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Review

A review on impacts and management of climate change on forest and forest products

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Climate change is caused by increased atmospheric composition of greenhouse gases (GHG) emitted from fossil fuel combustion, land use change and deforestation. Although rainfall patterns and seasonal temperature are commonly used, the average surface temperature is a key global climate variable. CO\textsubscript{2} is a major GHG accounting for more than 75% of the total GHG. Climate change is manifested by unpredictable flood, and drought. The global mean carbon dioxide concentration ([CO\textsubscript{2}]) increased from 280 to 392.6ppm in the period 1750-2012. Climate change has both positive and negative impacts on the growth and production of forests. Increased [CO\textsubscript{2}] has fertilizer effect that enables C\textsubscript{3} plants like most forest trees to photosynthesize more and use water efficiently. However, climate change reduces forest composition and facilitates damages from pest, and disease that require appropriate forest management including adjusting harvesting schedule, and modifying silvicultural treatments. Watershed management and indigenous tree planting practices were some of the compatible adaptive actions practiced in Ethiopia to protect negative impacts of climate change. For successful forest development and research in the face of climate change selection of high yielding species, maintaining diversity and establishing of forestry enterprises should be practiced.

Key words: Climate change, forest, forest product, management, and tree species.

INTRODUCTION

Climate change is a change in statistical descriptions of weather conditions (temperature, humidity, precipitation, atmospheric pressure, and wind) and their variations, averages and extremes at a particular location. However, the changes in weather from day to day, between seasons, and from one year to the next, do not represent climate change. The period for estimating climate change is over 30 years. Although rainfall patterns and seasonal temperature are common in climate expressions, the average surface temperature is a key global climate variable (Rafferty, 2011).

The intergovernmental panel on climate change (IPCC) fifth assessment report (AR5) confirmed with 95-100% certainty that climate change is the result of human activity, emission of greenhouse gases (GHG) (e.g. CO\textsubscript{2}, CH\textsubscript{4}, and N\textsubscript{2}O, etc.) from burning fossil fuel, deforestation and land use change. CO\textsubscript{2} is the most abundant GHG, which accounts for more than 75% of the total GHG emissions annually. Increase in CO\textsubscript{2} emitted has been causing the atmosphere to trap more heat, which results in global warming (IPCC, 2013).

Forests are environmental goods that provide many other goods and services to human being and natural systems such as wood, food, feed, aesthetic value, etc. Forests regulate hydrologic, and carbon dioxide cycle (Bonan, 2008). Loss of tree cover affects virtually all species that make up a complex forest ecosystem (Hardy, 2003). The 1997 Kyoto Protocol's Clean Development Mechanism (CDM) acknowledged the importance of forests in mitigating climate change. However, forests, and their goods and services are susceptible to the adverse effects of climate change as forest trees have long lifespans of staying one place and slowly responding to rapid environmental change (Lukac et al., 2010). Therefore, the objective of this review is to summarize the observed and projected impacts of
climate change on forests and forest products in different parts of the globe with their management options.

TRENDS OF GLOBAL WARMING

IPCC (2013) states that Global Mean Surface Temperature (GMST) has increased since the late 19th century. Especially the past three decades has been warmer than all the previous decades, and the warmest being the decade of the 2000’s. The global combined land and ocean temperature data show an increase of about 0.89°C [0.69–1.08] over the period 1901–2012 and about 0.72°C [0.49–0.89] over the period 1951–2012 when described by a linear trend. The global mean carbon dioxide concentration ([CO$_2$]) increased from 280ppm-392.6ppm over the period pre 1750-2012. It predicts that the impacts of climate change will be more severe with negative impacts for millions of people in the poorest parts of the world especially Africa. Williams and Funk (2011) explained about a reduction in the long rains over Kenya and Ethiopia in response to warmer Indian Ocean sea surface temperatures (SSSTs). It is very likely that the numbers of warm days and nights have increased globally since 1950 (IPCC, 2013) with limited data on African heat waves. However, the IPCC report suggests that it is not too late to prevent the worst impacts of climate change, if countries of the world act now (IPCC, 2013).

