been formed through the following approach for each sub-component of each major component.

$$Index_{sv} = \frac{S_v - S_{\min}}{S_{\max} - S_{\min}}$$

Where,

S_v is the sub-component or indicator value for v^{th} village/ community,

S_{max} and S_{min} is the maximum and minimum value of sub-component.

After standardization for all sub-components, each major component was calculated as follows.

$$M_v = \frac{\sum_{i=1}^{n} Index_{svi}}{n}$$

Where,

M_v is one of the major components for CVI,

$Index_{svi}$ is i^{th} sub-component value, belonging to major component M_v for v^{th} village or community,

n is the number of sub-components in the major component.

These major components have been segregated as per the three dimensions of vulnerability. These were 'adaptive capability, which include socio-demographic profile, livelihood strategies, and social networks due to the nature and content of this component. The dimension of 'sensitivity' was dealt with health, food, water components; however, 'exposure' was due to the natural disasters and climate variability.

Several methods have been proposed in the literature to assign the weights. Democratic principles in terms of expert opinion and stakeholder discussion were recommended to determine weighting schemes (Vincent 2004, 2007, Sullivan *et al.* 2002). The equal weighing approach has been criticized by the Eakin and Bojorquez-Tapia (2008) due to the implicit judgment about the degree of influence of each indicator and recommended for a more objective approach. The balanced weighted average approach (Sullivan *et al.* 2002) was used for CVI due to the various hidden and ambiguous shares and relationships of different components with each other. In CVI, each sub-component contributes equally to the overall index even though each major component is comprised of a different number of sub-components as also used in various other indices (Hahn *et al.* 2009). The aim of equal weighting revolves around the resource poor settings of the respondents in terms of infrastructure, remoteness, marginality, fragility etc of mountainous region, besides being simple in approach and interpretation. These components have been directly and indirectly; linearly and non-linearly related with the individual family's inherent quality, resources availability and accessibility. Thus, the dimensions of vulnerability were assessed at the scale of 0 to 1 with equal weighing to all associated sub-components.

The index for exposure (*Exp*) containing Natural Disaster (ND) and Climate Variability (CV), has been calculated as follows.

$$Exp = \frac{W_{e1}ND + W_{e2}CV}{W_{e1} + W_{e2}}$$

Where,

W_{e1} and W_{e2} is the weight for natural disaster and climate variability, in present study, it was number of indicators under the sub-components.

The index for sensitivity (*Sen)* has been calculated as follows:

$$Sen = \frac{W_{s1}H + W_{s2}F + W_{s3}Wa}{W_{s1} + W_{s2} + W_{s3}}$$

Where,

$W_{s1,}$ $W_{s2,}$ and W_{s3} is the weight for Major-components as Health, Food and Water respectively, in present study, it was number of indicators under the sub-components.

The index for Adaptive Capability (*Ada. Cap*) has been calculated as follows.

$$CVI = 1 - \left| \left\{ \frac{N_1 Exp - N_2 Ada.Cap}{(N_1 + N_2)} \right\} \right| * \left\{ \frac{1}{Sen} \right\}$$

Where,

W_{a1}, W_{a2}, W_{a3} is the weight for socio-demographic profile, livelihood strategies and social network, respectively.

The weightage of CVI has been assigned with the objective to draw inference on per unit basis of relevant parameters. The inverse relationship for sensitivity has been considered keeping in view of analyzing the per unit strength of the system bearing capability on absolute performance under the climate threats. The CVI defines the capability of the society to attain the no vulnerability status.

$$CVI = 1 - \left| \left\{ \frac{N_1 Exp - N_2 Ada.Cap}{(N_1 + N_2)} \right\} \right| * \left\{ \frac{1}{Sen} \right\}$$

Where,

N_i is the number of Major Components in the i^{th} dimensions of vulnerability for all i =1(1)3.

The value of each dimension will attain at the most 1 and at least to zero. The number of components for Sensitivity (Sen) has been cancelled out each other (Denominator and Numerator), therefore not included in the CVI index. Based on the analogy of mathematical logic, the higher the value of Climate Vulnerability Index (CVI), the systems will be less vulnerable i.e. high CVI reflects low vulnerability.

The CVI focuses on quantifying the strength of current livelihood including the dependence of natural resources and available infrastructures besides the prevailing local adaptive capability of communities. This may lead to suggest and provide sufficient tools to improve the capacity of communities to alter these strategies in response to climate-related exposures through assessing the ground level information.

Table 1: **Description of major and sub-components of CVI parameters in survey questionnaire**

Major components	Sub-components	Explanation of sub-components	Survey questions	Potential limitations
Socio-demo-graphic Profile	Family dependency index	Ratio derived on population upto 18 and above 55 to the population 19 – 54.	Household age distribution.	Confusion about age of household member in some cases.
	House type diversity index	The inverse of (type of house +1) reported by a Household.	Type of house.	No issue.
	Family decision index.	Percentage of household where head of household is literate male with more than 50 years of age.	Head of household.	Definition of literate (Whether educated or able to understand)
Livelihood strategies	Percent of household with migrated members.	Percentage of household in which at least 1 member has migrated for earning.	Members migrated for earning.	Unavailability of reliable data from household, where family has already migrated with earning member, though rarely.
	Percent of household changes crop variety.	Proportion of household who has not change crop variety.	Change in crop variety.	Lack of knowledge about crop variety.
	Percent of household introduced new crop.	Percentage of household not introducing new crop.	Introduced new crop	Cultivation is traditional, thus introducing new crop is very rare.
	Percent of household reported change in sowing/planting time.	Percentage of household reported forward/backward sowing/planting time.	Any change or forward/backward sowing or planting time.	Happens, but commonly no actual records available.
	Fodder and fuelwood collection index.	Amount of fodder and fuelwood collected by household.	Quantity of fodder and fuelwood collected by household daily.	Lack of information about accurate quantity.
	Percent of household dependent solely on agriculture as a source of income	Percentage of households with agriculture as an only source of livelihood.	Type of primary and secondary profession.	Variability in volume among households cannot be appreciated.

	Natural resource diversification index	The inverse of (the number of activities dependent on natural resource +1) reported by a household.	Number of livestock and collect of fodder and fuelwood from forest.	Ranking of primary and secondary professions, which are same for both and contribute differently.
	Percent of household reported reduction in volume or quality of natural resource.	Percentage of household reported increase in time or distance of source of natural resources from residence.	Time required for fuelwood and fodder collection, natural water quality change, intensity and frequency of forest fire and access time for natural water source	Components of natural resources may get affected temporarily at particular sites but may remains unaffected at other sites in the same region.
Social network	Percent of household received or seek assistance through social networks.	Percentage of household reported to have received help from friends, government and NGOs.	Assistance obtained during extreme event.	Government support is treated as part of process, therefore, generally overlooked.
	Percent of household provide help to others.	Percentage of households reported that they help others.	Assistance provided to others during calamities.	No considerations for services without payment or exchange
	Percentage of household with money transaction between friends.	Percentage of households reported borrowed or lend money from friends.	Money transaction among community.	Chances of manipulated information against the ostentatious behavior.
	Profession diversity index.	The inverse of (profession of head of household +1) reported by a household.	Type of profession	No clear demarcation for different members' earnings in a household.
Health	Percent of household with recent death of infant.	Percentage of household reported death of an infant.	Any infant death in your family.	People don't appreciate such questions. Collection of information is difficult due to sentiments.
	Percent of household with recent death	Percentage of household reported death of any individual.	Death of any individual from your family.	Sensitive issue, actual cause may not be known at remote locations
	Percent of household with disease due to climatic factor.	Percentage of household reported disease due to climate variability.	Disease due to climatic factor.	Clear cut demarcation is problematic.
	Percent of household reported stress due to climatic factors.	Percentage of household reported some sort of stress due to temperature and rainfall.	Stress due to temperature/rainfall.	Sometimes, not easily distinguished.
	Percent of household having new disease.	Percent of household observed new disease in last 6 years.	Any new disease observed due to climatic factor	Lack of knowledge about the symptoms of new diseases.
Food	Percent of households dependent on agriculture for food.	Percentage of households that get their food primarily from agriculture.	Source of food.	Ambiguous as household can have multiple sources of food.

	Percent of households with insufficient food form farm.	Percentage of households that do not get sufficient food across the year.	Food sufficiency across the year i.e. 0-3, 3-6, 6-9, 9-12 months.	No clear understanding about food sufficiency and may not reflect overall trend of food.
	Percent of households with decreasing food production.	Percentage of households that reported decrease in food production.	Impact of changing climate on food production.	Decrease in food production may be due to other reasons.
	Percent of household with reductions in nutrition.	Percentage of household having decreased nutritious food items like diary, fruit, legumes, meat and fish.	Any increase, decrease, no change and uncertainty in your daily food item.	Poor recalling by people about change in quantity of food item.
	Percent of household using pesticide.	Percentage of household using pesticides in crop field.	Pesticides application to crop.	Confusion about use of pesticides, and locally available biological agents.
	Percent of household using fertilizer.	Percentage of household using fertilizer in agricultural field.	Fertilizer application to crop.	Sometimes, no consideration to farmyard manure
	Percent of household with loss of agricultural land.	Percentage of household reported loss of agricultural land due to extreme event.	Impact of extreme event on agricultural land.	No clear cut information about the causes of loss of land.
Water	Percent of households with problem for access of potable water.	Percentage of households did not get portable water across the year.	Availability portable water across the year.	Sufficiency criterion for potable water is not well understood.
	Percent of households with problem for access of irrigation water.	Percentage of households did not get irrigation water across the year.	Availability irrigation water across the year.	Requirement of households depend on size of land holdings.
	Percent of households utilizing natural water source.	Percentage of households that report spring as their primary water source.	Source of portable water.	No issue.
Natural disaster	Percent of household with an injury or death due to natural disaster.	Percentage of households that report that injury or death due to landslide, drought, cloudburst or any extreme climatic event.	Impact of extreme event (rainfall, drought, cloudburst, and landslide) on life.	Death or injury may be due to other factors but not clearly defined causes.
	Percent of household losses housing or property due to natural disaster.	Percentage of household reported loss of house or property i.e. breaking of wall, sliding of balcony, subsidence, livestock loss, loss of agricultural land etc. due to extreme event.	Impact of extreme event (rainfall, drought, cloudburst, and landslide) on property, agricultural land, finance, employment.	Disaster cause may not be clearly understood as developmental activities are going on.
	Percent of household reported high forest fire frequency.	Percentage of household reported that frequency of forest fire is increased.	Response for frequency of forest fire.	No issue.
	Percent of household reported increase in forest fire intensity.	Percentage of household reported that intensity of forest fire is increased.	Response for intensity of forest fire.	No issue.

Climate variability	Temperature and hot months perception index	The inverse of (change +1) reported by a household.	Perception about temperature and hot months.	Generalization to whole year, sometimes may not be actual.
	Rainfall and rainfall pattern perception index	The inverse of (change +1) reported by a household.	Perception about rain-fall and rainfall pattern.	Generalization to whole year, sometimes may not be actual.
	Hailstorms and cold waves perception index	The inverse of (change +1) reported by a household.	Perception about cold waves and hailstorms.	Generalization to whole year, sometimes may not be actual.

PROFILE OF STUDY REGION

The spatial focus of the study was Srinagar, a district of Pauri Garhwal, Uttarakhand. The district Pauri Garhwal is situated in the central part of Garhwal Himalaya and western part of Himalayas and lies between 29º20´ N-30 º15´N latitude and 78 º 10´E-79 º 20´E longitudes lies at an elevation of 1650 m above sea level and encompasses an area of 5440 sq. km. (Rajwar 1993). The region has a sub-temperate to temperate climate, with mean monthly temperature ranges from 25°C to 30°C (maximum of 45°C in June and minimum of 1.3°C in January), average annual rainfall of 218 cm (90 percent receives during monsoon), and 54 to 63 percent of relative humidity with some snow in winter at the higher reaches.

Soils of the region have been formed either through pedogenetic processes or are transported soils and fertility. The topography is by and large rugged and the entire region is mountainous. The region contain a unique set of ecological characteristics over a complex variety of systems such as, meadows, savannah grasslands, marshes and rivers (Alaknanda and Nayyar), wildlife, geology and several other phyto-geographically distinctive peculiarities. Forests dominate in the phyto-geography and also constitute the most valuable natural resource of the district.

