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Impact of Climate Change on Forest

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"The future belongs to those who give the next generation reason for hope."
—Pierre Teilhard de Chardin

The spatio-temporal distribution of forest vegetation and structural integrity are influenced predominantly by climate. Consequently, a change in climate will cause ecological imbalances in the forest ecosystem. Natural forest ecosystems will be more vulnerable to climate change. A small change in the climate niche of forest species will drastically affect their survivability. The vulnerability of the species to change in climate will vary from species to species. But predominantly, the forest tree species will become more prone to the biotic stress like pest and diseases. The positive influence of climate change in the form of CO2 fertilization effect is likely to be offset by the negative effects.

The total area covered by forest is almost one third of the world's land area, of which 95% is natural forest and 5% planted forest. About 47% of forests worldwide are tropical, 9% sub-tropical, 11% temperate and 33% boreal (Houghton, 2009). Forest cover is almost equally divided between the temperate and the tropical regions. The forest ecosystem provides services like climate regulation, maintenance of soil fertility, natural pest control and ecosystem goods such as food, fresh water and timber. Besides timber and fuel production, the forest services includes non timber forest products, wildlife habitats, biodiversity conservation, soil and water protection, recreation opportunities, tourism, etc. (Kirilenko and Sedjo, 2007). The ecosystem services provided by forest are enormous. These services are endangered due to human induced climate change. The changes in climate alter the ecosystem processes and change the resilence of ecosystems to environmental changes. Forests play a dual role in climate change when forests are cut or burned, CO2 is released. Deforestation contributes 20-25 % of total carbon emission into the atmosphere. Intact forests act as carbon sinks by taking atmospheric CO2 through the process of photosynthesis.

1. Forests as Carbon Sink

Forests are storehouse of carbon. Forests store 20 to 100 times more carbon per unit area than croplands and act as major terrestrial carbon sink (Ciesla, 1995). The world's forests have been estimated to contain up to 80% of all above ground terrestrial carbon and approximately 40% of all below ground terrestrial carbon (Dixon et al., 1994). Different forest ecosystems vary considerably in their capacity to absorb and store carbon. Closed forests have a greater capacity to store carbon than open forests and woodlands. The size of the total global carbon pool in forest vegetation has been estimated at 359 gigatonnes of carbon (GtC), compared to annual global carbon emission from industrial sources of approximately 6.3 GtC (IPCC, 2000b).

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2. Forests as Drivers of Climate Change

At the global level, the net loss in forest area during the 1990's was an estimated 940,000 km2 (2.4% of total forest area). The loss of forest cover due to deforestation may lead in addition to biodiversity depletion, land and soil degradation, reduction in regional precipitation, an increase in atmospheric CO2 concentration. Forest removal also endangers the livelihoods of forest dwellers. The forest removal/deforestation alters the climate directly by increasing reflectivity and decreasing evapo-transpiration. Of late, unprecedented deforestation particularly in the tropical region augmented the atmospheric CO2 concentration. The shifting cultivation practiced in different parts of the world (jhum, humah, caingin, roca, milpa, etc) also releases the stored carbon in the forest biomass. Naturally occurring forest fires and burning of forest for human induced land use changes contribute significantly to the greenhouse gases load is the atmosphere.

3. Positive Impact of Climate Change on Forest

Increasing atmospheric carbon dioxide concentration will increase the forest production and productivity through Carbon dioxide fertilization effect. Long term Free-air CO2 enrichment (FACE) studies suggest an average net primary productivity (NPP) increase of 23% under 2 x CO2 climate in young tree stands. (Kirilenko and Sedjo, 2007). Trees have shown species-specific increases in growth under elevated CO2, but nutrient and water limitation can reduce forest growth. Rising temperature due to increase in atmospheric CO2 can increase tree metabolic processes and increase the growing season and thereby forest growth (Mc Mahon et al., 2010). The forest growth rate also witnessed an increasing trend since the middle of the last century. BIOME 4 vegetation response modelling study have reported that increasing atmospheric CO2 concentration will increase the net primary productivity of forest ecosystems in India to the extent of 73% under moderate B2 (575 ppm CO2) scenario of Special Report on Emission Scenarios. (Ravindranath et al., 2006).

4. Negative Impact of Climate Change on Forest

The increase in global average temperature may bring in changes in spatial distribution of forest trees, species composition, productivity, health, biodiversity and life of forest dependent communities. There is ample evidence in the fossil record that plants have undergone significant range shifts in response to changing climates. If the change in climate is gradual, the tree species can respond through migration. But anthropogenic induced climate change occurs over a period of few decades and is not gradual and so many tree species cannot respond to the change and ultimately may become extinct. The situation is quite alarming given the fact that the earth has witnessed an increase of 0.74o C in the last century. However, biogeographical models demonstrate a poleward shift of potential vegetation for the 2 x CO2 climate by 500km or more for boreal forest zones. (Kirilenko and Sedjo, 2007). At the same time, the Southern boundary of the boreal forests, may be prone for deforestation and other biotic and abiotic stresses.

