Review Article

Climate Change Impact on Forest Cover: A Critical Review

ABSTRACT

Climate change affects forest cover through increased temperature, change in precipitation, frequent extreme events, and a shifting disturbance regime. In view of understanding the existing studies carried out on climate change impact on forest cover, we reviewed the findings of several researchers to assess the impact of changing climatic parameters on forest cover. The role of deforestation on climate change was analyzed by presenting some of the arguments made by several researchers. Further, the influence of forests in climate change was evaluated by the amount of carbon sequestrated in the forests throughout the world and the effect of climate change on carbon sequestration was also done with the help of review of the literature. Direct, Indirect and compound effects of climate change impact on forest cover were also shortlisted and discussed. Then certain coping mechanisms were also discussed by the authors for the forests whose health was highly affected due to climate change. Several research publications demonstrating the response of forest cover to climate change were critically analyzed. The review revelaed that climatic variations are very important to understand the forest cover changes of an ecosystem in which the climate prevails. It is also understood that the variability of rainfall and temperature were not the main cause for forest cover changes. Climate change impact assessment has significant implications on carbon sequestration greenhouse gas mitigation and adaptation strategies to climate change. Utilising remote sensing data for documenting and identifying forest degradation status is a viable option for planning climate change mitigation in forest regions.

Keywords: *Climate change, carbon sequestration, deforestation, forest cover, Ecosystem, Biodiversity.*

1. INTRODUCTION

The forest ecosystem plays significant role in capturing carbon dioxide from the atmosphere and sequestering the huge amount of carbon as tree biomass that is 1.3 times higher than the carbon pool stored in fossil fuels. Forest also balances the surface temperatures and enhances the water availability to human beings and livestock. Forests contribute 40 per cent of rainfall from the forest ecosystem. Forest trees are vital for decreasing the velocity of falling raindrops and reducing soil erosion. The present climate change scenario with increased temperature, unpredictable precipitation patterns, frequent extreme events, and increased greenhouse gas emissions pose a significant challenge to the forest ecosystem. Climate change also leads to few changes in tree species [1] and disturbs the forest ecological balances [2] . The risk of climate change impact increases as the warming continues [3]. Disturbances are natural for any ecosystem development that reset the possible pathways of change at irregular intervals. The abiotic disturbances like extreme rainfall, increased temperature, and frequent forest fires also affect the forest ecosystem. Direct climate change effects like temperature and precipitation affect forest biodiversity, and indirect changes affect forest structure, composition, and abundance of species [4]. The response of forest structure and composition is slow for environmental changes. At the same time unexpected and rapid forest fire, wind, and pests can be easily alter the forest composition. Many kinds of forest disturbances have been climate sensitive and intensified in recent past ([5],[6]). Models canbe used to predict the relationship between climate change variables and forest diversity. The present review explains the various effects of climate change on forest cover.

2. CLIMATE CHANGE AND FORESTS

Forest growth rates are significantly affected by climate change and water availability. A high growth rate will be found if there is enough water, a short and not very intense dry period, and a high temperature [7] . In low land Bolivia, where the temperature varies from 24.2° C to 26.4 ° C boosted temperature and annual precipitation increased the diameter and basal area tree growth rate within 4 to 7 months, however, in summer, the growth rate dropped with an increased dry spell. Studies carried out in the peninsular forest, where mean temperatures ranged from 4° C to 18° C found that water availability had a positive relationship with growth rate of forest [8], whereas mean temperature had a negative relationship (R2 D 0.622, $p < 0.001$). In pan-tropical forests, the precipitation and soil water content also had positive correlations with tree growth rate [9]. Solar radiation is another important factor that affects the growth of vegetation. However, the impact on tree growth rate significantly varies when solar radiation is combined with the temperature effects. In tropical forests of South and Southeast Asia and Africa, the correlation relation among tree growth rate at stand level and incoming solar radiation was positive. In contrast, the correlation between the growth rate and nighttime temperature was negative at R2 D 0.88, $p < 0.001$ level [10]. Precipitation and solar radiation had a positive association with tree growth at $p < 0.0001$ [9]. Rainfall caused 19.8 % variation in tree growth, while solar radiation caused 16.3% variation. Precipitation, solar radiation, increased temperature and soil water content combinely caused 29.8% variation in tree growth in pan-tropical forests. In Polar Regions, solar weighted UV-B radiation caused 10% reduction in plant height at $p < 0.05$ [11]. Few studies conducted on the direct effects of climate change on forest cover are reviewed and furnished in Table.1.