SAMPLE SELECTION AND HOUSEHOLD SURVEY

The study area is stratified on the basis of the development and approach to village. Villages were selected randomly under two category based on distance to district headquarter. Villages such as Melatha, Dangchaura, Gahar, Dhari, Dungri, Khirshu, Kotki fall under the category of away from the district headquarter (ADH) and villages such as Barkot, Kileshwar, Thapli, Supana are under near to the district headquarter (NDH). From these villages, households were selected at random to collect the data with the protocol that interviews would be conducted only with head of household, through questionnaire to avoid the disadvantages of secondary data and dependency on climate models, followed by informal and formal meetings and discussions with the other members.

The survey questionnaire consisted of three broad sections: Exposure, Sensitivity and Adaptive Capability as per the proposed CVI. Twenty five households in each region were surveyed due to limited resources. Data were coded and cleaned, and analyzed by using SPSS 7.5 (SPSS Inc. 1997).

RESULT AND DISCUSSIONS

The socio-demographic profile has similar response for both strata; however the contributing indicators were diverse. The family dependency index for NDH (0.33) was much higher than ADH (0.18) because people from NDH had higher education status due to better educational facilities. House type diversity index is almost similar due to similar status of type of houses. NDH (0.73) is less pronounced for family decision index compared to ADH (0.82), due to relatively young head of household, however majority of households were male in both the region (Table 2).

The livelihood strategies of NDH (0.44) were less diversified than ADH (0.54). The ADH households have more opportunity for adjustment for livelihood strategies against climate change due to their primary profession as farmer, inspite of the fact that the NDH household have better accessibility in terms of facilities and better aware in terms of different mechanism of livelihood than ADH household. NDH households change crop variety and introduce more new crop as compared to ADH household, probably due to better equip in terms of practical knowledge gains since generations about the cropping pattern against the stress and with expectation of better income through diversification of crops. Household reported change planting and sowing time due to extreme event is more in ADH (0.25) as compared to NDH (0.18) due to having better acquaintances about the response of crops with weather fluctuation. Fodder and fuelwood collection from forest in both strata were approximately similar because they are dependent on forest for these resources and forest are in abundance relative to the extraction. Household reported relying solely on agriculture household from NDH is lower because they get more opportunities of earning. Natural resource diversification index including number of livestock and collection from forests are similar. The ADH (0.90) reported depletion in natural resources leads to more distance from forest to village as source of natural water is depleting and intensity and frequency of forest fire in this area is increasing, as reported by the households (Table 2).

The social network status was similar, probably due to the mountainous specificities. This shows that these households are interdependent and seek co-operations among themselves. The profession diversity index governed the status of household, therefore liable for addressing and seeking the co-operation. The profession diversity index was more favored to NDH due to availability of diversified opportunities of income earning (Table 2).

Infant mortality and recent death of household member was 5% and 10%; and nil and 6%, in NDH and ADH, respectively.

The households of both the region reported that climatic factor is responsible for disease, probably due to health problem caused due to cold. The high level of stress due to climate was noted in ADH, probably due to their high dependency on the natural resources and agriculture, which is rainfed. The households of NDH reported occurrence of more new diseases than the ADH, due to better health awareness and available facilities, as a medical college is situated at the heart of the city. Based on the data, it can be argued that the NDH household is better for health status than ADH households (Table 2).

Low proportion of households relying in agriculture in ADH (0.35) compared to ADH (0.60) for food, probably due to the local settings. As ADH households were having more land than the NDH households. However, 100% household from NDH reported insufficient food from farm due to low availability of agriculture land and dependence on other profession. Only 7% household from ADH gets sufficient food from farm, in spite of fact that majority of households of the region was farmer. These farmers were better off and have more agriculture land, the indepath analysis confirms. The food production decreases more in ADH (0.83) compared to NDH (0.75) due to poor rainfall pattern, reported by them. A higher percentage of reduction in nutritious food is reported in ADH (0.27) because of decreasing food production, and decrease in the volume of the nutritious food from the forests due to depletion of forest resources. Insect and pest attack is about 20% in ADH due to better understanding of the insect manifestation in the crops and no reporting from NDH. The use of more fertilizer by ADH (0.47) households was apparently due to their more dependency on agriculture as compared to NDH (0.30). The loss of agriculture land due to land slide and slips was low in both the strata, due to rebuilding of farms after the natural incidents. The overall food was low for NDH than ADH due to low dependency on farm cultivation (Table 2).

NDH also had lower vulnerability score for water component than ADH. In NDH only 3% household reported using natural source of water and 97% household getting water from pump or government supply contrary to 37% household from ADH depends on natural source of water. The 10% households of both the regions reported problem in availing potable water, whereas problem of irrigation water was higher in NDH (0.80) as compared to ADH (0.30). The ADH households, who were dependent of agriculture has developed the personal and community irrigation facilities in terms of pond and other measures (Table 2).

Natural disaster due to extreme event was high in the ADH household, as these households were more prone to mountain specificity in terms of fragility, marginality and accessibility. The household from NDH (0.09) is less affected by loss of property due to relatively better equip for natural disaster being the near to district head quarter than (0.24) for ADH because of restricted and sometimes without response for readressal from other sources for disaster mitigation. The frequency of forest fire is more in ADH (0.87) with similar intensity (low) in both regions, as forest fire is routine phenomenon during summer (Table 2).

Climate variability perceptions, was reported more pronounce in the NDH household due to better awareness and strategic settings of near town. The perception about temperature and hot months of NDH (0.57) household was greater than ADH (0.49). Rainfall and rainfall pattern perception was 56 and 48 in NDH and ADH, respectively and the perception about cold waves and hailstorm was slightly differ between two (Table 2).

The components of various dimensions of vulnerability were reported in the Table 3. Table 3 clearly reflects that the adaptive capability and sensitivity of ADH households was high than NDH, however, the exposure realization was more pronounced in the NDH households (Figure 2). The overall vulnerability was more for the NDH, probably due to low sensitivity and less departure from the adaptive capabilities (Table 3). This clearly shows that the sensitivity components should be addressed through external support for their improvements and the adaptive capabilities should be developed better in terms of intrinsic quality within the household.

Table 2: **Indexed major components, sub-components for assessing climate vulnerability**

Major components	Sub-components	Sub-components		Major components	
		NDH	ADH	NDH	ADH
Socio-demographic Profile	Family dependency index	0.33	0.18	0.51	0.49
	House type diversity index	0.47	0.48		
	Family decision index	0.73	0.82		
Livelihood strategies	Percent of household with migrated members	0.08	0.07	0.44	0.54
	Percent of household not changes crop variety	0.70	0.90		
	Percent of household not introduced new crop	0.85	0.93		
	Percent of household reported change in sowing/planting time	0.18	0.28		
	Fodder and fuelwood collection index	0.43	0.45		
	Percent of household sole dependent on agriculture	0.35	0.60		
	Natural resource diversification index	0.21	0.21		
	Percent of household reported depletion in natural resource	0.76	0.90		

Social network	Percent of household obtained/seek help from social networks	0.25	0.25	0.67	0.66
	Percent of household provide help to others	0.95	0.97		
	Percent of household with money transaction between friends	0.95	0.97		
	Profession diversity index	0.53	0.48		
Health	Percent of household with recent death of infant	0.05	00	0.46	0.36
	Percent of household with recent death	0.10	0.06		
	Percent of household reported disease due to climatic factor	0.80	0.73		
	Percent of household reported stress due to climatic factor	01	0.83		
	Percent of household having new disease	0.35	0.20		
Food	Percent of households dependent on agriculture for food	0.35	0.60	0.34	0.48
	Percent of households with insufficient food form farm	01	0.93		
	Percent of households with decreasing food production	0.75	0.83		
	Percent of household with reductions in nutrition	0.17	0.27		
	Percent of household using pesticides	00	0.20		
	Percent of household using fertilizer	0.03	0.47		
	Percent of household having loss of agricultural land	0.10	0.10		
Water	Percent of households with problem in availing potable water	0.10	0.10	0.31	0.25
	Percent of households with problem in availing irrigation water	0.80	0.30		
	Percent of households utilizing natural source of water	0.03	0.37		
Natural disaster	Percent of household faced injury or death due to natural disaster	00	00	0.47	0.52
	Percent of household losses property due to natural disaster	0.09	0.24		
	Percent of household reported high frequency of forest fire	0.80	0.87		
	Percent of household reported increase in intensity of forest fire	01	01		
Climate variability	Temperature and hot months perception index	0.57	0.49	0.49	0.43
	Rainfall and rainfall pattern perception index	0.56	0.48		
	Hailstorms and cold waves perception index	0.35	0.34		

Table 3: **Indexed major components and its value for NDH and ADH**

Vulnerability components	Major components	Vulnerability components	
		NDH	ADH
Adaptive capacity	Socio-demographic profile	0.51	0.56
	Livelihood strategies		
	Social network		
Sensitivity	Health	0.37	0.39
	Food		
	Water		
Exposure	Natural disaster	0.47	0.48
	Climate variability		
Climate vulnerability index		**0.69**	**0.64**

DISCUSSION AND CONCLUSION

This longitudinal analysis of rural indigenous mountainous community's response to climate change impacts reveals the vulnerable status and adaptive capabilities of these communities. The possibility of enhance social-ecological resilience and improve livelihoods may be important to reorient in the context of reorientation of natural resources, agricultural production, renewed social cohesion through honest, free and ethical networking, in addition to the creation of more diverse income-generation strategies with conservation and sustainable use of primary forest resources.

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Carbon Sequestration: Organic Carbon Store in the Soils under Chir (*Pinus roxburghii*) Forests at Different Altitudes in Uttarakhand State of India

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INTRODUCTION

Concentration of atmospheric CO_2 can be lowered either by reducing emissions or by enhancing the storage of CO_2 in the terrestrial ecosystems. Soil plays an important role in the carbon cycle by storing it in the form of soil organic carbon. Most of the carbon enters the ecosystem through the process of photosynthesis in the leaves. After the litter fall, the detritus is decomposed and forms soil organic carbon by microbial process. The Intergovernmental Panel on Climate Change (IPCC) identified creation and strengthening of carbon sinks in the soil as a clear option for increasing removal of CO_2 from the atmosphere. It is mandatory for all nations to provide soil organic carbon pool and changes from LULUCF sector of the forests under Nation Communications to the UNFCCC. Enhanced sequestration of atmospheric CO_2 in the soil, ultimately as stable soil organic matter, provides a more lasting solution than sequestering CO_2 in standing biomass. Adoption of better management practices can enhance soil carbon, and improve soil quality and productivity in the forest areas. Normally the soils at higher altitudes contain higher soil organic carbon due to higher accumulation of litter. Dai and Huang (2006) reported that in eastern and southern China, variables of precipitation and altitude are key factors regulating surface SOM concentration. Correlation analysis indicates that surface SOM concentration is in general positively correlated with annual mean precipitation and altitude. The relationship between SOM and altitude has also been investigated and positive correlations were reported by Sims and Nielsen (1986) and Tate (1992). Temperate climate favour organic carbon accumulation in soils (Arrouays *et al.,* 2001; Jones *et al.,* 2005) and a major concern for such regions is the change that may take place in the large SOC stocks as temperatures rise. Although, so far the soil organic carbon stock studies in Indian Himalayan forests in relation to altitudinal gradient are not available (Sheikh *et al*., 2009).

Pinus roxburghii is a very prominent forest cover in Uttarakhand. Out of total 24414.80 km^2 area under forests, it occupies 3,943.83 km^2 which is 16.15% of total forest area of the state. Accurate quantification of soil carbon is necessary for detection and prediction of changes in response to changing global climate**.** No systematic study has been undertaken to estimate the soil organic carbon in these forests, by following uniform methodology for field and laboratory work. However, some investigations have been carried out and data generated on the soil organic carbon pool in the forests, but the data is based on some assumptions. Therefore, this study was conducted to estimate SOC pool in the soils under *Pinus roxburghii* as per the IPCC methodology giving due consideration to minimize uncertainty.