Plant species with broad geographic ranges will be the most likely to survive climate change. The geographically constrained or restricted species would be at a greater risk of extinction. Fossil records indicate that the maximum rate at which most plant species have migrated in the past is less than 1km per year. The constraints imposed by the dispersal process categorically suggest that without human intervention, many species would not be able to keep up with the rate of movement of their preferred climate niche projected for the

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21st century. So the forests, a repository of diverse organisms need to be protected from global warming. There is a consensus that declining forest biodiversity can decrease ecosystem functioning and services. Species diversity has functional consequences because the species richness, species evenness and species composition present in an forest ecosystem determine the organismal traits that influence ecosystem processes. Species traits may mediate energy and material fluxes directly or may alter abiotic conditions (for example climate) that regulate process rates. (chaplin et al., 2000).

The effect of climate change on agricultural pest population is well documented. A similar effect may be observed in the forest ecosystem given the fact that the forest pest biology and population dynamics are influenced by change in temperature and other ecological variables. The biotic agents like insect and pathogen cause immense and severe stress on the functioning of forest ecosystem. For instance, in the boreal forests of Canada, insect-caused timber losses (tree death) may be up to 1.3-2.0 times greater than the mean annual losses due to fires. The particular insects involved in large-scale boreal outbreaks include bark and wood-boring beetles, defoliating insects (often Lepidopteran insect pest) and insects that attack roots and cones.

Temperature changes may differentially affect the biology of each of the component species in multitrophic interactions that normally prevails in an ecosystem. The insect herbivores, their natural enemies and hyperparasitoids show differential response to the changes in temperature. The effects vary from defoliation and growth loss, to timber damage, to massive forest diebacks. The effects of climate change on insect pest communities can be short-term or long-term. Short-term consequences include the direct effects of temperature on different life history traits such as development time, metabolic rate and sex allocation. Long – term effects involve genetic changes in populations associated with climatic adaptations (Baaren et al., 2010)

The lepidopteran insect pest Lymantria monacha and Lymantria dispar under high temperature conditions experienced reduced duration of development of larvae. (Leather and MacKenzie 1994). Lymantria sp. is an important pest of Pinus sylvestris and Quercus robus.

Fluctuations in conifer mortality caused by bark beetles can be related to climatic variation. The ponderosa and pinon pine mortality due to bark beetles during 2002-2003 and the decline of aspen from 1999 to 2004 are examples of events that appear to be tied to the warm climatic episodes (Breshears et al., 2005). The bark beetle outbreaks noticed in the Kenai Peninsula, Alaska may be linked to warmer than average temperatures in the past decade (Juday, 2004). Logan et al., (2003) have reported that mountain pine beetle populations increased due to elevated temperatures in the Stanley Valley of Idaho. In fact, the increase in temperature has reduced the generation time of mountain pine beetle (Dendroctonus Ponderosae) which is a true predator.

The elevated CO2 mediates its effect on insect herbivores indirectly via host plant. Elevated atmospheric CO2 expected in the near future because of increasing emissions will alter the quantity and quality of plant foliage, which in turn can influence the growth and development of insect herbivores. The plant foliage grown under elevated CO2 had lower N, and higher C, C/N ratio and polyphenols. (Srinivasa rao et al., 2009). The foliar N typically decreases by 10-30% causing an increase in the C/N ratio. The mature leaves will be less nutritious for herbivores. The dilution of foliar N under elevated CO2 may be less in plants associated with nitrogen fixing symbionts. The increased C/N ratio in the plant foliage due to CO2 fertilization effect enhances the loss due to the insect defoliators, which for consuming a

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single unit of nitrogen has to consume more biomass. Lindroth et al, 1993 reported that the insect species (Gypsy moth and forest tent caterpillar, Malacosoma disstria) feeding on the forest tree saplings grown under enriched CO2 atmospheric condition showed increased consumption rates and longer growth duration.

The frequency and intensity of wild fires may increase in response to climate change. Although, the spatial occurrence of the phenomenon may vary, it is more likely to occur in the regions experiencing reduction in precipitation and high temperature. The explicit expression of high temperature is reduced soil water content and consequent drought that also induces the wild fire event. The last two decades demonstrated increasing burned areas in Canada, the Western United States and Russia, because of both climatic conditions and other factors such as fuel condition, ignition sources, land-use changes and variation in fire protection strategies. (Westerling et al., 2006; Kirilenko and Sedjo, 2007). Weather disturbances due to climate change like prolonged drought in the forest region can result in catastrophic surface and crown fires. Such wild fires results in positive feedback due to which green house gases are released into the atmosphere.

