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Forests in Peril: Climate Change, Biodiversity Loss, and Carbon Sink Decline in Northeast China

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Abstract. Forests in northeast China are critical for climate regulation and biodiversity conservation. Over the past few decades, climate change has become a strong stressor for these forests, resulting in changes in temperature, precipitation regimes, and ecological processes. Recent studies have begun to explore how these environmental changes affect forest structure and carbon processes. This paper explores the impacts of climate change on forest ecosystems in northeast China, especially biodiversity and carbon sinks. Rising temperatures, changing precipitation patterns, and frequent extreme weather events have altered forest structure, species diversity, and ecosystem processes in the region. These climate changes are weakening forest stability and health, and reducing forests' ability to serve as carbon sinks. This study also explores how feedback mechanisms and regional heterogeneity enhance these impacts. Recommendations are proposed to strengthen adaptation measures, increase carbon sinks, and improve governance. This discussion not only provides policy-relevant information for regional forest management in China, but also contributes to a comprehensive understanding of climate-related issues facing temperate and boreal forests worldwide.

Keywords: Forest, biodiversity, climate change.

1. Introduction

Northeast China contains some of the largest temperate and boreal forest ecosystems in the world within the country. The forests exhibit a high level of biodiversity that supports a variety of tree, plant, and animal species, and they serve as carbon sinks, thus playing a fundamental role in climate regulation. However, the region has been subject to increasing environmental problems in the last decades that can be attributed to climate change. Increasing average temperatures, shifts in rainfall patterns, and rising numbers of extreme events like heatwaves and storms have already started to destabilize the ecological balance of the region's forest ecosystems.

Recent research has established that climate change is now modifying both the structure and function of these forests. For example, rising temperatures have been associated with the northward migration of certain tree species, altering the overall species mix within much of the forest cover [1]. Simultaneously, decreased or erratic precipitation has resulted in drought-like situations in some areas, compromising tree health and reducing growth rates [2]. This has contributed to a significant decline in biodiversity, where vulnerable species either experience population declines or are

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rendered entirely extirpated from their natural habitats [3]. The stress brought about by environmental changes also makes forests more vulnerable to disease and insect attack, again destabilizing the balance in such ecosystems.

Among the most significant concerns is the impact of these changes on the forests' carbon sequestration capability. Healthy trees in forests absorb enormous amounts of carbon dioxide from the atmosphere, reducing the pace of global warming. Climatic stressors such as prolonged droughts and insect epidemics can diminish this potential.

In certain regions, deforestation has resulted in the reduction of carbon sequestration capacity [4]. Although specific warmer temperatures may permit increased tree growth at some points temporarily, the general trend is for a sustained reduction in forest health and carbon storage [5].

Even as the literature on this subject has grown in recent years, most research has emphasized wide patterns or national-level comparisons. There is a shortage of sufficient comprehensive studies with regard to the impact of climatic factors on certain forest ecosystems in Northeast China. More precisely, there is a shortage of sufficient knowledge regarding the interaction of changes in biodiversity with reduced carbon sequestration under future climate scenarios. This shortage of knowledge poses an obstacle for policymakers and conservationists to come up with effective strategies for forest conservation and carbon management in the area. The present research tries to fill this gap by addressing forest ecosystems in Northeast China and in particular emphasizing biodiversity losses and changes in carbon sequestration potential. The study tries to examine the impact of increasing temperatures, changing precipitation regimes, and extreme weather events on species distribution, forest structure, and ecosystem processes. By examining regional variation and identifying susceptible forest types, the study will ensure greater understanding of the ecological effects of climate change and advise future policy-making on forest management [6].

2. Present situation of forest ecosystems in Northeast China

Northeast China, comprising Heilongjiang, Jilin, and Liaoning provinces, has some of the most extensive forest ecosystems in Asia. The area covers both the temperate broadleaf and boreal coniferous regions and is characterized by various topographical conditions, including the Changbai and Lesser Khingan Mountains. These areas create a range of microclimates and environments that allow for complex forest structures and ecological interactions [7].

2.1. Biodiversity of forests

These forests are highly biodiverse with thousands of plant species, numerous mammal and bird populations, and endemic life. Broadleaf trees such as Mongolian oak (Quercus mongolica) and Korean pine (Pinus koraiensis) exist alongside coniferous species such as larch (Larix gmelinii). Animal populations include Siberian tiger, Asiatic black bear, and hazel grouse. However, habitat fragmentation through logging and agriculture has disrupted traditional migration and reproductive processes [8].Human activities like road construction and illegal logging have caused edge effects that reduce interior forest habitat, exposing species to increased wind exposure, insects, and temperature fluctuations [9]. These pressures heighten the risk of extinction for interior-dependent species and undermine ecosystem resilience.

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2.2. Contribution to carbon sequestration

Northeast China forests are important carbon sinks as they take up atmospheric CO_2 through photosynthesis and store it in biomass and soil. The region is approximated to hold 15–20% of China's total forest carbon storage [10]. Long-term soil carbon studies also point out that the region's cold soils effectively lock away organic material for decades or centuries [11]. However, increased decomposition under warming conditions could threaten this stability.