MATERIALS AND METHODS

Soil sampling was done in entire Uttarakhand which is a newly created 27th state of India. It is located between 28° 43' – 31° 27' N latitudes and 77° 34' – 81° 02' E longitudes. All the districts supporting *P.roxburghii* forests were included in the study for soil sample collection. Total 834 soil samples were collected for soil organic carbon, bulk density and coarse fragments estimation from different locations of Uttarakhand state. Statistically, two stage sampling was done in which first stage unit *i.e.* Forest Ranges have been selected randomly (minimum three Forest Ranges or 50% of total Forest Ranges in each Forest Division, whichever is higher, were selected randomly) and second stage unit *i.e.* sampling sites have been selected systematically and sampling points were selected randomly. Five samples, randomly, were collected for organic carbon estimation and two samples were collected for bulk density and coarse fragment estimation from each sampling sites. Details of the sites from where soil samples were collected in different districts and number of samples collected are presented in Table 1.

Because the input of organic matter is largely from aboveground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper profile is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances (IPCC, 2003). Therefore, soil organic carbon pool was estimated up to the depth of 30 cm

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Table 1: **Details of the sites under *P.roxburghii* forest in Uttarakhand**

Sl. No.	Altitude range (m)	Districts Covered	Forest Ranges	No. of samples Collected
1	< 1000	Pauri Garhwal, Rudrapryag, Chamoli, Dehra Dun, Champawat, Pithoragarh, Bageshwer	Srinagar, Rudrapryag, Dhanpur, Atagad, Nandaprayag, Chamoli, Narian Garh, Madhya Pindari, River, Kali Kumaun, Melatha, Batelghat, Bageshwer,	120
2	1001 – 1500	Tehri Garhwal, Nainital, Uttarkashi, Chamoli, Champawat, Almora, Pauri Garhwal, Bageshwer, Pithoragarh,	Jaunpur, Saklana,Tehri, Nainital, Mungersanti, Rawai, Civil Soyam Kuthnor, Yamunotri, Chamoli, Papil koti, Pashmi Pindari, Madhya Pindari, Kali Kumaun, Someshwer, Jogeshwer, Dwarhat, Ranikhet, Almora, Lansdown, Duggadda, Pathani, Pauri, Baijnath, Kapkot, Bageshwer, Askot, Dharchula,	329
3	1501 - 2000	Tehri Garhwal, Nainital, Uttarkashi, Dehra Dun, Champawat, Almora, Pauri Garhwal, Chamoli, Bageshwer, Pithoragarh	Jaunpur, Naina, Bhowali, Rawai, Tehri Dam, River, Champawat, Kalagarh Tiger Reserve, Almora, Jogeshwer, Kosi, Binser, Someshwer, Dwarhat, Ranikhet, Kosi, Pauri, Joshimath, Pipal koti, Madhya Pindari, Baijnath, Kapkot, Bageshwer, Askot, Didihat, Pithoragarh	364
4	> 2000	Uttarkashi, Tehri Garhwal	Rawai, Tehri, Tehri Dam,	21
			Total	**834**

in this study.

Forest floor litter of an area of 0.5 m x 0.5 m, at each sampling point was removed and a pit 30 cm wide, 30 cm deep and 50 cm in length was dug out. Soil from 0 to 30 cm depth, from three sides of the pit was scraped and mixed thoroughly. In the laboratory, samples were air dried and sieved through 100 mesh sieve for soil organic carbon estimation. Soil organic carbon was estimated by standard Walkley & Black (1934) method. Amount of coarse fragments was estimated in each sample and deducted from the soil weight to get an accurate soil weight on per hectare basis and soil organic carbon calculation accordingly. Bulk density of every site was estimated by standard core method (Wilde *et al*., 1964). All the methods used in this study are in accordance to Ravindranath, and Ostwald, (2008).

The data for SOC pool was calculated by using the following equation as suggested by IPCC Good Practice Guidance for LULUCF (IPCC, 2003):

EQUATION FOR SOC

$$SOC = \sum_{Horizon=1}^{Horizon=n} SOC_{horizon} = \sum_{Horizon=1}^{Horizon=n} ([SOC] * \text{Bulk density} * \text{depth} * (1 - \text{C frag}) * 10)_{horizon}$$

Where,

SOC = Representative soil organic carbon content for the forest type and soil of interest, tones C $ha.^{-1}$

$SOC_{horizon}$ = soil organic carbon content for a constituent soil horizon, tones C ha^{-1}

[SOC] = concentration of SOC in a given soil mass obtained from analysis, g C $(kg\ soil)^{-1}$

Bulk density = soil mass per sample volume, tones soil m^{-3} (equivalent to Mg m^{-3})

Depth = horizon depth or thickness of soil layer, m

C Fragment = % volume of coarse fragments / 100, dimensionless

RESULTS AND DISCUSSIONS

P. roxburghii in Uttarakhand was found to grow on wide range of altitude varying from 700 m above msl at Kirtinagar, Pharsu in Pauri Garhwal district to 2184 m above msl at Gharipani in Tehri range of Tehri Garhwal district. However, a major portion of *P. roxburghii* forests occur between 1000-2000 m above mean sea level. The soil samples were collected from four altitudinal ranges *i.e.* < 1000 m, 1001-1500 m, 1501-2000 and > 2000 m altitude above msl. As the area under *P. roxburghii* forest was less above 2000 m therefore, 21 samples were collected in this altitudinal class. However, 120 samples were collected from < 1000 m altitude, 329 from 1001-1500 m and 364 samples from 1501-2000 m were collected. All the locations in different districts *i.e.* Dehradun, Tehri Garhwal, Nainital, Champawat, Pauri Garhwal, Bageshwer, Uttarkashi, Almora, Chamoli, Rudrapryag and Pithoragarh of Uttarakhand, where *P. roxburghii* forests were growing, have been included.

Data of SOC pool under *P. roxburghii* forests in Uttarakhand is presented in Table 2. Maximum SOC pool, 75.81 t ha^{-1} (CI 65.53 – 86.09), was estimated in the soils above 2001 m altitude followed by 67.43 t ha^{-1} (CI 64.21-70.65) at 1501-2000 m altitude, 56.41 t ha (CI 53.68-59.13) at 1001-1500 m altitude and the least SOC pool was below 1000 m altitude *i.e.* 49.27 t ha^{-1} (CI 44.70-53.83). Subset for $\alpha = 0.05$ indicate that SOC pool at > 2001 m and 1501-2000 m stood together (a) and 1001-1500 and < 1000 m were grouped together (b) (Table 2). SOC pool at > 2001 m altitude was 12.43% higher as compared to 1501-2000 m altitude while it was 34.41 and 53.87% higher in comparison to 1000-1501 and < 1000 m altitudes, respectively. SOC pool at the 1501

Table 2: **Soil organic carbon pool under *P. roxburghii* forests of Uttarakhand**

(up to 30 cm)

S. No.	Altitude	SOC Pool ($t\ ha^{-1}$)	SD	Mitigation Potential	SE	Confidence Interval ($t\ ha^{-1}$) (♋ = 0.05)	
						Lower bound	Upper bound
1	< 1000 m	49.27[a]	± 25.0437	1.00	2.31	44.70	53.83
2	1001 – 1500 m	56.41[a]	± 22.0803	1.14	1.38	53.68	59.13
3	1501 – 2000 m	67.43[b]	± 26.4059	1.37	1.65	64.21	70.65
4	> 2001 m	75.81[b]	± 18.5663	1.54	4.79	65.53	86.09
	Uttarakhand state	**61.10**	**25.4641**		**1.00**	--	--

Same alphabets represent statistically at par group
± Standard Deviation; SE - Standard Error

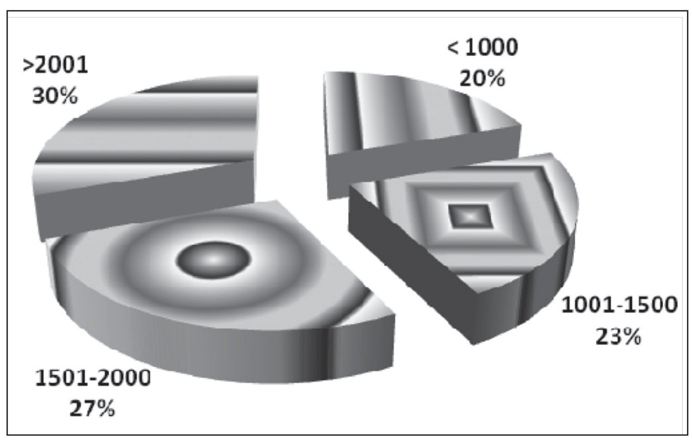
-2000 m altitude was 19.56 and 36.86% higher as compared to 1001-1500 m and < 1000 m altitude respectively. SOC pool at 1001-1500 m altitude was 14.47% higher as compared to that at <1000 m altitude. Correlation between altitude and SOC pool was worked out and it was observed that altitude was significantly positively correlated with SOC pool under *P. roxburghii* forests with correlation coefficient 0.96* (Significant at $P < 0.05$ level). It is evident from the data that SOC pool in the soils is increasing with the increase in altitude.

Higher SOC content in the soils at higher altitude is a natural phenomenon since slow decomposition of organic matter due to low temperature facilitates accumulation of thicker litter layer and soil organic matter. Among the factors affecting SOC, the annual temperature, precipitation, and soil moisture content constituted the first principal component. Rawat (2005) while investigating the soil characteristics along an altitudinal gradient from 1,700 to 2,100 m above msl in a mountain flank of Garhwal Himalaya reported that soil organic carbon and potassium were positively correlated with the altitudinal gradient. The study conducted on the shady and sunny northern slopes of Qilian Mountains along an altitude gradient from 2600 m to 3600 m in China by Zhang *et. al.* (2009) revealed that SOC contents were significantly higher on shady than on sunny slope, and the SOC increased with increasing altitude. SOC had significant positive correlations with altitude, annual precipitation, soil moisture. Zhang *et al.,* (2010) reported that under natural conditions the contents of SOC and LOC were largest in *Betula ermanii* forest (altitude 1996 m), moderate in spruce-fir forest (altitude 1350 m), and smallest in Korean pine mixed broad-leaf tree forest (altitude 740 m).

Mitigation potential was worked out with respect to SOC pool < 1000 m as the SOC pool was minimum at this altitude. The data revealed that maximum mitigation potential (1.54) was of the soil at an altitude > 2001 m. It indicated that soils at an elevation of > 2001 m can hold one and half time more organic carbon as compared to the soils at < 1000 m altitude. Mitigation potential of the soils at 1501-2000 m was 1.37 while the mitigation potential of soil at an altitude 1001-1500 m was very small. Standard error varied from 1.38 to 4.79 and it was little higher (4.79) at an altitude > 2001. It may be because of less number of soil samples collected from this altitude since the area supporting *P.roxburghii* at this altitude was less.

Out of total SOC pool, percent share at different altitudes was also worked out (Fig. 1). Data revealed that maximum share (30.46%) was contributed at the altitude > 2001 m fllowed by 27.09 % at 1501-2000 m, 22.66 % at 1001-1500 m and the least was below 1000 m altitude under *P. roxburghii* forests in Uttarakhand. With the increase in altitude, there is a decrease in temperature and pH and an increase in rainfall, which favours the accumulation of organic matter hence, soil organic carbon content is generally higher at higher altitude. Similar findings have also been reported by Nath and Deori (1976) and Palaniappan *et. al.* (1978).

Fig. 1: **Percent Share of SOC at different altitudes**



Results of one-way ANOVA indicates that SOC pool between different altitudes were significantly different at 0.05 level (Variance ratio, $F = 19.634$; $p < 0.05$). SOC pool at < 1000 m and 1001-1500 m altitudes was significantly different from the SOC pool at other altitudes. However, SOC pool at 1501-2000 m altitude was non-significantly different from the SOC pool at > 2001 m altitude (Table 3).

Table 3: **Statistically significant mean differences on the basis of CD (LSD)**

S. No.	Altitudes	Mean Difference	p value
1	< 1000 m Vs 1001 – 1500 m	7.1376*	0.009
2	< 1000 m Vs 1501 – 2000 m	18.1642*	0.000
3	< 1000 m Vs 2001 m	26.5423*	0.000
4	1001 – 1500 m Vs 1501 – 2000 m	11.0266*	0.000
5	1001 – 1500 m Vs > 2000 m	19.4047*	0.003

** Mean difference is significant at the 0.05 level*

It is a well accepted fact that adoption of better management practices can enhance soil carbon, and improve soil quality and productivity in the forest areas. Moreover, soils provide a significant reservoir for organic carbon, storing twice as much as the atmosphere and three times as much as plants. Changes in forest type, productivity, decay rates and disturbances can effectively modify the carbon contents of forest soils. Different forest management activities, such as rotation, length, harvest practices, site preparation activities and fertilization, interfere more or less strongly with soil organic carbon (Harmon and Marks, 2002; Johnson and Curtis, 2001). CO_2 emissions from land use, land use change in forestry sectors in the tropics were estimated at 1.1± 0.27 Gt C/yr (IPCC 2007), which is dominated by conversion of forest (tropical deforestation) to other land use, and forest degradation due to non-sustainable logging, fuel wood collection, and forest fires. There is a major potential for increasing soil organic carbon through restoration of degraded soils and widespread adoption of soil conservation practices (Lal and Kimble, 1997). The magnitude of soil carbon depletion is increased by soil degradation, especially due to erosion. Soil management is a relatively more intricate aspect of the whole mitigation strategy since soil is a heterogeneous resource and careful handling is required. It can serve, as both source and sink for GHGs, therefore, well understood soil behaviour could help in effective stabilization of GHGs.

