Review Article

Climate Change Impact on Forest Cover: A Critical Review

ABSTRACT

Climate change affects forest cover through a combination of warming, altering precipitation, altered extreme event patterns, and a shifting disturbance regime. In view of understanding the existing studies carried out on claimate change impact on forest cover, an attempt was made to review the findings of several researchers to assess the impact of changing climatic parameters on forest cover. Then the role of deforestation on climate change was analyzed by presenting some of the arguments made by several researchers. Further, the role 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 affecteddue to climate change. Several research publications demonstrating the response of forest cover to climate change were critically analysed. It is concluded that the climatic conditions should be taken into account when studying the changes in forest cover in the environments in which the climate prevails, which is characterized by the high amount of rain within a short period of time and subsequent a long dry period. It is concluded that climate change impacts regarding fluctuation of rainfall and temperature were not the main driver for forest cover changes. Assessment of the impacts of climate change has significant implications for the specific impacts of greenhouse gas mitigation, carbon sequestration and the level needed for adaptation to climate change. Utilising the remote sensing data for documenting and identifying forest degradation status is the suitable option for planning climate mitigation activities in forest region.

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

1. INTRODUCTION

The forest ecosystem plays an essential 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 livestocks. 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 withincreased temperature, unpredictable precipitation patterns, frequent extreme events, and increased greenhouse gas emissionspose a significant challenge to the forest ecosystem. Climate change also lead to few changes in tree species [1] and disturb the forest ecological balances [2] . The risk of climate change impact increases as the warming continues [3]. Disturbances are natural in any ecosystem development that reset the possible pathways of change at irregular intervals. Abiotic disturbances like extreme rainfall, increased temperature, and frequent forest fires resulted due to climate change. Direct climate change effects like temperature and precipitation affect forest biodiversity, and indirect climate mediated changes affect forest structure, composition, and abundance [4]. Forest structure and composition generally respond slowly to environmental changes;simultaneously, they can be easily altered by sudden tree mortality due to forest fire, wind, and pests. Many kinds of forest disturbances have been climate sensitive and intensified during the last decades ([5],[6]).Many models have been developed to predict the relationship between climate change variables and forest diversity. Hence, the present review explains the various effects of climate change in forest cover.

2. CLIMATE CHANGE AND FORESTS

In general the forest growth rates are significantly affected with change in climate and water availability. If there is enough water, a short and not very intense dry period, and high temperature, a high growth rate will be found [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 spells. 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 which affects the forest growth. However, the impact on tree growth rate is significantly varies if the solar radiation is combined with the temperature effects. Variations in solar radiation and temperature affected tree growth rate at the stand level, although each factor separately did not affect tree growth rate. 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]. It is showed that precipitation and solar radiation had a positive association with tree growth at $p < 0.0001$ [9]. Rainfall caused 19.8 % of tree growth variation, while solar radiation caused 16.3% of growth variation. Moreover, the combined impacts of precipitation, solar radiation, temperature increase and soil water content caused 29.8% of tree growth variation in pan-tropical forests ($p < 0.001$). In Polar Regions, solar weighted UV-B radiation caused 10% reduction in plant height at $p < 0.05$ [11]. Few studies conducted on Direct effects of climate change impact on forest cover are reviewed and furnished in Table.1.

Table.1 Direct Effects of Climate Change Impact on Forest Cover

Disturbance agent	Direct effects	Authors
Fire	Fuel moisture	Williams and Abatzoglou, 2016 [12]
	Ignition Fire spread	Billmire, M., *et al.,* 2014 [13]

Drought	Occurrence of water limitation Duration of water limitation intensity of water deficit	Cook, B. I., *et al.,* 2014 [14]
Wind	Occurrence of strong winds Duration 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	Snow occurrence Snow Duration Occurrence of freezing rain	Teich, M., *et al.,* 2012 [18] Gregow, H., *et al.,* 2011 [19] Cheng, C. S., *et al.,* 2007 [20]
Insects	Agent metabolic rate Agent behaviour Agent survival	Jonsson, A. M., *et al.,* 2011 [21] Lemoine, N. P., *et al.,* 2014 [22] Battisti, A., *et al.,* 2005 [23]
Pathogens	Agent metabolic rate Agent abundance	Munteanu, C *et al.,* 2014 [24] Aguayo, J., *et al.,* 2014 [25]