Table.1 Direct Effects of Climate Change on Forest Cover

Disturbance agent	Direct effects	Authors
Fire	Spread of fire Easy ignition	Williams and Abatzoglou, 2016 [12] Billmire, M., *et al.,* 2014 [13]

Drought	Water scarcity Water limitation intensity and duration	Cook, B. I., *et al.,* 2014 [14]
Wind	Frequency of wind events The intensity of wind events	Donat, M. G., *et al.,* 2011 [15] Peltola, H., *et al.,* 2010 [16] Usbeck, T., *et al.,* 2010 [17]
Snow and ice	Freezing rain Snow occurrence Snow Duration	Teich, M., *et al.,* 2012 [18] Gregow, H., *et al.,* 2011 [19] Cheng, C. S., *et al.,* 2007 [20]
Insects	Behaviour of insects Change in metabolic rate Behavioural change	Jonsson, A. M., *et al.,* 2011 [21] Lemoine, N. P., *et al.,* 2014 [22] Battisti, A., *et al.,* 2005 [23]
Pathogens	Abundance of pathogen Frequencyof infection	Munteanu, C *et al.,* 2014 [24] Aguayo, J., *et al.,* 2014 [25]

3. DEFORESTATION EFFECTS ON THE CLIMATE CHANGE

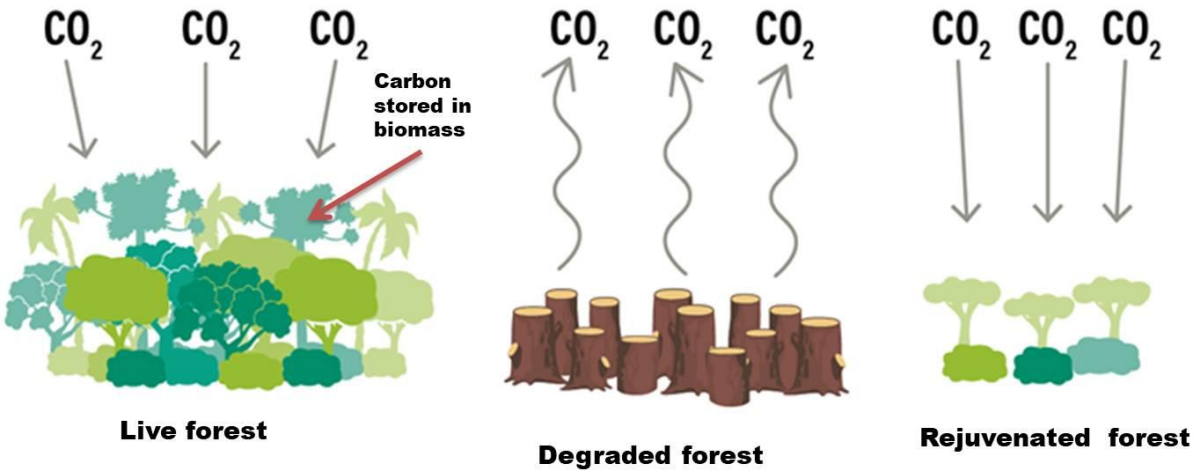
Climate change generally driven by anthropogenic activities like land use changes, deforestation, industrialization and fossil fuel burning. The natural causes like changes in solar radiation and valconoic erruptoions also cause climate change. So, deforestation and forest degradation play a major role in global climate change, and reciprocally, deforestation is indirectly affected by climate change. Before 10,000 years forests covered around 6 billion hectares of the world that is 45% of the total land area. However, in 2010 the forest cover decreased to 31 % of the world's area [26]. From 2001 to 2021, 437 Mha of tree cover was lost globally ie.,11% decrease in tree cover accounts for 176Gt of CO_2 emissions. Conversion of forest land to agricultural purpose for shifting cultivation is one of the major anthropogenic factor of deforestation in the tropical region [27]. In India North eastern states are responsible for 50 % of tree cover loss for last two decades. According to the Food and Agriculture Organization (FAO), the deforestation rate is 0.14% per year that is 5.2 million hectares per year of net annual deforestation [26]. Deforestation rate was slow in temperate forests during the 21st century. In contrast, deforestation was still high in tropical forests [28]. Globally, greenhouse gas (GHG) emissions in the atmosphere from deforestation and also forest degradation have accounted one-fifth of the total GHG emissions. Annual CO_2 emission due to land use change was estimated about 0.9 Gt C/yr (IPCC 2013). Impacts on climate change due to CO_2 emission from deforestation was high in Indonesia and Brazil, which are the third and fourth contributers of largest CO_2 emiisson in the world. Deforestation and forest degradation has no significant change over two decades in net carbon emission [27]. Between 2000 and 2012 [29], 2.3 million square kilometres of world forest were lost, with just 0.8 million square kilometres of forest being created. Deforestation and forest degradation are critical issues for sustainable environmental management. Based on the preceding principles, that have a large impact on the climate, and deforestation has not been controlled until now.