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Carbon Store by Trees outside Forests

Sparsh Kala & VK Dhawan *

INTRODUCTION

Researchers and scientists have acknowledged the fact that the world is changing measurably and in quantifiable amount because of Global warming. Scientists believe that the temperature of the Earth's surface – which has already risen by 0.6°C since the late 1800s – is likely to rise by another 0.8 to 4°C and sea level from 0.28 to 0.43 m by 2100 (IPCC, 2007). The main cause of global warming is said to be build up of Greenhouse gases, which are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (NO_2), Chlorofloro Carbons (CFCs), Ozone (O_3) and Water vapours. Carbon Dioxide (CO_2) is the major contributor out of all the GHGs. The compounded annual growth rate of CO_2eq emissions in India is 4.2%. Burning of fossil fuels is the major cause for CO_2 emission. However, deforestation, forest degradation, fragmentation and diversion of forest land for non-forest purposes are also sources of CO_2 emissions (Gera *et al.*, 2011). Carbon, in the form of CO_2 is accumulating in the atmosphere at the rate of about 3.5 billion metric tonnes per annum as a result of fossil fuel combustion, tropical deforestation and forest fuel combustion (Borah *et al.*, 2011).

Forests and trees outside forests act as carbon sink and they remove CO_2 from atmosphere through carbon sequestration. Carbon sequestration can be defined as the removal of CO_2 from atmosphere into green plants (Above Ground Biomass (AGB) and in the soil) where it can be stored indefinitely (Watson *et al.,* 2000 cited by Borah *et al.*, 2011). Roughly half of total carbon is found in forest biomass and dead wood combined and half in soils and litter combined (FAO, 2006). Model-based projections of carbon stocks in the Indian forest sector show a likely increase from 8.79 GtC in 2005 to 9.75 GtC in 2030. (Ravindranath *et. al.,* 2008).

There has been shortage of industrial woods and shortage of fuel wood. Growing population has put enormous pressure on forests, there by arousing the need to grow trees in wastelands and lands which are unproductive (Giri *et. al.*, 2000). According to FSI Tree Outside Forest (TOF) are the trees growing outside the recorded forest which comprises of 1599.57 M m^3 (FSI, 2009).

Carbon sequestration through Farm-forestry/Agro-forestry is also a common practice in India. Under the Farm Forestry programme in Uttar Pradesh, nearly 1906.8 million trees have been planted during the period 1979-94. It is estimated that nearly 20 million tonnes of carbon has been sequestered by these Farm Forestry plantations (Singh, *et al.*, 2000). Poplar plantations are a step to meet the acute shortage of wood. Roads, canals and farm lands are important sites outside traditional forests where plantation can be raised (Dalal and Trigotra, 1983). Another most widely planted species in India is *Eucalyptus tereticornis* (Mysore gum). Estimation of carbon stock of Rubber plantations in the North-east region indicate that an average carbon store in rubber plantation is around 136 tonnes. About 7 million tonnes of carbon is stored in the rubber plantation of this region. This study reflects the immense ecological value that rubber plantations provide, by storing carbon despite low productivity in these marginal lands (Dey, 2005).

The current study has been undertaken to deal with the subject by estimating carbon proportion for some trees outside forest (TOF), so that the carbon stored in the standing trees may be accounted for. The objective of the study is estimating carbon proportion for some trees outside forest, so that the carbon stored in the standing trees may be accounted for.

ACCOUNTING CARBON STOCKS

The total forest carbon stock is divided into two parts: soil and biomass carbon. Biomass carbon includes carbon stocks in tree (above and below ground) biomass and forest floor biomass. The biomass carbon estimation of carbon stock of the forests can be done by estimation of merchantable biomass of tree. The merchantable biomass is used for computation of above ground and below ground biomass based on expansion and conversion factor, and ratio of above and below ground biomass. The total tree biomass is used for estimation of forest floor biomass based on the ratio of tree to forest floor biomass (IPCC, 2000). Therefore, these three parameters (Biomass expansion and conversion factor – BEF; Ratio - above and below ground biomass; Ratio - Tree to forest floor biomass) are fundamentally required to obtain the total forest biomass. Besides this, the mean wood density is also essential for accurate estimation due to its contribution for carbon estimation. The mean wood density value for majority of tree species has been estimated (Rajput *et al.*, 1996), therefore the precise estimation of carbon content proportion further adds for improvement in the estimation. Most of the carbon analysis studies for biomass use carbon proportions between 40 to 50% depending on the requirements (IPCC, 1997; Susott, *et al.,* 1996; Ludwig, *et al.*, 2003 cited by Kishwan *et al*, 2009).

Mathematically, assessment of forest carbon stocks in the study can be represented by Kishwan *et al*, 2009 as:

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$$C_{Carbon} = C_{Biomass} + C_{Soil}$$

Where,

C_{Carbon} - Total available carbon in the forest, i.e., in the vegetation and in soil

$C_{Biomass}$ - Total available carbon in the above and below ground biomass of all forest vegetation

C_{Soil} - Total available soil organic carbon (SOC) up to 30 cm depth in the forest

Mathematically, the above ground biomass of tree component is as follows:

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

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

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

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

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

$V_{Above\ Ground}$ - $GS_{Commercial}$ x Expansion factor

$GS_{Commercial}$ - Growing stock of tree bole up to 10 cm diameter

METHODOLOGY

The data for the estimation of the carbon storage potential by trees outside forests for the year 2005 and year 2009 were collected from respective State Forest Reports of FSI. Using Biomass Expansion Factor (BEF) and ratio of below ground biomass to above ground biomass, total biomass was estimated in million m^3. These factors were taken to be 1.58 and 0.27, respectively (Kaul *et al*., 2009). Using Mean Wood Density (MWD) of each species, the total biomass was calculated in metric tonnes. The MWD for certain species, whose exact MWD were not known , were taken to be as 0.72 (average MWD for the entire country, Kaul *et al*., 2009). The total biomass thus calculated was multiplied by 0.8 to get the dry weight biomass for the trees outside forests (dry weight = 80% of the total biomass). Carbon stock was estimated by multiplying 0.5 to the dry weight (total carbon = 50% of the dry weight). These calculated data of the carbon stock for years 2005 and 2009 were compared on the parameters of years (2005 and 2009), species (carbon sequestration potential of different species for the two years) and the diameter classes (carbon stock for trees falling under different diameter classes). Thus, the change in carbon stock of trees outside forests for the entire country was reported from 2005 to 2009.

RESULTS AND DISCUSSION

The total carbon stock of trees outside forest in 2005 was 861.599 Mt and 851.187 Mt in 2009. In the years 2005 and 2009 *Mangifera indica* had maximum carbon stock of 84.694 Mt with 459,549 stem number in former and 77.706 Mt with 391,619 stem number in later, *Alnus nepalensis* stored minimum carbon, 2.222 Mt with 8,866 stems in 2005 and 3.638 Mt with 25,906 stems in 2009 (Table 1). It was observed that different species showed variation in the carbon storage potential for the years 2005 and 2009 due to difference in the number of stems and the volume. Thus a comparison was made between the carbon stock of 2005 and carbon stock of 2009 for different tree species outside forests. The given table 1 & fig.1 show the comparison between the carbon stock for the years 2005 and 2009.

Table 1: **Total Carbon Stock and Stem Number variation from 2005 to 2009 (According to species)**

S. No.	Species	No. of stems ('000) in 2005	No. of stems ('000) in 2009	Change %	Carbon stock 2005	Carbon stock 2009	Change %
1	*Acacia nilotica**	1,99,503	1,97,553	-0.97743	21.579	21.755	0.82
2	*Acacia catechu*	99,318	1,12,915	13.69037	8.306	6.617	-20.33
3	*Acacia lenticularis*	83,755	97,248	16.11008	5.452	6.570	20.50
4	*Albizzia species*	31,205	45,707	46.47332	6.978	8.159	16.91
5	*Alnus nepalensis*	8,866	25,906	192.1949	2.222	3.638	63.68
6	*Anacardium occidentale **	1,09,939	1,03,621	-5.74682	6.867	7.512	9.39
7	*Areca catechu **	3,86,576	3,71,203	-3.97671	14.586	11.230	-23.01
8	*Artocarpus heterophyllus*	54,623	57,315	4.928327	12.529	12.121	-3.25
9	*Azadirachta indica*	2,24,782	2,23,092	-0.75184	35.162	36.954	5.10
10	*Bombax ceiba*	53,615	53,613	-0.00373	6.595	5.659	-14.19
11	*Borassus flabelliformis**	92,223	1,04,175	12.95989	33.978	33.675	-0.89
12	*Butea monosperma*	1,18,275	1,28,812	8.908899	6.455	8.020	24.24
13	*Cedrela toona **	24,603	31,415	27.68768	5.569	6.179	10.97
14	*Cocos nucifera **	2,21,289	2,74,597	24.08976	46.103	52.787	14.50

15	*Dalbergia sissoo*	88,569	82,220	-7.16842	9.909	8.353	-15.71
16	*Eucalyptus species*	1,06,387	1,07,435	0.985083	13.420	13.884	3.45
17	*Ficus bengalensis* *	9,481	8,206	-13.4479	14.220	10.825	-23.87
18	*Ficus religiosa*	11,149	10,486	-5.94672	8.224	7.108	-13.57
19	*Ficus species* *	34,024	35,405	4.0589	25.398	22.382	-11.87
20	*Grevillea robusta*	41,617	41,167	-1.08129	5.943	5.549	-6.62
21	*Hevea brasiliensis*	56,408	78,811	39.716	4.415	6.435	45.77
22	*Lannea coromendelica*	50,605	49,416	-2.34957	4.472	4.312	-3.57
23	*Madhuca latifolia* *	56,323	46,786	-16.9327	34.727	38.641	11.27
24	*Mangifera indica*	4,59,549	3,91,619	-14.7819	84.694	77.706	-8.25
25	*Phoenix sylvestris* *	44,052	49,402	12.14474	8.741	11.909	36.24
26	*Pinus roxburghii*	88,690	2,10,929	137.8273	13.144	19.891	51.34
27	*Prosopis cineraria* *	1,68,271	1,42,348	-15.4055	24.794	21.548	-13.09
28	*Quercus leucotrichophora* *	35,036	99,542	184.1135	6.381	10.307	61.54
29	*Schima wallichii* *	50,243	46,488	-7.47368	5.594	4.987	-10.85
30	*Shorea robusta*	56,395	36,059	-36.0599	18.225	12.147	-33.35
31	*Syzygium cumini*	63,669	69,987	9.923197	35.279	26.281	-25.51
32	*Tamarindus indica*	31,889	30,795	-3.43065	24.919	21.312	-14.48
33	*Tectona grandis*	1,19,639	1,42,084	18.7606	10.178	10.593	4.08
34	*Terminalia arjuna*	31,026	25,880	-16.5861	5.793	5.523	-4.67
35	*Terminalia crenulata**	96,431	85,575	-11.2578	8.972	8.106	-9.66
36	*Zizyphus mauritiana*	65,684	61,198	-6.82967	4.764	5.025	5.49
37	Rest of Species	16,86,038	18,29,623	8.516119	277.014	277.487	0.17
	Total	**5,159,747**	**5,508,633**	**6.761688**	**861.599**	**851.187**	**-1.21**

** Mean Wood Density 0.72 in Indian context (Kaul et. al., 2009); Mean Biomass Expansion Factor 1.58 in Indian context (Kaul et. al., 2009); Mean Ratio of BGB to AGB 0.27 in Indian context (Kaul et. al., 2009); Dry weight- 80% 0f total biomass and Total carbon- 50 % of dry weight.*