2.3. Human activity imact

Industrial logging, mining, and agricultural conversion have compromised forest quality across much of the region. Large-scale timber harvesting since the 1950s has caused forest loss and biodiversity degradation. While the Natural Forest Protection Program (NFPP) initiated in the 1990s enhanced forest cover, monoculture plantations and low species mix restrict biodiversity gains [12]. In addition, illegal hunting and lack of enforcement of protection legislation remain threats to endangered species like Panthera tigris altaica.In recent years, there have been efforts at the national scale to create nature reserves and reconstruct degraded ecosystems. Most of these reserves, however, are too small or fragmented to sustain wide-ranging species, and the enforcement of conservation law remains spotty. Reforestation programs also often rely on fast-growing single-species plantations, which fail to replicate the ecological processes of indigenous forests [12]. Encroachment by human activities near protected areas also results in invasive species and pollution, further undermining restoration efforts.

3. Effects of climate change on forest biodiversity

3.1. Temperature change

Rising mean temperatures have altered growing seasons, accelerated phenological changes, and disrupted the reproductive patterns of many species. Tree species suited to colder climates, such as spruce (Picea jezoensis), are facing a reduction in the southern part of their range, while broadleaf species are expanding northward [13]. This northward expansion is causing a mismatch between forest composition and local fauna that depend upon certain plant species for survival.Some endemic species like Rhododendron dauricum are losing their suitable habitats as warming accelerates, resulting in contraction of their geographic distributions. Species that cannot migrate quickly or physiologically acclimatize are particularly vulnerable [13].

3.2. Shifting precipitation patterns

In addition to temperature, precipitation volatility is also on the rise. Droughts have become more frequent in Liaoning and southern Jilin and have impacted seedling mortality and forest regeneration. Drought-tolerant species such as Betula platyphylla suffer decreased growth rates and increased mortality during dry years [14]. On the other hand, excessively wet years lead to soil saturation, root rot, and the transmission of fungal diseases.Climate-induced hydrological shifts disrupt nutrient cycling and microhabitat stability, resulting in population decline of soil invertebrates and understory plants that play a significant role in forest food webs [14].

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3.3. Climate extremes

.Extreme weather conditions such as late frosts, storms, and extended heat waves have both increased their frequency and intensity. Such events cause damage to tree canopies, result in branch breakage, and heighten the risk of pest infestation, such as Dendrolimus punctatus, that compromise tree defense and quickly spread in high temperature regimes [15]. Certain areas, especially in the Changbai Mountains, are emerging as hotspots of both biotic and abiotic stress, causing what researchers refer to as "forest diebacks"—abrupt reductions in the health and vigor of extensive areas of forest [15].

3.4. Species vulnerability

Species that have specialized ecological niches, such as the Ussuri dhole (Cuon alpinus), are particularly vulnerable in the face of climate change. These species rely on specific structures of habitat and prey species that are disappearing or being displaced. Similarly, temperature-sensitive life cycles of pollinators and fungi are struggling to adapt, disrupting tree reproduction and forest regeneration.Amphibians like the Northeast Asian salamander (Hynobius leechii) are particularly susceptible to drought and habitat change. Their eggs require damp soil and shaded microhabitats, which are being eliminated by forest thinning and rising temperatures. Migratory or breeding bird species that rely on seasonal cues, like the Siberian thrush (Zoothera sibirica), are also being affected by mismatches between breeding timetables and food availability. These fluctuationsresult in reduced reproductive success and fewer juveniles surviving.The cascading effect of losing biodiversity is not confined to single species. Changes in trophic chains and disrupted mutualistic interactions (e.g., seed dispersal by birds or insect pollination) reduce the overall functionality of the forest ecosystem [14]. Such disruptions threaten not just local biodiversity, but also the long-term health of forest systems to future climate stressors.

4. Climate change effects on carbon sequestration

4.1. Carbon sequestration processes

Forests store carbon primarily in two ways: carbon sequestration in biomass and soil carbon. The trunks, branches, and leaves of the trees take up atmospheric CO_2 and store it in the form of organic carbon Soil carbon is accumulated from decaying plant litter, deceased roots, and microorganisms.In Northeast China, mixed forests have exhibited the highest long-term carbon sequestration potential, especially those with complex age structure and species composition [15]. The addition of deep-rooted species enhances belowground carbon storage, especially in the loamy soils of the higher elevation forests. environmental circumstances. Augmented photosynthesis under elevated CO_2 has the possibility of increasing short-term carbon assimilation, provided that other factors—i.e., water and nutrient supply—are at their optimum levels [15]. Conversely, trees under stress could divert energy to survival from growth and consequently lower sequestration rates.Moreover, forest management by humans is also important. Thinning, planting with multiple species, and longer rotation times can encourage carbon storage in the long run. On the other hand, low-diversity, short-rotation plantations of poplar or larch store less carbon and face higher disturbance risk. Replacing such plantations with more diversified, native forest ecosystems is a desirable choice for facilitating climate resilience and carbon mitigation simultaneously.