Deforestation may be a result of climate change, on the other hand, this deforestation also cause climate change [30]. Frequent drought and heat causes tree mortality, that alters species composition and diversity [31]. Many tree species have retreated from a lower elevations due to increased temperature and decreased precipitation [32]. Reduced rainfall and increasing temperature substantially impacted the seedlings mortality risk [33]. Many tree species shrunken their habitats and a few species expanded to favourable environment due the warming climate [34]. Most of the tree species will naturally adjust to survive by shifting to higher altitudes [35]. Climate change will increase forest fire incidents, which in turn reduce forest carbon storage [36]. Recent epidemics of bark beetles and defoliating insects have been linked to climate change, according to convincing evidence. These have a significant impact on ecosystems and forest insect groups ([37], [38] [39]). Forest management decisions are taken into account in the mathematical models. These models have advantages and disadvantages but not listed suitably. The carbon sink function will reduce or even stop when the

forests get into a steady state of carbon sequestration in soil organic matter, biomass and carbon loss due to the decomposition of residues and soil organic matter ([40],[41],[42]). The natural ecosystem dynamics will exert dynamic ecosystem self-regulation due to climate change. ([43],[44]). Climate change has a vital impact on forest cover [45]. At local hotspots, the discrepancy can occur within a few decades, whereas elsewhere, it takes longer. However, utilizing remote sensing data, attempts have lately been made to document torrential hazard episodes comprehensively and identify forest damages([46],[47]).

4. ROLE OF FORESTS IN CARBON STORAGE

Forest Ecosystems plays a major role in the global C cycle by exchange of energy, water, and nutrients and carbon with surrounding ecosystems. They are the largest terrestrial C sinks with large C densities and store huge amounts of atmospheric CO_2 through carbon sequestration. People could understand better about the importance forests in the global fight against climate change. Forest carbon storage capacity depends on the forest cover and biomass. Forests carbon pools includes both living and dead trees, root systems and forest soils. Live trees have the highest carbon density followed by soils. Around 650 billion tons of carbon is stored in the forests of the world. Among this 44% of the carbon is stored in biomass, 45% in the soil and 11% in dead wood and litter [26]. Unlike other sectors, where carbon is emitted to the atmosphere, forests act as source and sink by absorbing CO_2 and store as biomass and releasing when it is decomposed. Tropical forests store more caron than the temperate forests [48].The aboveground carbon stock accumulated in the vegetation of tropical teak forest in India is 112.19 Mg C/ha [49] and in Myanmar ranged from 185.2 Mg C/ha to 227.7 Mg C/ha [50].