Fig. 1: **Assessment of carbon stock in 2005 & 2009 years**

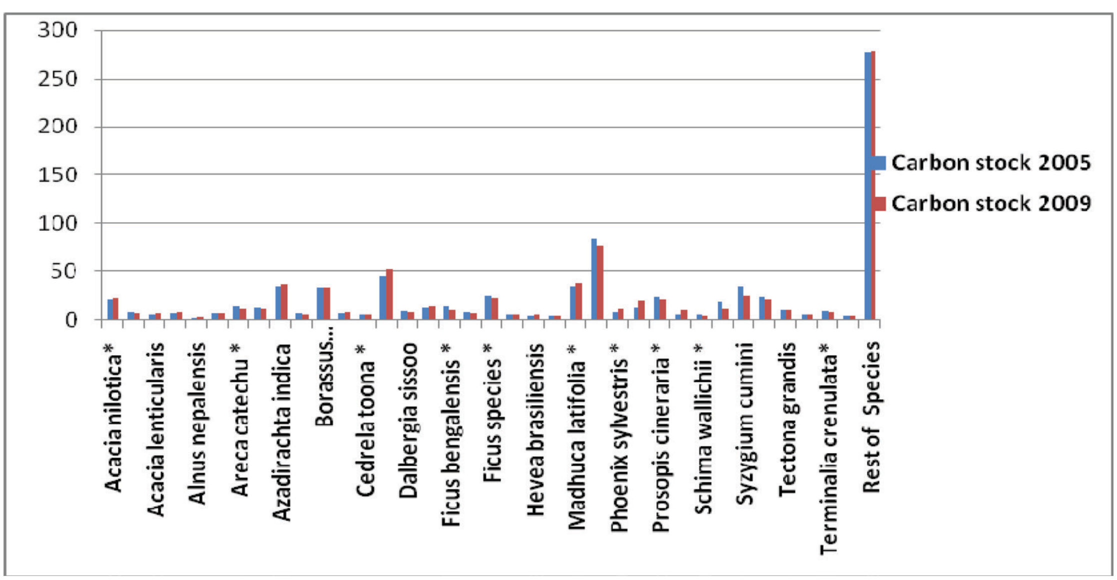

Table 2: **Total Carbon Stock Variation from 2005 to 2009 (According to diameter class)**

Diameter class (cm)	Year	No. of Stems (nos. in '000)	Volume (million m^3)	Total Biomass (million m^3)	Weight (Mt)	Dry wt. (Mt)	Carbon Stock (Mt)
10- 30	2005	43,15,102	549.418	1102.462	793.773	635.018	317.509
	2009	46,52,830	567.455	1139.659	820.555	656.444	328.222
Increment %		**7.83**	**3.28**	**3.37**	**3.37**	**3.37**	**3.37**
30-50	2005	6,81,000	488.476	980.176	705.727	564.582	282.291
	2009	7,01,950	486.824	976.861	703.34	562.671	281.336
Increment %		**3.08**	**-0.34**	**-0.34**	**-0.34**	**-0.34**	**-0.34**
50+	2005	163,645	578.35	1160.517	835.572	668.458	334.229
	2009	153,676	544.791	1093.178	787.088	629.671	314.835
Increment %		**-6.09**	**-5.80**	**-5.80**	**-5.80**	**-5.80**	**-5.80**

** Mean Biomass Expansion Factor 1.58 in Indian context (Kaul et. al., 2009); Mean Ratio of BGB to AGB 0.27 in Indian context (Kaul et. al., 2009); Dry weight- 80 % of total biomass; Total carbon- 50% of dry weight.*

A net decrease of total carbon stock by 1.21% was observed since the year 2005 to 2009. *Shorea robusta* showed maximum decrease, 33.35% where as *Borassus flabelliformis* showed minimum loss of carbon stock, of 0.89% (Table 1). Since a few species showed decrease in carbon content even after increment in stem number, a comparison was made between the number of stems and the volume for different diameter classes. The given table (Table 2) shows comparison between the volume and number of stems falling under different diameter classes.

An increment of 7.83% stems and 3.37% carbon stock in the diameter class 10-30 cm was observed in the studied time period. 3.08% increment in stems was found but a decrease of 0.34% in carbon stock was recorded in 30-50 cm diameter class. This may be due to presence of more number of trees in the lower limit of the diameter class in 2009 when compared with 2005 where as lesser number of trees in upper limit, causing a net decrease in carbon stock. Trees with more than 50 cm diameter showed an overall decrease, 6.09% in case of stem number and 5.80% in carbon stock was observed (Table 2).

CONCLUSION

The study estimates that there was a net decrease in the total carbon sequestered by trees outside forests in year 2005 to 2009. The decrease in carbon stock may be due to decrease in number of stems in more than 50 cm diameter class, which stores more carbon as compared to lower diameter classes. Even though there is rise in number of stems falling under diameter classes 10-30 cm and 30-50 cm, it might not compensate the decrease in net carbon stock. Since the volume is proportional to the diameter, the decrease in number of stems in the largest diameter class lead to net decrease in the carbon stock. Since it is assumed that the net carbon stock of the country has risen for the given period of time, it can be said that the increase in net carbon stock may be due to the effect of trees outside forests which may not have been accounted for in the current study.

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Implementation of Forest Rights Act, Changing Forest Landscape and 'Politics of REDD+' in India

Ashish Aggarwal *

1. INTRODUCTION

Internationally, there is increased focus on forests because of their role in climate change mitigation. Deforestation and degradation in tropical countries contribute between 12-17% of global greenhouse gas (GHG) emissions (IPCC, 2007; Vander Werf et al., 2009). Besides, the potential for large scale reduction in GHGs, reducing emissions from deforestation and degradation (REDD) has been projected as a low cost and effective strategy to mitigate climate change (Sathaye et al., 2007; Stern, 2007). It has resulted in rapid development of Reducing Emissions from Deforestation and Degradation[3] (REDD+) mechanism in international climate change negotiations hosted under United Nations Framework Convention on Climate Change (UNFCCC). Idea of REDD+ was first accepted at the Conference of Parties (CoP) 13 at Bali in 2007 and it was ratified by Conference of parties in Cancun in 2010. So it is almost certain that REDD+ would constitute an integral part of any future climate change policy framework.

There are various studies which reflect on how REDD+ will affect and get affected by people's rights and forest governance mechanisms on the ground (Corbera and Schroeder, 2011; Irland 2011, Larson and Petkova, 2010). Some researchers and civil society groups argue that REDD+ projects could adversely impact livelihoods and rights of indigenous groups and local communities as rights of the communities remain contested over the large part of the forest land in the developing world (Griffiths, 2007; Lovera 2008; Rawles, 2008). Hence, it has been argued that recognition of rights and security of tenure is critical for equitable REDD+ (Hatcher, 2009; Sikor et al, 2010). Similarly it has been suggested that REDD+ would face immense governance challenges such as coordinating policies and addressing governance issues such as corruption (Angelsen, 2009). There has been little progress on the ground in addressing these governance challenges despite the eagerness of many developing countries to participate in REDD+ (Sunderlin and Atmadija, 2009; Sunderlin et al, 2009).

Despite so much literature, there is little empirical evidence on how REDD+ will affect community rights and forest governance on the ground. Indian case could provide some illuminating evidence in this regard. There is a huge programme underway for recognition of peoples rights over forest resources in the country through a unique legislative measure known as The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights Act), (henceforth, Forest Rights Act or FRA). FRA is set to redistribute control over forest resources if implemented in the right spirit (Sarin and Springate-Baginski, 2010).

It has been reported that up to 30th April 2011, 1.169 million claims for individual and community rights over forest resources have been accepted across India (MoTA, 2011). These claims cover around 3% of forest area in the country and have already started changing the 'playing field' (Springate-Baginski et.al, undated). Implementation of FRA has been slow so far because of many challenges, however it is expected to improve with certain policy changes and constant pressure from the civil society. FRA will change the forest landscape of the country with recognition of more individual and community rights. Local people will have more control over the management of the forests and their resources.

As FRA is being implemented on the ground, idea of REDD+ is also gaining momentum in the country. Indian government supports implementation of REDD+. It considers forests as an important part of its climate change strategy. In fact Government has proposed National Mission for A Green India (or Green India Mission or GIM in short) to address climate change issues through forestry sector. Indian government wants to finance GIM through REDD+ funding from international community (Sharma, 2010). This is problematic for the civil society groups supporting the implementation of FRA. These groups are very sceptical about REDD+ and they see it as a 'way to deny People's rights' and allow private sector to exploit forest resources for profit (CFSD and NFFPFW, undated). They are strongly opposing REDD+, which has led to a contestation on the ground.

This paper aims to discuss how contestation or 'politics of REDD+' is interacting with implementation of FRA and changing forest landscape in the country. How is it affecting and getting affected by the changing conditions. It will also highlight some of the research gaps that need to be plugged to understand this conundrum better.

The second section discusses the forestry context of India. It highlights ownership and management control of the forest resources in the country. Third section of the chapter discusses historical context, genesis and implementation challenges of FRA to understand the scepticism of the civil society groups towards state[4] and REDD+. Fourth section discusses how FRA is changing the forestry landscape of the country. Fifth and sixth sections

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discuss emergence of REDD+ at international level, India's approach and politics of REDD+. Final section concludes this paper.

2. INDIAN FORESTRY CONTEXT

2.1 Forest resources

India is one of the seventeen mega diverse countries of the world (MoEF, undated b). It has great diversity of ecosystems and animal and plant species. Forest ecosystems constitute an important part of this diversity. India has 78.37 Mha of area under forest and tree cover, which constitutes 23.84% of its geographical area (FSI,2009). Forests[5] cover 69.09 Mha and trees[6] cover 9.28 Mha out of the total area. Tree cover is important from the management point of view as it lies outside the designated forest boundaries. Forest cover has been further divided into three density categories of very dense forests (VDF), moderately dense forests (MDF) and open forests (OF) with more than 70%, 40-70% and 10-40% canopy densities respectively.

Of the forest cover, 42% is in the open forest cover category. Much of this area is degraded because of huge human and cattle population pressure. India has 2% of the global forest area, and is faced with the demands of 16% of the world's human and 18% of world's cattle population (MOEF, undated a). 200 M rural people depend on forests for at least part of their livelihoods (FSI, 2009). 40% of the population still depends on the fuel wood as source of energy (NSSO, 2001), a substantial part of which is exploited from the forests beyond their carrying capacities (Aggarwal et al, 2009a,; MOEF, 2006). All these pressures have resulted in widespread forest degradation.

2.2 Legal status, ownership and management

2.2.1 Legal Status

Forests have been classified broadly into two categories of reserve forests and protected forests as per the Indian Forest Act of 1927. Reserve and protected forests cover 56% and 27% of the forest area (Fig1). There is another category of village forests mentioned in the Act. Village forests are the reserve forests which are assigned to the communities for management (MoEF, 2006). Another category, which does not find mention in Indian Forest Act but covers around 17% of the forest area, is known as 'unclassed forests'. This category of forests awaits to be notified in to reserve or protected forest category (ibid)

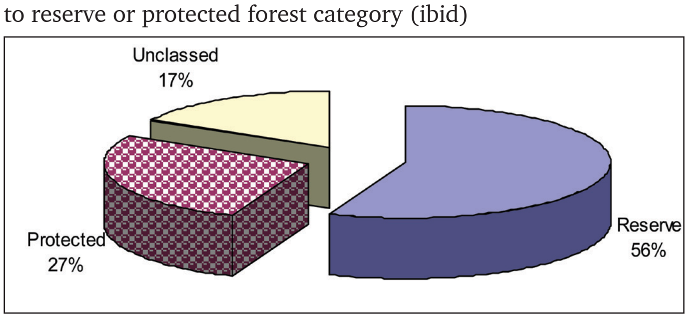

Fig 1: **Forest categories in India**

Source: FSI, 2009

Status of rights varies across these legal categories. Local people have minimal rights in the reserve forests. Protected areas like national parks and wild life sanctuaries along with other forests come in this category. People have some rights in the protected forests while rights have not been recognized in the unclassed category. So, across 73% of forest area which constitute of reserve and unclassed forests, people have either minimal rights or their rights have not been recognized.