3. DEFORESTATION EFFECTS OF THE CLIMATE CHANGE

The major drivers of climate change can be divided into anthropogenic causes such as land use changes, deforestation and forest degradation, fossil fuel burning and industrial processes, and natural causes such as solar radiation changes and volcanic activity. So, deforestation and forest degradation play a major role in global climate change, and reciprocally, deforestation is indirectly affected by climate change. The world's forests covered around 6 billion hectares before 10,000 years, about 45% of the total land area. However, the forest covers has been decreasing from that period and forests cover only about 31 % of the world's area in 2010 [26]. Agricultural expansion including shifting cultivation is one of the major anthropogenic divers for deforestation in the tropical region [27]. According to the reports of the Food and Agriculture Organization (FAO), annual rate of deforestation is 0.14% per year (5.2 million hectares per year of net annual deforestation) [26] and, during the twenty-first century, deforestation was slow in temperate forests whereas deforestation was still high in tropical forests [28]. Globally, greenhouse gas (GHG) effulents in the atmosphere from the deforestation and also the forest degradation have accounted for about one-fifth of the total GHG emissions. Among the GHGs, annual CO2 emission by anthropogenic land use change was 0.9 Gt C/yr (IPCC 2013). Evidence of vast impacts on climate change by CO_2 emission from deforestation was found in Indonesia and Brazil, the third and fourth largest CO_2 emitters of the world. The net annual carbon emission from deforestation and forest degradation has seen no significant change over two decades [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, because they have a large impact on the climate, and deforestation has not been controlled till now.

Deforestaion can lead to desertification, on other hand this deforestation is a major driver of climate change [30]. Drought and heat have a large impacts on the climate change that cause tree mortality, altering species composition and diversity [31]. The species retreated from a lower elevations and concentrated at higher elevations because temperature increases and precipitation decreases [32]. Reduced rainfall and increasing temperature had a substantial impact on the seedlings mortality risk of Aextoxiconpunctatum in subtropical woods [33]. Tree species have reduced their habitats even though a few species expanded their habitats because of the warming climate [34]. Tree species make natural adjustments to respond to global warming by shifting to higher altitudes to survive [35].Climate change can increase the potential for forest fires, and forest fires can 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. However, the advantages and disadvantages were not listed suitably by the various authors. Carbon sink function will decrease or even stop when the forests get into a steady state of carbon sequestration in biomass and soil organic matter and carbon loss due to the decomposition of dead wood debris and soil organic matter ([40],[41],[42]). The assumption is that natural ecosystem dynamics will exert dynamic ecosystem self-regulation in the face of climate change. Private owners of tiny forest assets maintained by non-experts on an ad hoc basis are increasingly adopting this viewpoint([43],[44]). Climate change has been found to have a vital impact on forest cover [45]. At local hotspots, the discrepancy can occur within a few decades, whereas elsewhere, it takes longer. However, utilising remote sensing data, attempts have lately been made to comprehensively document torrential hazard episodes and identify forest damages([46],[47]).