Globally, there will be average temperature increase of 2°C by 2100 (Sokolov et al., 2009). According to IPCC (2012) predictions, global temperatures will increase by 1 to 3 °C by the mid-21st century and by about 2 to 5 °C by the late 21st century. The frequency of heavy precipitation is likely to increase, even in areas where total annual rainfall is expected to decrease that will affect livelihoods of people especially developing countries in Africa (IPCC, 2012). Similarly, Ethiopia in the Horn of Africa is becoming hotter and hotter as the mean annual temperature is projected to increase by 1.1 to 3.1 °C by 2060s, and 1.5 to 5.1 °C by 2090s (Raleigh and Kniveton, 2012).

CLIMATE CHANGE AND FOREST GROWTH

CO$_2$ fertilization in C3 and C4 plants

Different plants react differently to the concentration of carbon dioxide [CO$_2$] in photosynthetic CO$_2$ fixation (Cerling et al., 1993). Based on plant products chemical makeup, there are three major photosynthetic pathways namely C$_3$, C$_4$ and Crassulacean Acid Metabolism (CAM). C$_3$ plants convert atmospheric carbon primarily into a three carbon chemical compound and C$_4$ plants to four. CAM plants follow either C$_3$ or C$_4$ photosynthetic pathway. C$_3$ plants including barley, rice, wheat, soybeans, cassava, potatoes, legumes and most trees grow in cool climates. C$_4$ plants including maize, sorghum, sugarcane, tef, etc. grow in subtropics (Hatch, 1987). As can be seen from Figure 1, the increase in [CO$_2$] has higher effects in the assimilation of CO$_2$ in C$_3$ plants than C$_4$ plants.

In C$_3$ plants, the assimilation of solar energy into carbohydrates generally increases with [CO$_2$] and decreases with temperature (Figure 1). Doubling [CO$_2$] increases photosynthetic rate of C$_3$ plants by 25–75% (Urban, 2003), therefore, [CO$_2$] has “fertilizer” effect (Ehleringer and Björkman, 1977). Generally, increase in [CO$_2$] reduces the opening of stomata which reduces transpiration of trees, increases water use efficiency, increases plant growth and increases nutrient availability (Sievänen et al., 2013). However, more CO$_2$ increases warming and limits water availability that could affect plant physiological processes and cause mortality (Reddy and Hodges, 2000).

Impact of climate change on species composition and distribution

Species adapts to climate change through in situ physiological alteration or migration (latitudinal and altitudinal spatial shift); and temporal shift (phenological event). The ability of a species to migrate will depend on its capacity to disperse and on the connectivity of suitable habitat (Thomas et al., 2004). Climate change is able to decrease genetic diversity of populations due to directional selection and rapid migration (Botkin et al., 2007). As the temperature increases warm mixed forests replace cold and temperate forests (EPI, 2012). The failure to adapt climate change results in loss of biodiversity and extinction of species (MEA, 2005).

In Africa climate change affected many aspects of forest ecosystems. In Burkina Faso, for example, the local extinction of several species (e.g. *Adansonia digitata*, and *Anogeissus leiocarpa*) and in Ethiopia, the devastation of *Cupressus lusitanica* has been attributed to a combination of recurrent drought. A modeling study predicted that the areas of suitable climate for over 80% of African plant species would decrease in size and shift to higher altitudes. The current habitats of 25–41% of African plant species would be entirely lost by the year 2085 (Lovett et al., 2005).

Impact of climate change on tree species phenology

Phenology is developmental stages of plants including vegetative, flowering, fruiting, and seeding. Due to drought maturity of fruits could delay and no seeding could take place. Phenological shifts in insect pollinated flowering plants causes mismatches with the metamorphosis of insects that lead to the extinctions of
CLIMATE CHANGE AND FOREST PRODUCTS

Impact of climate change on fuel wood and charcoal

Biomass based energy attracted the attention of government and markets due to climate change concerns and fossil fuel depletion or price. For example, fuel wood consumed in Ghana increased 50% in 2012 in ten years (Figure 2) with declining GDP and stable population growth. The number of people relying on fuel wood and charcoal in Africa is projected to rise from 583 million in 2000 to 823 million in 2030 (Quartey, 2014).

The impact of biomass energy on climate change

Reabsorption of CO$_2$ takes place when using biomass (firewood) (Colac, 2008) (Figure 3). Electricity production from biomass emits only 5 to 10% of the emissions from fossil fuel (IEA, 2011), and then biomass energy reduces global warming and prevents climate change.