2.2.2 Ownership and Management

Of the total forest area, around 97% is legally owned by the government (comprising 93% of the forest area controlled by state forest departments and 4% by state revenue departments) and 3% is owned by private entities and communities (MoEF 2006). Though government owns the large part of forests, but there has been an increasing involvement of communities in the management over the years. Reportedly, 28% of forest area is managed in collaboration with communities under the JFM (Joint Forests Management) programme (Aggarwal et al., 2009a). Similarly, there have been efforts by companies and individual farmers to manage vegetative cover mainly outside forest area. After the 1980 Forest Conservation Act, which substantially reduced the supply of raw material from state forest lands to wood based industries, the government promoted plantation of trees under various agroforestry and social forestry plantation schemes.

Despite the involvement of communities, government still manages 69% of the forest area on its own, through the state forest departments (Table 1).

Table 1: **Management pattern of Indian forests**

S.No	*Management*	*%age forest area*
1	Government	69
2	Government and communities	28
3	Communities and private entities	3

Source: Aggarwal et al., 2009a

The state owns and manages the largest part of forest estate in the country, where rights of people have not been recognized. It has marginalized forest dependant communities in the country. They have protested against this deprivation of rights for long (Guha, 2000). These protests finally resulted in the Forest Rights Act (FRA).

3. FOREST RIGHTS ACT: HISTORICAL CONTEXT, IMPLEMENTATION STATUS AND ISSUES

FRA was enacted in the year 2006 and its implementation started in the year 2008. This act recognizes a range of individual and communal rights on forest resources including ownership of forest land, which have been neglected since independence. It not only aims to undo the 'historical injustice' to scheduled tribes and other traditional forest dwelling communities but also to empower the communities for the 'responsibilities and authority for sustainable use, conservation of biodiversity and maintenance of ecological balance' (MoLJ, 2007; MoEF and MoTA, 2010). It marked an unprecedented event in Indian politics, when rights of the tribal and other forest dependant communities took centre stage.

However, FRA did not emerge in an 'unproblematic and consensual' way (Bose, 2010). Different stakeholder groups contested for their interests over a long period of time. In fact history of this contestation dates back to colonial era when rights of people were systematically usurped.

3.1. Historical context and genesis of FRA

The genesis of FRA lies in the historical deprivation of rights of tribal and other forest dependant communities in India (Springate-Baginski et.al, 2009). It started with the colonial rule in 19th century when British started centralizing and restricting the forest use for commercial exploitation through legislative measures such as the Indian Forest Act of 1864 and later on 1927 (Sarin et al., 2003; Springate-Baginski et.al., 2009). This centralisation and reservation of forest land changed the forest-people relations (Sarin et al., 2003).This policy of reserving forests and restricting people's rights continued even after independence, which is a common feature of many postcolonial nations.

In independent India, large areas of unsurveyed community lands were transferred to the forest departments through blanket notifications without recognition of their rights or consultation with local people (Bose, 2010). In some states like present day Uttarakhand then part of Uttar Pradesh) the notifications were accompanied with a 'forest settlement' process, where rights of communities were partially recognized. But in many areas, forests were notified as reserve and protected forests without recognition of rights (Springate-Baginski et.al, 2009; Bose 2010). In many cases, where private feudal forests were annexed to the forest estate of the country, the situation of forest dependent people became even worse as their already existing minimal rights were not recognized (Bose, 2010). The forest estate of the country increased by 26 Mha between 1951 and 1988 through the annexations under colonial Forest Act of 1927 (Sarin et al., 2003). The Indian state became the 'biggest violator of the spirit of the Constitution' which provides for the protection of the rights of tribal people (Sarin, 2005). Similarly, the rights over major non timber forest produce (NTFP), which constitute an important part of the livelihoods of forest dependant communities, were centralised through various policies between 1960 to 1970s (Saxena, undated).

Increasing concern for the conservation of forests and wild life in the country resulted in the Wildlife Protection Act of 1972 and Forest Conservation Act of 1980. Wildlife reserves, which had minimal rights for tribal people, increased from 131 in 1975 to 572 in 1999 covering 4.7% of the land area of the country (Bose, 2010). These laws made the tribal and other forest dependant communities 'encroachers' on their own lands. On the proactive efforts of a bureaucrat, government issued guidelines to regularize the pre 1980 'encroachments', in the year 1990 but these were barely implemented.

Besides the conservation concerns, there was a growing demand for development in the country. Mines, industry, large dams and other infrastructure were created. These further marginalized the tribal and forest dependant communities. They were displaced from their lands without adequate compensation. It is estimated that 21.3 million people were displaced between 1951 and 1990, out of which 8.54 million or 40% belonged to scheduled tribe category, which constitute around 8% of the country's population (Sarin et al., 2003; Bose, 2010). Hence tribal communities have paid a heavy price for the 'conservation' and 'development' of the country. It is one of the main reasons for spread of left wing extremism across the tribal districts in the country.

In this historical setting, the actual trigger for the FRA came up in the year 2002, when in response to a decision by Supreme Court, the Ministry of Environment and forests (MOEF) issued a directive to the state forest departments to evict all the encroachments from the forestland in a fixed time. This order estimated an area of 12,50,000 ha under encroachments spread across eight states. Many state forest departments started the eviction process. It is estimated that between 1,50,000 to 3,00,000 families were evicted (CSD,2007; Springate-Baginski et.al., undated). This led to a massive uproar and protests and the MoEF had to intervene to stop the process. It resulted in a loosely united campaign of various civil society activists and organizations christened as 'Campaign for Survival and Dignity' (Springate-Baginski et.al, undated). It became a major political issue. Both the parties promised legislation to recognise rights of tribal and forest dependant communities for forthcoming elections in 2004 (MoEF and MoTA, 2010). Once the elections were won by United Progressive Alliance led by the major political party Indian National Congress, the pressure on the government mounted to fulfil its promises. The Prime Minister (PM) of the country asked the Ministry of Tribal affairs (MoTA) instead of Ministry of Environment and Forests, which has been handling these affairs so far, to draft a bill to recognise the rights of forest dependant communities. This was a major shift because of the protests of civil society (Springate-Baginski et.al, 2009; Bose, 2010). Then it took three years of strong contestation among various stakeholders before implementation of the FRA began in 2008.

The majority of the stakeholders aligned themselves into two coalitions – one strongly favoured the status quo based on conservation ideas and other coalition wanted a change for the tribal and forest dependant people (Sarin and Springate-Baginski, 2010; MoEF and MoTA, 2010). There was conflict within the government- MoTA and MoEF based on different ideologies, which was finally sorted out by the PM himself (MoEF and MoTA, 2010). Powerful lobbies worked on both sides. Pro rights groups advocated their cause based on the arguments of democratic rights, poverty alleviation and improved incentive for the tribal people for conservation whereas the pro conservation coalition, based their campaign on the ideas of wildlife and nature conservation (Bose, 2010). It has been argued that powerful conservation lobby influenced the media to launch a 'misinformation campaign' (ibid). Data and information provided by both the coalitions varied to a great extent. For example, the pro conservation lobby argued that the proposed bill could result in a loss of 15% of India's forest cover whereas pro rights group argued that it dealt only with 2% of India's forest land (Bose, 2010). But due to immense pressure from civil society and its potential political ramifications, the Act was passed in the parliament in year 2006. However, there was a strong contestation on the text of both the Act and the rules between both the stakeholder coalitions. It is argued that FRA which was enacted is a much watered down version of what was proposed initially (Sarin and Springate-Baginski, 2010).

3.2 Implementation of FRA - Status and Issues

3.2.1 Status

The act is being implemented for more than two years now. It has been reported that up till April 30, 2011, 1.169 million titles for individual and community rights have been distributed across India (MoTA, 2011). More detailed information is available for the four states of Chhattisgarh, Maharashtra, Rajasthan and West Bengal (table 2), which highlights the disparity in recognition of individual and community rights. Individual rights constitute 99.78% of the total recognized claims as against 0.2% of recognized community rights. Similarly, area recognized under individual rights constitutes 97.5% of the total area as compared to the 2.5% of the area recognized for community rights. So, very few community rights have been recognized as compared to individual rights. Average area given for individual and community claims is 0.88 ha and 10.39 ha respectively.

Table 2: **Detailed analysis of recognized claims under FRA in four states of Chhattisgarh, Maharashtra, Rajasthan and West Bengal**

S.N	Claim	Number	Number (%age of total)	Area (ha)	Area (%age of total)	Av. Area/ claim (ha)
1	Individual	376835	99.78	333282	97.49	0.88
2	Community	826	0.22	8584	2.51	10.39
		377661	100.00	341866	100.00	

Source: MoTA, 2011

Similarly, aggregate information is available for 13 major FRA states of the country- Andhra Pradesh, Assam, Chhattisgarh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tripura, Uttar Pradesh and west Bengal. Around 1 Million titles with rights over 1.42 M ha of forest area have been distributed in these states (table3). It constitutes 2.8% of the forest area and 3.2% of the forest cover in these states.

Table 3: **Recognized claims under FRA in 13 major FRA states**

Claims recognized (Number)	Area (ha)	Av area/ claim (ha)
1002792	1425206	**1.42**

Source: MoTA, 2011

As mentioned above, 1.169 M claims have been recognized across the country. However, there is not easily comprehensible information available about the total forest area covered under these claims. Based on a combined average of 1.42 ha/claim derived above, it has been estimated that 1.66 Mha of forest area has been distributed so far (table 4).

Table 4: **Total claims and forest area recognized under FRA at country level**

Claims recognized (Number)	Area (Mha)
1169000	**1.66**

Source: MoTA, 2011 and area extrapolated from average fig. in table 3

3.2.2 Issues

Despite the progress, there are many issues like low rate of acceptance of claims, low recognition of community rights and institutional issues, which have marred the implementation of process. These issues are analyzed here

Unequal geographies

FRA has been implemented unevenly across the country. While it is progressing well at least numerically in states like Orissa, Chhattisgarh, Madhya Pradesh, Tripura and others but it has not even started in ten states and Union territories like Arunachal Pradesh, Goa, Tamil Nadu and Uttarakhand. In some states like Bihar and Himachal Pradesh, progress is very slow (Fig 2). There are different reasons for the slow progress in various states. In most of the north-eastern states, state governments are not clear about the relevance of the Act for their tribal areas, which already have autonomous administration under sixth schedule of the constitution (MoEF and MoTA, 2010). Implementation has been stalled in Tamil Nadu because of a petition against the Act in the high court of the state (ibid). In many other states state governments are slow to start the process.

Different state governments are implementing the Act as per their understanding, motivation and agenda. For example, states of Andhra Pradesh and Madhya Pradesh see the Act as 'an opportunity to 'distribute' forest land and secure the individual rights' (ibid) These unequal geographies have frustrated tribal, forest dependant communities and civil society groups in these areas.

Low rates of acceptance

There has generally been a low rate of acceptance by government of individual and community claims across the country. Country wide combined rate of acceptance is only 37.60% (table 4). However in some states like Himachal Pradesh and Bihar acceptance rates are abysmally low at below 1%. There are various reasons for these low rates of acceptance. A report by the joint committee of MoEF and MoTA suggests that there is severe shortage of trained manpower at the ground level. Implementation of FRA is an additional responsibility of the concerned departments, which has led to slow progress and rejections of claims (MoEF and MoTA, 2010). Sathyapalan (2010) cites difference in objectives and perceptions of departments leading to lack of coordination and low rates of acceptance. Civil society groups like Campaign for Survival and Dignity (CFSD) accuse state Forest Departments (SFD) of 'illegally blocking people's rights to their homes, lands' (CFSD, 2009)

The data in table (4) does not give disaggregated information about the claims of tribal and other forest dependant communities, and also about individual and community claims. Rejection rate of the claims submitted by non tribals might be even higher as they have to prove continuity of their rights over last 75 years, which is difficult (Jena, 2010; Sarker 2011). Jena (2010) reports it as one of the main reasons for rejection of two thirds of the claims in state of Orissa.

Table 4: **Range of variations in accepted claims across the country**

State	Claims received	Accepted	%age accepted
Himachal Pradesh	5648	19	0.34
Bihar	2311	22	0.95
Orissa	449523	261500	58.17
Andhra Pradesh	330143	167605	50.77
Country wide	**3109000**	**1169000**	**37.60**

Source: MoTA, 2011

Minimal recognition of community rights

Sarker (2011) reports that only 0.67% of the community claims have been accepted up to February 2010. This is one of the biggest challenges of FRA. It has undermined the foundation of FRA that emphasizes security of tenure and livelihoods to the communities. FRA has provision for recognition of more number of community rights than the individual rights. But so far, most of the titles have been given for individual land rights mainly for agriculture and habitation purposes. There are various reasons for this misconception of the act as a provision for individual land rights among public and lower officials, lack of baseline information on community rights and confusion over demarcating community rights (CSD, 2010; MoEF and MoTA, 2010).