The change in frequency of extreme events such as strong winds, winter storms, droughts, etc. can cause severe economic and ecological loss to global forestry. High wind events can damage trees through branch breaking, trunks breakage, and crown loss. On the global economic front, the climate change can also cause forest product trade imbalances.

5. Responses to Climate Change

Responses to climate change include adaptation and mitigation. Adaptation moderates vulnerability to climate change. An adaptive capability is a necessary component of sustainability (Holling, 2001). Adaptation to climate change refers to adjustments in ecological, social and economic systems (Spittlehouse and stewart, 2003). The forest disturbances should be minimized by adopting suitable silvicultural practices and forest management strategies. The forest genetic resources should be conserved by exsitu conservation techniques. The breeding for insect pest, disease resistance and abiotic stress (high temperature) demands highest premium in the adaptation strategies.

6. Carbon Sequestration in the Forest as a Mitigation Option

Forest–carbon management will be an important element of any international agreement on climate change and strategies for mitigating the ill effects of climate change (Plantinga and Richards, 2008). Forests play a major role in the natural global carbon cycle by capturing carbon (C) from the atmosphere through photosynthesis, converting it to forest biomass, and releasing it into the atmosphere through plant respiration and decomposition.

Forest-carbon flows comprise a significant part of overall global greenhouse-gas emissions. While global forests as a whole may be a net sink (Nabuurs and Masera, 2007), global emissions from deforestation contribute between 20 and 25 per cent of all greenhouse-gas emissions (Sedjo and Sohngen, 2007; Skutsch et al., 2007). Activities that increase the biomass accumulation in a forest or in forest products increase carbon sequestration (Obersteiner et al., 2005).

There is a growing interest in carbon sequestration as a means for offsetting the effects of climate change. It is for this reason that policy makers are looking at ways to use forest growth as an inexpensive way to mitigate increasing carbon emissions. The Intergovernmental Panel on Climate Change (IPCC) suggests that up to 87 PgC (1 Pg = 1X106 Mg = 1 billion t C) can

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be sequestered in the world's forests by 2050 (Metz et al., 2001). Richards and Stokes (2004) reported 0.5–2.0 Pg C/yr could be sequestered globally for the next several decades for $10 - $150 per t C.

Forest management can contribute to carbon sequestration by promoting forest growth and biomass accumulation. There are a number of activities that could result in an increase in forest and forest-related carbon compared with the base situation. These include reducing deforestation, expanding forest cover, expanding forest biomass per unit area, adoption of agroforestry and urban forestry practices, establishment of short-rotation woody biomass plantations and expanding the inventory of long-lived wood products inventory (Shah et al., 2009).

Other approaches include forest protection, the forest management for carbon for joint products i.e., the management of forests to generate both carbon and timber as products, forest modifications to emphasize carbon storage, adoption of low-impact harvesting methods to reduce carbon releases, lengthening of forest rotation cycles and preservation of forest land from conversion to alternative uses, holding timber longer than the currently optimal rotation age, managing forests more intensively, and setting aside timberland. (Lecocq and Capoor, 2003; Murray et al., 2004 and Sohngen and Brown, 2004).

Although carbon sequestration through forestry does have limitations, it is generally agreed that large amounts of carbon could be sequestered utilizing existing technology (IPCC 2001). Carbon sequestration through forestry does have the potential of stabilizing, or at least contributing to the stabilization, of atmospheric carbon in the near term (20–50 years) and thereby allowing time for the development of a more fundamental technological solution in the form of reduced carbon emission energy sources. Therefore, the potential of carbon sequestration projects through land-use change and forestry activities is intriguing. The projects can not only conserve and augment carbon stock but also improve rural livelihoods. Of late, the effectiveness of afforestation projects in the boreal and midlatitude zones in reducing the temperature increase was evaluated. Forested areas are less reflective than croplands, and hence the absorption of incoming solar radiation is greater over afforested areas. So afforestation can result in net climate warming particularly at high latitudes. (Betts, 2000, Kirilenko and Sedjo, 2007; Arora and Montenegro, 2011). A comprehensive earth system modelling studies indicated that afforestation is not a substitute for reducing green house gas emission. The study further show that warming reductions per unit afforested areas are around three times higher in the tropics than in the boreal and northern temperate regions. (Arora and Montenegro, 2011).

Further, the Kyoto's clean development mechanism use a project-by project approach that excludes potentially beneficial projects. (Santilli et al., 2005). Silva–Chavez, 2005 has anticipated accelerated deforestation under the current mechanism of Kyoto Protocol by which the host countries in Annex I countries are continuing the forest exploitation in terms of land use changes, industrial round wood production and fuel production.

7. Conclusion

The impending danger on forest ecosystems due to climate variability and climate change demands the countries to integrate the climate change issue into their national forest programmes. The stake holders need to be sensitised and educated with respect to sustainable management of forests, effective mitigation and adaptation measures, and about community-

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based forestry management efforts like joint forest management, so that forest provide both tangible and intangible services to the generations to come.

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