Impact of climate change on other non-timber products

A research conducted in Cameroon indicates that the production of non-timber forest products (NTFP) provide safety net during food shortages as they are less sensitive to climate change than agricultural crops and livestock. However, increased evaporation may cause moisture stress and reduce yields as in the case of gum arabic in Sudan that will result in 25% decline by 2030 and 30% decline by 2060. Non climatic factors such as deforestation, agricultural expansion and overharvesting increase the vulnerability of non-timber forest products to climatic effects (IUFRO, 2010).

Impact of climate change on timber products

Salvage logging due to storm damage, forest fires, pest infestations, and other disturbances reduce prices of...
timber (Peltola et al., 1999; McCarthy et al., 2001). According to Sohngen et al. (2001) consumers gain the most because of forest growth (carbon fertilization) and more timber available for markets. Producers lose welfare in most cases because of prices decline and increased forests yield is not strong enough to offset the lower prices. Tree species vary in climate change resilience and their productivity. Hardwoods are more susceptible to drought than soft woods species (Pérez et al., 2007). The best solution is the use of short rotation timber species and selection of appropriate species to minimize cost of management.

However, CO₂ fertilization and selection of short rotation species may not increase productivity as the success of getting dieback resistant short rotation tree species is unknown. As projected by Sohngen et al. (2001) the global timber price is increasing year after year. Therefore, it seems that climate change affects the welfare of both consumers and producers.

Dieback and Forests during climate change

Dieback problem expands throughout the World. As can be seen from Table 1, in North America, 17% increase of forest growth projected in 60 years, (2001 to 2060), the 2001 growth increase is only 0.28% (0.17*1/60) average of the whole species every year. In UIUC Climate Model scenario projection, the forest area in North America occupied by dieback by 2060 is 28%. The 2001 dieback is 0.48% (0.28*1/60) of the whole stock of the different species every year. The yield increase at 60th year is 13% in Oceania to 52% in Russia making World average 30% with respective diebacks of 56%, 21% and 16%. The lower yield increase resulted in from higher die back in Oceania indicates that the poor quality of forest management to protect dieback.

Impact of climate change in African forests

Agricultural expansion and the overuse of forests in Africa are currently more pressing than climate change. Climate-change adaptation planning about current and future climate related impacts and vulnerabilities and wood production in Africa are hampered by a lack of information (IUFRO, 2010). Generally, physical, environmental and socioeconomic factors reduce timber productivity in dry tropics and subtropics mainly by the limitation of moisture exacerbated by climate change, the less availability of soil nutrients due to land degradation, and the use of short rotation crops which may not produce quality timber.

FOREST MANGEMENT IN RESPONSE TO CLIMATE CHANGE

The impacts of climate change and climate variability on forest ecosystems are evident around the world and further impacts are unavoidable.

Components of forest management

Adjusting forest management practices to reduce vulnerabilities and facilitate adaptation to climate change is likely to incur additional costs, but these will probably be less costly than the costs of remedial actions (FAO, 2013).

Adaptation and mitigation are two main responses to climate change. In forestry sector adaptation measures are aimed to secure the continued delivery of forest goods and services, while mitigation could be reducing emissions from deforestation, and forest degradation; enhancing forest carbon sinks; and product substitution.
Table 1. Predicted Yield Change, Dieback and Change in Forest Area using BIOME3 model from 2001 to 2060.

<table>
<thead>
<tr>
<th>Selected Regions</th>
<th>UIUC Climate Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Yield Change in 2060</td>
</tr>
<tr>
<td>North America</td>
<td>17%</td>
</tr>
<tr>
<td>South America</td>
<td>23%</td>
</tr>
<tr>
<td>Europe</td>
<td>34%</td>
</tr>
<tr>
<td>Russia</td>
<td>52%</td>
</tr>
<tr>
<td>China</td>
<td>38%</td>
</tr>
<tr>
<td>Oceania</td>
<td>13%</td>
</tr>
<tr>
<td>Rest of World</td>
<td>18%</td>
</tr>
<tr>
<td>Non-N. Amer.</td>
<td>32%</td>
</tr>
<tr>
<td>World</td>
<td>30%</td>
</tr>
</tbody>
</table>

Source: Schlesinger et al. (1997).

In order to ensure that adaptation and mitigation measures are synergistic and balanced sustainable forest management (SFM) was proposed by United Nations in 1998 through landscape approach by considering social, economic and ecological issues (FAO, 2013).