Source: Adopted from Global Forest Watch [51].

Figure 1 : ROLE OF FORESTS IN CARBON STORAGE

Natural forests store more carbon than man mande forests, due to dense trees and accumulation of carbon in the ground [52]. Mangrove forests have the high amount of carbon in among all the forests. Global forests show substantial carbon sequestration potential, which will vary depending on the canopy coverage of forests. If additional 0.9 billion hectares planted with trees we can capture 205 Gt C from 100 years now that is approximately one-third of total anthropogenic carbon emissions of 600 Gt C (53). The efforts for extensive afforestation and reforestation can capture and store 40 and 100 GtC from the atmosphere at forest maturity [54,55]. Forest ecosystems alone can contribute to more than 70% of global SOC storage , and 43% of total forest ecosystem Carbon is stored in forest soils of

1 m depth [56,57]. But afforestation alone may not be sufficient to increases the atmospheric CO_2 unless combined with immediate and drastic reductions in fossil fuel emissions.

5. INDIRECT EFFECTS OF CLIMATE CHANGE ON FOREST COVER

Less forest cover and fragmentation of forests are susceptible to drying if global warming continues [58] and will have least adaptive capacity associated with forest cover. The regions with water availability will increase forest cover and allows native pollinators to recolonize after a climatic shock. The most valuable sites are forested areas where reservoir sites are available. This is a notion that works on a variety of scales. Drought during dry season may results in chronic diseases in the trees which may exceeds 80%. This indicates declines in forest health due to climate change, likely sufficient to cause limited mortality of mature trees. There are few more indirect effects of climate change on forest cover [62, 63]. Several authors listed various indirect effects of climate change impact on forest cover is tabulated in Table. 2.

Table 2. Indirect Effects of Climate Change on Forest Cover

Disturbance agent	Indirect effects	References
Fire	Fuel availability Increased frequency Fuel continuity	Pausas, J. G., amd Ribeiro, E., 2013 [59] Bowman, *et al.,* 2014 [60]
Drought	Water use and water-use efficiency Water stress	Suarez, M. L, and Kitzberger, T., 2008 [61]
Wind	Root and tree anchourage Wind exposure Wind resistance	Usbeck, T., *et al.,* 2010 [62] Moore, J. R., and Watt, M. S., 2015 [63] Panferov, O., *et al.,* 2009 [64]
Snow and ice	Exposure of forest to snow Risk of soil erosion	Kilpeläinen, A., *et al.,* 2010 [36] Bebi, P., Kulakowski, D, and Rixen, C., 2009 [65]
Insects	Distribution pattern of host Agent – host synchronization Host defense	Evangelista, P. H., *et al*., 2011 [66] Schwartzberg, E. G., *et al.,* 2014 [67]
Pathogens	Host abundance and diversity Host defense	Vacher, C., *et al.,* 2008 [68] Karnosky, D. F., *et al.,* 2002 [69]

6. COMPUND EFFECTS OF CLIMATE CHANGE IN FOREST ECOSYSTEM

Climate change affects a wide range of ecosystem functions and processes. This will affect forest density and foliar nutritional status. Forest fires, drought and other climate-related disturbances will have indirect consequences on the forest ecosystem. The indirect effects includes timber supply, water yield from the forest and soil erosion. Many studies of forest ecosystem responses to climate change were based on ecosystem process models at various scales ([70],[71],[72]). Significant studies have investigated the impact of past and current climate change on forest cover, often with surprising effects [73]. Loss of tree cover results increased stream flow at the same time evaporation and water loss also increases [74]. The frequently occuring wildfires are becoming more common and play a major role in defining hydrological responses to climate change ([75],[76]). Changes in forest composition directly affects the habitat of vertebrate and invertebrate species. ([77],[78],[79],[80],[81],[82]). Climate change resulted in variations in tree distribution and bird habitat for 60% of the species. Birds have a close affinity with vegetation, on the other hand, tempers their response to climate change because small patches of suitable habitat may continue even after tree species distribution [83]. Understanding the thresholds in climatic change conditions that are probable to occur in a shift in ecological status and