4. ROLE OF FOREST IN CARBON STORAGE

Forest carbon storage capacity is significantly affected by changes in forest cover. The forests of the world store over 650 billion tons of carbon in various components: 44% in the biomass, 45% in the soil and 11% in dead wood and litter [26]. In Asia and Oceania region, the carbon storage of tropical forests ranged from 89 Mg C/ha to 180 Mg C/ ha whereas the carbon storage of tropical forests in Latin America and Sub-Saharan Africa ranged from 84 Mg C/ha to 160 Mg C/ha and from 44 Mg C/ha to 165 Mg C/ha, respectively [48] .The aboveground carbon stock accumulated in vegetation of tropical teak dominant forest in India was found to be 112.19 Mg C/ha [49] .However, aboveground carbon storage of tropical teak-dominant forest in Myanmar is higher than that of India. Aboveground carbon storage of tropical teak dominant forest in Myanmar ranged from 185.2 Mg C/ha to 227.7 Mg C/ha and the total carbon storage ranged from 413.7 Mg C/ha to 480.5 Mg C/ha [50].In the temperate forest of Central Mexico, carbon storage ranged from 42.63 Mg C/ha to 181.88 Mg C/ha whereas carbon storage in temperate grassland ranged from 3.74 Mg C/ha to 9.83 Mg C/ha [51].Mangrove forests are having the high amount of carbon in among all the forests. In the Indo-Pacific region, mangrove forests store an average of 1023 Mg C/ha, and if these mangrove forests are differentiated in detail into two groups, estuarine and oceanic, estuarine mangroves store 1074 Mg C/ha whereas oceanic mangroves store 990 Mg C/ha [52].Global forests show substantial carbon sequestrations potential, which will vary depending on the canopy coverage of forests.

Reduced precipitation affects the carbon storage and aboveground biomass of forests. In tropical lowland forest of Madagascar where the annual rainfall is about 3000 mm and mean temperature is approximately 27 ^{0}C, 2% of carbon storage is lost from the forest when the annual rainfall is reduced by 20%. But the impact is stronger when the annual rainfall is reduced by 60%: carbon storage was reduced by 22% in aboveground living biomass and also by the change in both the soil and deadwood pool [53]. Increased water deficiency due to increased mean annual temperature and decreased annual precipitation is a dominant factor for reduction of biomass carbon sink. In Canada's boreal forests, the rate of biomass change showed a significant decrease over years in the region where increased water deficiency occurred [54]. But in temperate and evergreen needle-leaf and deciduous broadleaf forests of the Southern United States, there was a net increase of carbon storage by the combined effects of temperature and precipitation, atmospheric CO_2, tropospheric O_3 concentration, nitrogen deposition and land use and land cover chang [55]. Climate change can increase the potential for forest fires, and forest fires can also reduce forest carbon storage. For example, in boreal forest of Finland, an increase of 1% in mean annual temperature and 2 to 5% in annual precipitation induced a 5% increase in forest fire potential in a 30-year period [36], and carbon emission from combustion of surface and ground fuels ranged from 4.48 t C/ha to 15.89 t C/ ha in southern Taiga of the over Angara region in Siberia, Russia [56]. Moreover, solar UV radiation had a negative regression with aboveground biomass at $p < 0.01$. In polar regions, weighted solar UV radiation reduced above ground biomass to the tune of 14.7% at $p < 0.05$ [57].

5. INDIRECT EFFECTS OF CLIMATE CHANGE ON FOREST COVER

Low forest cover is frequently linked to significant fragmentation, and forestry fragments will be particularly vulnerable to drying as the climate changes [58].The area's most exposed to climate change therefore have the least adaptive capacity associated with forest cover. Reservoir areas can help with adaptability in places with a lot of forest cover by allowing native forest pollinators to recolonize after a climatic shock. The most value sites are forested areas where reservoir sites are available. This is a notion that works on a variety of scales. Local farms might potentially identify and conserve potential forest reservoir regions. By limiting the distances pollinators must travel to reoccupy destroyed habitats, distributing reservoir areas around a region or farm can be predicted to reduce recovery times following drought and other climatic shocks. Changes in climatic water stress during the dry season are used to estimate changes in forest health particularly chronic wasting disease (CWD). However, predicted dry season CWD in several stdudies 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 Impact on Forest Cover

Disturbance agent	Indirect effects	References
Fire	Fuel availability Flammability Fuel continuity	Pausas, J. G., amd Ribeiro, E., 2013 [59] Bowman, *et al.,* 2014 [60]
Drought	Water use and water-use efficiency Susceptibility to water deficit	Suarez, M. L, and Kitzberger, T., 2008 [61]
Wind	Tree anchorage 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 Avalanche risk	Kilpeläinen, A., *et al.,* 2010 [36] Bebi, P., Kulakowski, D, and Rixen, C., 2009 [65]
Insects	Host distribution and range 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. IMPACT OF COMPUND EFFECTS ON CLIMATE CHANGE IN ECOSYSTEM