Institutional issues

Then, there are procedural and equity issues related to constitution of committees especially at grassroots level. Forest Rights Committees (FRC) have been constituted at grassroots level to help the gram sabhas to recognise rights claims. These committees are formed at panchayat[7] level in many cases instead of revenue village[8] or lower level. It becomes difficult to convene gram sabhas at such a big level (MoEF and MoTA, 2010; CSD, 2010). Similarly, institutions constituted at higher level like Sub Divisional Level Committees (SDLC) and District Level committees (DLC) have not helped communities proactively to claim rights. There are reports of corruption at grassroots level. Jena (2010) reports that lower government officials ask for Rs 5,000 bribe for processing the claim, which is a large amount for poor villagers.

Rights of extremely vulnerable groups

There is lack of information and confusion over the rights of extremely vulnerable groups like nomads, pastoralists and shifting cultivators (MoEF and MoTA, 2010). It involves complicated issues like tenure arrangements across different seasons and states. It requires a lot of consensus building and coordination among the stakeholders and cannot be sorted out quickly. People living in forest villages also face challenging conditions because of lack of infrastructure and other facilities. But process have not been started to convert these villages into revenue villages as per the provisions under the act (ibid).

Wild life conservation and forest rights

FRA though, applies to wildlife protected areas (PA) like national parks and sanctuaries but there is reluctance at the state level to recognise the rights in these areas (MoEF and MoTA, 2010). State forest departments are taking undue advantage of Critical Wild life Habitat' (CWH) provisions in FRA and are trying to relocate people from protected areas. Civil society

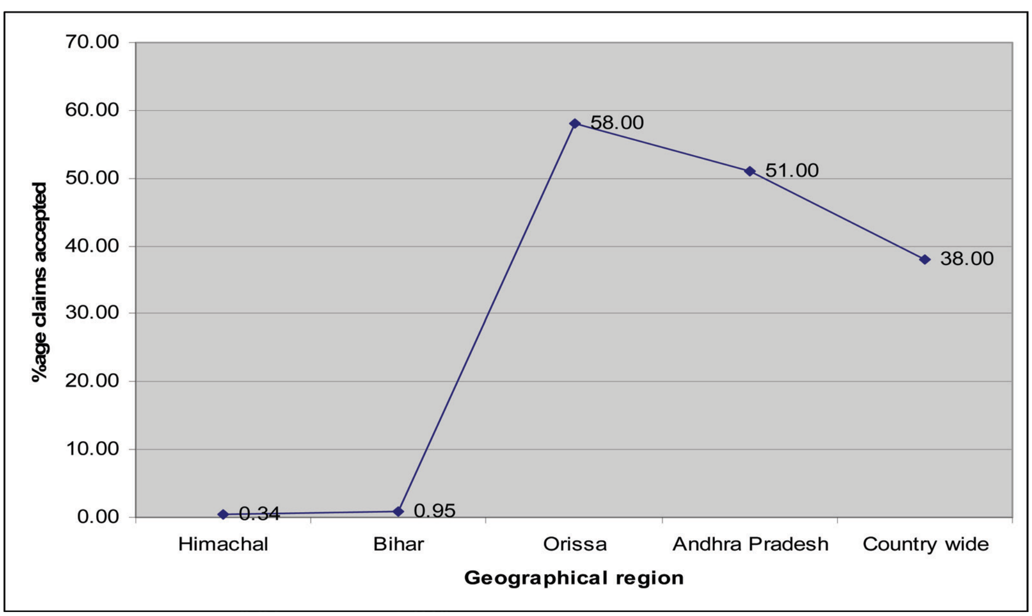

Fig2: **Range of variation in successful claims across the country**

Source: MoTA, 2011

groups have reported instances from various states like Madhya Pradesh, Rajasthan, Orissa where right of people are not being recognized under FRA and instead efforts are expedited to relocate them (CFSD, undated; MoEF and MoTA, 2010; Satpathy and Jain, 2010). Satpathy and Jain (2010) narrate the woes of the displaced people from village Jenabil in Simlipal tiger reserve in Orissa. These people were displaced under police pressure and were living under sub human conditions at the relocated site (ibid). A report from Centre for Social Development (CSD), a civil society organization, accuses government of continuing with the anti FRA actions such as afforestation on tribal lands, relocation of people from protected areas and mining in forest areas (CSD, 2010). It has been argued that because of bureaucratic 'apathy and sabotage' and above mentioned factors, implementation of FRA has been undermined (ibid).

MoEF under tremendous pressure from civil society groups have issued new guidelines in February 2011, which clearly lays out the process of declaring CWH areas (MoEF, 2011). It clearly states that such areas could not be created unless 'the process of recognition and resting of rights…. is complete in all the areas under consideration' (ibid).

Civil insurgency

It has been reported that 19% of the forest cover is affected by the civil insurgency especially left wing extremism known as naxalism in the country (De, 2006). It affects governance in 17 National parks, 35 wildlife sanctuaries, 18 reserve forests, mostly tiger reserves and many other forest areas (ibid). Half a million crimes are reported from India's forest areas every year and about 30% of it is related to the civil insurgency in these areas (ibid). It has affected implementation of developmental schemes in these districts (Tiwari and Sinha, 2010) It has also affected implementation of FRA in such areas (Jena, 2010).

Land grabbing and politics

FRA has led to fresh encroachments over forest land across various states in the country, expecting that these will be regularised (Ghate, 2009; PTI, 2007; Chauhan, 2011). Chauhan (2011) argues that various instances of land grabbing were found in a study of 10 states across the country. He reports that 11000 ha of forest land has been encroached in Andhra Pradesh since the Act has been implemented (ibid) Instances of land mafia paying tribals to encroach the land have been reported from the states of Maharashtra and Uttar Pradesh (ibid) Similar stories of fresh encroachments have been reported from states like West Bengal and Maharashtra (Ghate, 2009).

Encroachments are being promoted by political interests at some places (Kothairi, 2006). FRA is being used as a political tool. Even the joint committee of MoEF and MoTA has reported that state governments in Andhra Pradesh and Madhya Pradesh are using FRA as a political tool to distribute lands and gain from it in upcoming elections (MoEF and MoTA, 2010).

4. CHANGING FOREST LANDSCAPE

It is clear from the discussion so far that implementation of FRA has been slow and riddled with complex issues. However, it is expected to redistribute control and management of forest resources in the country, if implemented in the right spirit (Sarin and Springate-Baginski, 2010). It has addressed the complex issues of ownership non timber forest products and rights in governance of forests at legislative level for the very first time in Independent India (MoEF and MoTA, 2010).

It will '*restructure the relationship between rural forest-dependant communities, the forests they use ,and the state' (ibid*, emphasis in original*)*. FRA is expected to change forest landscape of the country significantly in many ways In fact, FRA has already started affecting the relationship between the forest bureaucracy and people (Springate-Baginski et.al, undated).

The FRA provides for a number of individual and community rights including right to hold and live in the forest land, community tenure, right over ownership and collection of non timber forest produce and any other right which is recognized under law (MoLJ, 2007). With the implementation of community forest resource (CFR) claims, communities will become major stakeholder in the management of the forest resources. It is expected to cover large part of the forest area in the country. It has been proposed that Community Forest Resource Management committees (CFRMC) could be constituted to manage the resources (MoEF and MoTA, 2010). These CFRMCs would act on the behalf of gram sabhas. Even JFM area which cover about 22 Mha or one third of country's forested landscape could be recognized as CFR (ibid). Similarly, self initiated community forest management regimes could be recognized under FRA with appropriate provisions for equity and gender balance wherever required (ibid). Hence FRA is expected to change forest governance of the country in a major ways. Some of the key areas, where it has already or is expected to impact forest governance in the country, have been discussed below.

4.1 Control and management of resources

So far, FRA has accepted 1.169 M claims and has redistributed control of around 3% of the forest area to individuals and communities Considering that 275 M people are dependent on forests for their livelihoods, what has been achieved so far is nominal. Limited cases of community forest rights have been recognized because of procedural confusions and complexity of the process, however it would cover a much larger area if these issues can be sorted out (MoEF and MoTA, 2010). It would impact a much bigger area than the actual area over which claims are accepted because these claims are scattered over the different forest patches. It has been reported that FRA could affect up to 16% of the forest area of the country (Ghate, 2009).

4.2 Non Timber Forest Produce (NTFP) management

FRA will also impact the management of non timber forest produce (NTFP) especially the ones which are commercially valuable and for which rights are currently centralised. The act provides 'right of ownership, access to collect, use, and dispose of minor forest produce, which has been traditionally collected within or outside village boundaries' (MoLJ, 2007). Communities would have access to the commercially important NTFPs like tendu leaves, sal and mahua seeds and many more, which are at present controlled by the state. At present, harvesting and trade of these NTFPs is done by the state controlled Forest Development

Corporations (FDC). Local people get the meagre labour used for harvesting the NTFPs, whereas middlemen and FDCs share large amount of revenues. It has been proposed to decentralise NTFP trade, provide price and policy support and build the capacities of the local people to manage the NTFPs in the changed scenario (MoEF and MoTA, 2010).

4.3 Biodiversity conservation and wildlife management

As mentioned earlier, there has been little progress in recognizing rights of people inside protected areas. It has been partly due to lack of clarity and partly due to unwillingness of state governments (MoEF and MoTA, 2010). But some of these issues have been sorted out with issuance of new guidelines regarding Critical Wildlife Habitats (CWH). These guidelines clearly state that rights of individuals and communities under FRA apply to all protected areas including tiger reserves (MoEF, 2011). Relocation of people from such areas without their consent and recognition of their rights has been declared as illegal (ibid). It is expected that process of recognizing rights in PAs will be expedited soon. It will legalise the coexistence of people in many protected areas. Hence, it becomes imperative to involve communities in management of biodiversity (MoEF and MoTA, 2010). It has been suggested to bring suitable changes in Wild Life Protection Act (WLPA), 1972 to accommodate these changes (ibid).

4.4 Role of gram sabhas[9]

Role of gram sabhas or village assemblies has been strengthened through enactment of FRA and some other key policy measures in the country. All the claims are recognized through gram sabhas under FRA. In addition, through an order in 2009, MoEF has made it mandatory to complete the process of recognition of rights and take approval from the local gram sabha before applying for diversion of forest land for development purposes (MoEF and MoTA, 2010). Gram sabhas have been proposed as key nodal institutions for implementation of Green India Mission (GIM in short, discussed later), a policy initiative designed to address climate change. It is also being proposed to register joint forest Management committees (JFMC) as committees of gram sabhas, which will give them a legal status (Sethi, 2011). These committees number around 100,000 across the country (MoEF and WII, 2005). So, there is an increasing control of the gram sabha or the village council over the resources. In fact, it has already started affecting the forest diversion process. MoEF has refused to grant approval to a large scale industrial steel plant in the state of Orissa because it failed to take proper consent from the involved gram sabhas (PTI, 2011). In fact, with these provisions and in wake of its efforts to promote industrialization, government is finding the implementation of FRA 'too hot to handle' (Sethi, 2010).

5. REDD+ AND INDIA'S APPROACH

In this changing landscape, the proposal of REDD+, which is being strongly supported by Government of India would also be affected (Aggarwal et al., 2009b). In the future, a significant area of forests would be owned and managed by individuals and local gram sabhas. This would change how REDD+ activities would be implemented and managed and how carbon revenues are shared. Community would have now complete ownership of carbon revenues generated from their lands. Implementation of FRA is going to affect REDD+ in a major way. Hence it is imperative to understand context of REDD+ and India's approach to it.