Global and national forest policy

Forest managers are affected by climate change policies made at the subnational, national, regional and global levels. For example, Reducing Emission from Deforestation and forest Degradation (REDD+) is designed as a national (or in some cases subnational) mechanism that would provide positive incentives to countries achieving verified emissions reductions or carbon removals in forests (1). The realization of REDD+ mechanisms could be considered as an opportunity to the forestry sector because forgotten forests have been conserved by different carbon trading mechanisms (Angelsen et al., 2012).

Ethiopia climate driven forest policy

Ethiopia formulated historical forest policy with no guidelines in 2007 and Ethiopia’s commitment in signing different conventions like the UN Framework Convention on Climate Change (UNFCCC) (EPA, 2012) are significant encouragement for the forestry sector. The government started climate resilient green economy (CRGE) in 2011 that include production and distribution fuel wood saving efficient stoves, and establishment of plantation forest in some parts of the country as CDM projects such as Humbold project in Southern Ethiopia. Moreover, the establishment of Ministry of Environment and Forestry (MEF) in 2013 is a big government commitment to promote forestry in Ethiopia. Ethiopia National Adaptation Program of Action (NAPA) in 2007 also desired promoting farm and homestead forestry, and agro-forestry practices (FDRE, 2011). Community watershed management, and indigenous tree planting (Bane et al., 2008), participatory forest management (PFM) and Farm Africa and SOS Sahel Ethiopia (2007) were essential government commitments.

Silvicultural management

Most plantation forest development practices in developing countries follow area expansion to compensate for the poor productivity. To improve productivity it is important to select high yielding resistance species through tree breeding programmes, and using clonal technology and tissue culture. For example, seed-raised eucalyptus plantation annually yields 6–10 m$^3$ per ha in India, but through genetic improvement, it can annually yield up to 50 m$^3$ per ha (Aggarwal et al., 2010). It is also important to maintain the wilderness of natural forests as a gene pool of indigenous species; plant mixed tree species so as to adopt risk-spreading approach (diversification of tree species) (Milad et al., 2012); determine rotation age to avoid future abiotic risks and proper health and hygiene of the forest ecosystems that can be used for short-rotation biomass instead of fossil fuels (Pawson et al., 2013). Establishing forestry enterprises

Marketing forest products by considering the various damaged woods due to wind, pest or fire. Developing the skills to non-timber forest product (NTFP) production and procession through innovative value addition technology are crucial (Aggarwal et al., 2010).

CONCLUSION AND RECOMMENDATION

Climate change is affects the productive capacity of
forests by changing the species composition, season of growth (phenology), making susceptible to pest and disease attack, frost, drought. Climate change affects the livelihood of forest dependent communities by damaging the products and service obtained from the forest and causing species extinction. Climate change increases CO\textsubscript{2} fertilization and water use efficiency for most forest trees species which are called C\textsubscript{3} plants and then increase productivity. The damage of climate change to forestry is more than its benefit as the extinction of tree species could not be compensated by increased productivity.

Hardwood species are more susceptible to drought than softwoods. Accordingly, Africa in general has more of hardwood species and it requires concerted efforts to conserve and propagate genetically superior hardwood species with appropriate of species site matching.

Forestry is doubly responsible for the adaptation and mitigation of climate change as forests act as a factory and a product. Therefore, proper management of high yielding forest tree/shrub species should be practiced.

**GENERAL CRITICISM AND FUTURE RESEARCH AREAS**

The forests which are naturally taking long rotation period to produce goods, they are mostly known for providing environmental services. There is a general lack of literature about the impact of climate change on forest growth and forest products. There are few species based studies in Africa. Since the species type in tropics and temperate are different their adaptation mechanism seems different, therefore, specific studies need to propose adaptation measure for tropical tree species. In most literatures consulted policy issues were greater than biological issues of forests. It seems that there is lack of expert knowledge on the silviculture of tree species.

*Some of the future research areas are:-*

i. The beneficial effects of CO\textsubscript{2} and increased rainfall for the growth of individual tree species under different temperature, pest and fire occurrence in tropical Africa.

ii. Since the occurrence of dieback of tree species become common in many forest types, models need to be developed to each of fire, pest infestation, or storm dieback and tree species.

iii. More research and empirical data are needed on the influences of climate change on the production of non-wood forest products and the methods of reducing vulnerability.

iv. Study on the impact of climate change on mixed and pure stands of forest plantations,

v. Resistant species selection and propagation is the most important way to cope with climate change and therefore resistant species breeding program of indigenous trees is crucial.

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