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4.2. Effects of changes in temperature and precipitation

4.2.1. Temperature increase and carbon absorption efficiency

Temperature increase can exert a twofold impact on forest carbon processes. On the one hand, moderate warming can, in the short term, promote photosynthesis and tree growth, which may increase carbon sequestration. On the other hand, long-term heat stress causes increased evapotranspiration and water deficits, especially when not accompanied by more precipitation. In southern Jilin and central Liaoning, decreased precipitation combined with summer heatwaves has increased tree mortality rates and suppressed forest regeneration, resulting in decreased carbon uptake capacity [10].

4.2.2. Changed precipitation and soil carbon instability

Alternations in precipitation regimes—whether reduced total rainfall or unpredictable seasonal distribution—can influence soil moisture and nutrient availability. Drought can reduce microbial activity that stores carbon in soils, whereas intense rain events favor leaching and erosion. Xu et al. noted that changing hydrological regimes in Northeast China destabilize subterranean carbon storage and restrain the capacity of soils to hold organic carbon [10].

4.3. Feedback mechanisms

4.3.1. Less sequestration resulting in additional emissions

Degradation or dieback of forests due to climate-driven stressors leads to a weakening of the carbon sink function. When trees that are stressed or dead return stored carbon to the atmosphere through decomposition or wildfires, CO_2 in the atmosphere increases, accelerating global warming.

4.3.2. Vegetation shift and functional loss

Climate-induced species compositional changes can decrease carbon storage in the long term. For instance, a compositional change from broadleaf to needleleaf species can decrease the efficiency of carbon sequestration because of variations in wood density and growth cycles. Replacing old-growth native species with fast-growing plantations (usually low in biodiversity) also compromises the soil carbon pool and ecosystem stability.

4.4. Regional variations

4.4.1. Forest type and climate zones variation

Northeast China's topography encompasses heterogeneous landscape from the Greater Khingan Mountains to river basin lowlands, leading to heterogeneous forest types and climatic responses. Northern Heilongjiang boreal coniferous forests are slow growing but store carbon longer in permafrost soil. Central Jilin mixed forests, however, are more productive with moderate warming but also more sensitive to drought .

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4.4.2. Land management and use practices

Regions experiencing intensive land-use change, like western Liaoning, are plagued by soil degradation and forest fragmentation, diminishing carbon storage. Reforestation activities frequently consist of single-species plantations, which have lower carbon storage and are also more susceptible to disturbance compared to native stands that are diverse. Research indicates that the customization of forest management to fit local ecological conditions can greatly enhance carbon sequestration results.

5. Recommendations and possible enhancements

5.1. Adaptive strategies for climate resilience

Forest managers should implement adaptive strategies tailored to regional climatic trends and ecological characteristics. For example, promoting mixed-species plantations over monocultures can enhance ecosystem resilience to climate variability and reduce vulnerability to pests or diseases. Establishing climate monitoring stations within key forest zones will also allow for early detection of stress responses and facilitate timely intervention. Furthermore, ecological corridors should be created to connect fragmented forest patches, enabling species migration in response to changing temperature zones.

5.2. Strengthening carbon sequestration activities

To improve carbon sink capacity, policies should prioritize reforestation projects that incorporate native species and diverse age structures. Long-term research supports the carbon storage superiority of heterogeneous forests with complex vertical layering. Additionally, forest management should include strategies such as selective thinning, controlled burning, and organic soil amendments to maintain healthy root systems and soil carbon pools. Incentive programs could be designed to reward sustainable forestry practices that show measurable carbon gains.

5.3. Policy and governance recommendations

Legislation must be strengthened to regulate illegal logging and land conversion near protected areas. At the same time, current conservation laws should be revised to address climate-related pressures and emphasize ecosystem functionality over mere forest coverage. Cross-sector collaboration between local governments, research institutes, and community stakeholders is essential for effective implementation. Finally, data from regional ecological studies must inform national forest policy, ensuring that decisions are evidence-based and locally adapted.

6. Conclusion

This paper has examined the influence of climate change on forest ecosystems in Northeast China, addressing biodiversity change, carbon sequestration potential, and regional differentiation. This study furnishes a framework for explaining the response of forest ecosystems within a climatically vulnerable area to environmental stresses. The findings add to and develop further the previous arguments presented in the introduction and the existing body of literature on climate–forest relationships. Through the definition of feedback loops and sensitivities, the research furnishes useful benchmarks for adaptive management practice and climate policy development. Yet the

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analysis is constrained by its concentration on large-scale patterns and lacks both in-depth field data and long-term projection modeling. It also fails to complete the analysis of the contribution of socio-economic drivers, including population pressure or forest policy enforcement, to ecosystem outcomes. Future research should enhance the empirical foundation of climate–forest interactions through site-based modeling and high-resolution monitoring. It would also be worthwhile to investigate how socio-political intervention can supplement ecological adaptation. With the increasing climate change, integration of ecological science and policy planning will be central to protecting forest-based carbon sinks and biodiversity hotspots.

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