Climate change affects a large range of ecosystem functions and processes. Changes in these systems will impact variety of characteristics including wood density and foliar nutritional status. Changes in fires as well as other climate-related disturbances will have indirect consequences. These changes have a vital impact on how much timber can be supllied and the water yield of the forest and the soil erosion in the forests. Most early studies of forest ecosystem responses to climate change were built around ecosystem process models at various scales ([70],[71],[72]). A number of recent studies have investigated the effects of past and current climate change on forest cover, often with surprising effects [73]. Loss of tree cover may increase stream flow but can also increase evaporation and water loss [74]. The amount to which wildfires are becoming more common will also play a role in defining hydrological responses to climate change([75],[76]). The habitat of vertebrate and invertebrate species will be affected by changes in forest composition. Climate change effects for biodiversity protection have been thoroughly investigated ([77],[78],[79],[80],[81],[82]). This is critical to use a analytical approach that considers both species and habitat implications. In a study of changing climate affects on bird habitat in the north eastern United States, the combination of changes in tree distribution and bird habitat resulted in significant impacts for 60% of the species. Birds close affinity with these 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 really are probable to occur in a shift in ecological status, and the processes that support ecosystem reactions for forest management [84]. The comprehensive procedure ecosystem research that identifies and studies key species interactions and feedback mechanisms, as well as defining features modelling, could provide useful information([85],[86]). Climate change also may cause a stepwise progression to unknown transitional states that track changing climate circumstances, necessitating a more phased approach in managerial decisions, rather than forcing systems across threshold into alternative states [87]. Finally, managerial decisions may be influenced by stresses that establish the physiological limitations of species distributions rather than whether we can predict future design thresholds. These limits will be determined by species physiology and local site conditions, with recent research revealing that ecosystem reactions to climate change have already been documented ([88],[89]). Several authors listed various compound effects of the climate change those are tabulated 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

One of the study investigated eleven distinct biodiversity indices for each simulated 1-ha grid cell to generate a thorough assessment of the climate change effects on forest biodiversity. Land simulations have been used to derive tree species diversity and canopy complexity. The small repeating index was used to quantify canopy complexity [98], which is the ratio of the canopy surface area to the projected ground surface area, calculated here at 10-m horizontal resolution. Based on ecological theory, the authors hypothesized an optimum relationship of temperature and canopy cover for each indicator and consequently transformed these predictors using second-order polynomial functions [99]. They determined the model using the Akaike's Information Criterion (AIC), Nagelkerke R^2 values as well as P-values from chi-square tests. Final models were tested for multicollinearity by means of variance inflation factors. To further analyze the thus-derived empirical models with regard to their response to climate and tree vegetation changes, a sensitivity analysis was conducted. Disturbance, in contrast to climate change, showed a clear beneficial effect on the forest biodiversity indices studied. This finding is consistent with a large body of knowledge about the effect occurring on the disturbance of the biodiversity in the forest ecosystems [100].

8. CONCLUSION

Climate change has been found to have a vital impact on forest cover. Deforestation and forest degradation are critical issues for sustainable environmental management, because they have a large 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. It can be noted that the distinct biodiversity responses to the changes in disturbance frequency, intensity, and magnitude and their impact on the forest cover. Climatic conditions should be taken into account when studying the changes in forest cover in the environments in which the Mediterranean climate prevails, which is characterized by the high amount of rain within a very less time period and also a long hot dry period. Utilising the remote sensing data for documenting and identifying forest degradation status is the suitable option for planning climate mitigation activities in forest region. It is concluded that climate change impacts regarding fluctuation of rainfall and temperature were not the main driver for forest cover changes. Assessment of the impacts of climate change has significant implications for the specific impacts of greenhouse gas mitigation, carbon sequestration and the level needed for adaptation to climate change.

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