5.1 REDD+: International context

REDD+ has rapidly emerged in international climate change negotiations because of its purported multiple benefits. It has been projected as a low cost and effective strategy to mitigate climate change (Sathaye et al., 2007; Stern, 2007). It has been estimated that 51-78% of the total carbon benefits could be attained by reducing deforestation and degradation by the year 2100 (Sathaye et al., 2007). Half of these carbon benefits could be availed at low carbon prices in the range of \$5 to \$10/ tC, which are much cheaper than other policy options (ibid). It could generate significant revenues for the developing countries as well. El lakany and others (2007) have estimated that annual revenues from REDD+ could go up to US\$23 billion. In addition, REDD+ could generate co-benefits in form of conservation and livelihoods (UNEP-WCMC, 2007). Therefore, REDD+ has been projected as a win-win strategy for mitigation of climate change and development of poor countries.

There is so much hype surrounding REDD that more than 170 pilot projects have already been started in anticipation (Cerbu et al., 2009). Multilateral, bilateral and private funding mechanisms are now supporting different REDD activities at various levels. Multilateral mechanisms like United Nation's joint REDD (UN-REDD) programme, World Banks' Forest Caron Partnership Facility (FCPF) and Forest Investment Programme (FIP) are supporting capacity building activities in many developing countries for the effective implementation of REDD. Norway is supporting REDD demonstration activities in Indonesia under a bilateral agreement worth US\$one billion (CIFOR, 2011). Seventy-one developed and developing nations have joined a multilateral 'REDD+ partnership' to support and implement REDD+ activities.

Different developed nations have already committed US\$4 billion for various REDD activities across the developing world between 2010 and 2012 under this partnership (Anon, 2010). Besides, private investors and financial companies like Merrill Lynch and Canopy Capital,are supporting REDD projects in various parts of the world (Rawles, 2008).

5.2 India's Approach

India has contributed significantly towards the development of comprehensive REDD+ approach. India proposed the concept of 'compensated conservation' approach, which advocated for compensating the countries for maintaining and increasing carbon stocks (ICFRE, 2007). A comprehensive REDD+ approach was accepted at United Nations' climate negotiations at CoP 13 in Bali in 2007 (MoEF, undated b). This approach argues for compensating countries not only for 'reducing deforestation' but also for 'conservation, sustainable management of forest and increase in forest cover' (ICFRE, 2007). In its latest submission to UNFCCC in August 2009, India has elaborated REDD as "Reducing Emissions from Deforestation in Developing countries (REDD), Sustainable Forest Management (SFM) and Afforestation and Reforestation (A&R)' which further substantiates its comprehensive approach

(MoEF, 2009). The basic principle of this approach is that unit of carbon saved is equal to one unit of carbon added and hence both should be equally compensated. Hence India has been consistently seeking equal treatment and compensation at par with tropical deforesting countries like Indonesia and Brazil (Sharma, 2010).

Indian advocates for a mix of market and global funds to finance REDD+ activities.; a central funding should compensate for maintenance of forest carbon stocks whereas money for compensating change in carbon stocks (due to decrease in deforestation and degradation or increase in forest cover) could be generated by selling carbon credits in the international markets (MoEF, 2009).

Indian government wants to finance its ambitious programme National Mission for A Green India (or Green India Mission or GIM in short) through REDD+ money over next ten years (Sharma, 2010). It has prepared a comprehensive National Action Plan on Climate Change (NAPCC), which has eight missions that deal with different sectors and issues. National Mission for A Green India (or Green India Mission or GIM in short) deals with forestry sector issues. It has been argued that GIM will be additional and innovative to usual afforestation programmes in the country. It proposes to '*shift in mindset from our traditional focus of merely increasing quantity of our forests cover, towards increasing the quality of our forest cover and improving provision of ecosystem services*' (Ramesh, 2010a; emphasis in original).

GIM has been designed on certain key principles. One of them is It takes 'holistic view of greening', which focuses not only on plantations but improving ecosystem services (MoEF, 2010a). Another one is to have a cross sectoral approach. It also intends to promote 'autonomy and decentralization' by implementing GIM through gram sabhas. It aims to train and develop a cadre of 'community foresters' who will help with field monitoring of the mission (ibid).

The mission plans to treat an additional 10Mha of forest and non forest area for improved ecosystem services under GIM over next 10 years, starting from 2011(MoEF, 2010a). It plans to increase forest and tree cover on 5Mha of land and improve the quality of existing forest and tree cover on 5Mha of land. The mission targets various types of forests and non forest lands for the interventions. It targets, moderately dense forests, open forests, degraded grasslands and wetlands for qualitative improvement; shifting cultivation areas, cold deserts, mangroves and abandoned mining areas for eco restoration and afforestation; and farm land and urban areas through agro forestry and urban forestry (ibid).

The mission intends to sequester an additional annual 50 to 60 M tonnes of CO_2 by the year 2020. It also aims to improve livelihood and income of 3 M households living in and around forests (MoEF, 2010a).

6. POLITICS OF REDD+

India is a rapidly growing economy which has achieved more than 8% of GDP growth rate in 2009-2010 despite the global economic recession (HT, 2011). A report by consulting firm Pricewaterhouse Coppers (PwC) suggests that India could be the third largest economy in purchasing power parity terms by 2011 just after USA and China (Sinha, 2010). With this rapid growth and increased energy use, India's CO_2 emissions have more than doubled between 1990 and 2008 (IEA, 2010). Though India's per capita emissions are one fourth of the world average but it has become one of the 10 largest emitters in the world in absolute emissions (ibid). There is immense pressure on the country to reduce its emissions (BBC, 2009; TOI, 2009). As a result India has taken some proactive steps and has reduced it's emissions per unit of GDP (Ramesh, 2010b). It has agreed to further reduce its GDP emissions intensity by 20-25% between 2005 -2020 (ibid).

As mentioned earlier, India has prepared a comprehensive National Action Plan on Climate Change (NAPCC) to reduce its emissions and address climate change concerns across various sectors and ecosystems in 2008. Government of India argues that NAPCC is based on the principles of protecting poor and vulnerable sections of the society, achieving national growth objectives through an alternative approach and developing new and innovative forms of market, regulatory and voluntary mechanisms (GOI, undated). It aims to address the climate change issues through eight specific missions that include- national solar mission, national mission for enhanced energy efficiency, national mission for sustainable habitat, national water mission, national mission for sustaining Himalayan ecosystems, national mission for a green India, national mission for sustainable agriculture and national mission for strategic knowledge for climate change.

Indian government has further stepped up its efforts to reduce emissions post Copenhagen accord in December 2009. It is preparing a roadmap for low carbon development, which will become an integral part of country's twelfth five year plan starting in 2012 (MoEF, 2010b). It has announced a carbon tax on coal to fund clean energy development in the country (ibid). Apart from this it has announced a range of scientific assessments, planning exercises and implementation programs to address climate change across different sectors and regions in the country.

Forests and ecosystems constitute an important part of India's strategy to address international concerns over it's growing CO_2 emissions. It has been strategically presenting its conservation efforts over a decade and half and has been trying to leverage these in climate change negotiations. In its submissions to UNFCCC, it has emphasized its REDD+ strategy (MoEF, 2009; MoEF, 2010c). In a recently released primer on 'India's Forests and REDD+', government argues that 'while most developing countries lost forest cover, *India added around 3mn hectares of forests* and tree cover over the last decade' (MoEF, undated b; emphasis in original). It further argues that forests neutralise 11% of India's emissions at 1994 levels (ibid).

Green India Mission, which is an important part of climate change action strategy, is one of the missions with huge budgets. It intends to treat additional 10 Mha of forest and non forest area with an estimated expenditure of US$10 billion over next 10 years (MOEF, 2010a). It claims that it will sequester an additional 6.35% of its GHG emissions by 2020 (MoEF,2010b). India wants to channelize global REDD+ funds for financing this mission (Sharma, 2010). Indian government argues that REDD+ could capture an additional 1 billion tonnes of Co_2 over next 3 decades in the country. It will generate US$3 billion worth of revenues, which will benefit forest dependent people of the country (MoEF, undated b).

But a number of civil society stakeholders are opposing REDD+. Civil society groups like CFSD and NFFPFW believe that

REDD+ would affect implementation of Forest Rights Act. They suspect that it would provide an incentive to the government to grab the forestlands in the name of afforestation and not recognise people's rights under FRA (CFSD and NFFPFW, undated). They believe that forests would be 'jealously guarded as "financial assets" and people's uses will be entirely stopped' (ibid). These groups have also questioned the implementation of Green India Mission (GIM) and REDD+ through joint forest management (JFM) institutions. As these committees are controlled by the state forest departments, the civil society groups believe that REDD would strengthen government's control over forests (ibid). Also, these groups believe that government of India's support to market based REDD+ would lead to the involvement of private sector companies, which will take control of the large areas of forest (CFSD and NFFPFW, undated).

Hence, implementation of REDD+ is being strongly contested among various stakeholders especially government and civil society groups. This contestation is being done on different perceptions and ideological grounds.

The apprehensions of the civil society groups in India are in line with views of Phelps et al (2010), which argue that REDD+ might recentralize the forest governance in the hands of state. However, this view seems to contrast much of the theoretical literature which views REDD+ as an opportunity to recognise community rights and provide security of tenure (Sunderlin and Atmadija, 2009; Sunderlin , Larson and Cronkleton, 2009; Agarwal and Angelsen, 2009). Hence, it requires a detailed primary examination to understand the basis of the apprehensions. Is it the historical relationship of mistrust with the state or are there deeper reasons?

7. CONCLUSION

Forest Rights Act has started a transformation of forest landscape in India. It is set to redraw not only forest boundaries but also state- people relations in context of resource management. Currently Implementation process is marred by several institutional and efficiency issues, due to which rights have been recognized only over a limited forest area. Also, mostly individual rights have been recognized so far. But implementation process is expected to improve with clarifications and amendments in the policy guidelines under the constant vigil of civil society. Once community forest rights are recognized over a large area, local people will have control over the management and conservation of resources. With the recognition of rights, they will have some control even in the management of protected areas, which have been exclusionary so far. Communities would have access to the commercially important NTFPs like tendu leaves, sal and mahua seeds which are at present controlled by the state. It will redistribute power and control of the forest resources.

Forest dependent communities and civil society groups are constantly pushing for rapid and transparent implementation of FRA. These groups, however are concerned by the fact that Indian government is supporting REDD+ mechanism in international climate change negotiations. They see it a ploy to jeopardise implementation of FRA and strengthen state's control over the forest resources. As REDD+ could be partly financed through sale of carbon credits in markets, civil society groups see it an effort by the state to involve private companies in forest management. These apprehensions are rooted in the historical relationship of mistrust and exploitation by the state.

Indian government on the other hand wants to leverage country's forest conservation efforts in climate change negotiations through REDD+. It considers REDD+ as a bargaining chip in the negotiations against its increasing energy emissions. It also wants to seek financial assistance from the international community through REDD+.

These divergent interests have resulted in a strong contestation on the ground.

Although this complex politics over carbon, capital, and community rights need further research and analysis, but it does raise some interesting issues, which might be relevant for implementation of REDD+ in other parts of the world as well. Indian case clearly points out how REDD+ might influence existing forest governance mechanisms and rights. It also points out concerns and suspicion of forest dependant communities and civil society groups towards REDD+. Because of these issues, REDD+ is expected to generate a strong contestation among different stakeholders with different interests. Hence, it is imperative to make REDD+ democratic and transparent for just and sustainable outcomes.

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(ENDNOTES)

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2 The Energy and Resources Institute (TERI), Delhi

3 '+' in REDD+ acknowledges the role of afforestation, sustainable forest management

and conservation in dealing with climate change besides addressing deforestation and degradation. It was a late addition to the policy discussions but now constitutes the part of approved text of UNFCCC

4 The term 'state' has two different meanings in this paper as per the context. In one context, it represents government at any level. In the second context it means a geographical unit. India is a federal union of different states, which are adminstered by their own governments.

5 Forest cover includes the areas, which are more than 1 ha in size and have more than 10% of the crown cover density. These also include areas outside designated forest boundaries with the above mentioned characteristics

6 Tree cover includes the areas, which are less than 1 ha in size but has crown cover more than 10%. It includes areas outside the designated forest boundaries

7 *Panchayats* are elected bodies constituted as the lowest level of local self government system (called Panchayati Raj) in India. These were provided constitutional status under the 73rd amendment act, 1992 of the constitution of India.

8 Revenue village means a revenue estate in the revenue records of a district in which it is situated or a village as may be specified, by notification in the Official Gazette, by the Government

9 As defined in Forest Rights Act, gram sabha is a village assembly which shall consist of all adult members of a village and in case of states having no panchayats, podas, toals and other village traditional institutions elected village committees with full and un restricted participation of women