the processes that support ecosystem reactions for forest management [84]. The comprehensive research that identifies and studies key species interactions and feedback mechanisms, as well as defining features modelling, could provide useful information([85],[86])[87]. The forest management strategies will be determined by species physiology and local environmental conditions ([88],[89]). Several authors listed various compound effects of climate change are presented in Table.3

Table 3. Compound Effects of Climate Change on Forest Cover

Disturbance agent	Compound Effects: climate change impact through changes in	Reference
Fire	Fuel availability Fuel continuity	Ryan, K. C., 2002 [90]
Drought	Water use and water-use efficiency Susceptibility to water deficit	Harvey, *et al.,* 2016 [91]
Wind	Wind exposure Soil anchorage Resistance to stem breakage	Whitney, *et al.,* 2002 [92]
Snow and ice	Avalanche risk	Maroschek, *et al.,* 2015 [93]
Insects	Host presence and abundance Host resistance and defense	Temperli, *et al.,* 2013 [94] Gaylord, *et al.,* 2013 [95]
Pathogens	Agent interaction and asynchrony Agent dispersal	Garnas, *et al.,* 2012 [96] Tsui, *et al.,* 2012 [97]

7. FOREST BIODIVERSITY RESPONSES ON CLIMATE CHANGE

Forests are one of the most biodiversity rich habitats on Earth. Forest ecosystem is crucially important for terrestrial biodiversity but the exploading population and forest for expansion of agriculture lands in forests, deforestation, soil erosion, pollution, and other human activities are impacting forest biodiversity. Climate change is a potential threat to forest biodiversity, soil and water and other ecosystem services. Extreme events like drought, fire and climate mediated disease and pest outbreaks likely to increase and can seriously affect forest [98] and affect the forest biodiversity more than gradual global or regional changes in averages [99] (Leemans and vanVliet, 2004). Regional climate change also impacts reproduction, migration, species distributions and population size and causes casualties of flora and fauna in the forest ecosystem. The type, intensity and frequency of ntural disturbances like fire and drought due to regional climate change and land use practices affects the productivity and species composition of forest ecosystem. Climate change also results in faster extinction of vulnerable species. Sometimes the invasion of alien species also alters the ecosystem. A biodiversity rich ecosystem will increase the resilience of any ecosystems particularly forest with high diversity can maintain soil fertility, reduce soil erosion, yield clean water, perform better nutrient cycle and resistant against pests and diseases [100].

8. CONCLUSION

Forest ecosystem can combat the soil erosion and degradation by stabilizing soils, increasing the infiltration, soil carbon content and maintaining nutrient cycling. Climate change has a vital impact on forest cover and deforestation and forest degradation are critical issues for sustainable environmental management, because they have a significant impact on the climate, and deforestation has not been controlled till now. Biotic factors are the most important factors as compared to direct climate effects on forest density in a changing climate. Insects and illnesses have substantially shorter generation lengths and can adapt to different environmental circumstances more faster than plants. India has a total carbon storage of 24.5 with 19.2 Gt (78.5 %) stored in soil and only 5.25 Gt stored as above and below ground biomass. This above and below ground biomass can effectively increased by the proper planning and management of forests in the country. Remote sensing data have revolutionised the documentation and identification of forest degradation status and provide timely deforestation alerts for

monitoring and planning climate mitigation activities. Assessment of the impacts of climate change has significant implications for the specific impacts of greenhouse gas mitigation, carbon sequestration and adaptation to climate change. Hence policy level decisions should be incorporated to stop the deforestation and encourage afforestation in wastelands to assure stability and sustainability of forest ecosystem..

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