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8. Climate Change Impact on Forests and Their Management

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Abstract:

Global forest ecosystems are seriously threatened by climate change, which will alter their makeup, structure, overall functioning, and the provision of essential ecosystem services. Climate change affects forests by causing temperature increases, changes in rainfall patterns, shifts in species distribution, outbreaks of pests and diseases that harm tree health, and alterations in ecosystem functions and services (Liu et al., 2013; Guo et al., 2022). Climate change adaptation integrates strategies to address climate change impacts, enhance forest resilience, and promote the long-term sustainability of ecosystem services. Adaptive silviculture, which involves adjusting forest management practices, species selection, and forest structure to enhance resilience and promote sustainable forest ecosystems, focuses on restoring natural habitats, enhancing biodiversity, and promoting the recovery of ecosystem functions and services, including carbon sequestration helps to enhances forest resilience, boosts biodiversity, and improves long-term ecosystem service sustainability. Regular monitoring and assessment of forest health indicators, such as tree vitality, disease prevalence, species diversity, and ecosystem services, are crucial for evaluating management strategies. These include tree vitality assessed by growth rates and leaf condition, disease prevalence identified by pest infestations, species diversity evaluated through biodiversity surveys, and ecosystem services like carbon sequestration rates.

This chapter reviews recent literature on the impact of climate change on forests and explores strategies for forest management in the context of changing climatic conditions.

Keywords:

Climate change, Forests, Management, Adaptive strategies, Resilience.

8.1 Introduction:

Forests are essential components of terrestrial ecosystems, providing critical habitat for biodiversity, regulating water cycles, and sequestering carbon dioxide (CO_2) from the atmosphere. However, climate change is increasingly affecting forests worldwide, presenting significant challenges for their management and conservation (IPCC, 2018). Climate change is significantly impacting forests by changing the distribution of trees, affecting productivity, and influencing biodiversity. It potentially increases the consequences of many existing challenges associated with environmental, social, or economic change (Keenan, 2012). Climate change is now universally recognized as a critical issue for forests and forest management worldwide, underscoring the urgent need for proactive strategies to mitigate its impacts. This change will affect forests' ability to provide ecosystem goods and services on which human communities depend: biodiversity, carbon sequestration, regulation of water quality and quantity, timber and non-timber products, as well as spiritual and cultural values. Global efforts are underway to reduce the causes of climate change (mitigation) and help natural systems and human societies adapt to its impacts (Chmura et al., 2010).

Climate change has a significant impact on forest cover through various factors such as temperature increases, changes in precipitation patterns, more frequent extreme events, altered disturbance regimes, and shifts in species distributions. Understanding climatic variations is crucial for comprehending changes in forest cover within ecosystems. Climate change assessments are essential for strategies related to carbon sequestration, greenhouse gas mitigation, and adaptation to climate change. It poses a serious risk to long-term sustainable forest management, with projected declines in above ground biomass and potential disruptions to forest ecosystem services.

Innovative forest management approaches and early detection of changes are crucial for mitigating the impacts of climate change and ensuring the resilience of forest ecosystems. Additionally, the implementation of adaptive forest management models can increase the resilience of forests in these vulnerable regions (Nunes et al., 2021; Williams, 2011). By integrating adaptive forest management models, forest ecosystems can bolster their resilience to climate change impacts and safeguard their ecological functions. This strategy can aid in alleviating the impacts of climate change on forest cover and fostering sustainable management practices for the long-term health of these ecosystems. Forests globally absorb billions of tons of CO_2 annually, providing significant economic benefits. Tropical regions offer a key opportunity for reducing carbon emissions by addressing deforestation and degradation through the implementation of sustainable logging practices, promoting reforestation initiatives, and protecting biodiversity hotspots. This may lead to alterations in ecosystem dynamics and the potential extinction of species.

8.2 Climate Change Impacts on Forests:

8.2.1 Temperature Increases or Heat Waves:

Rising temperatures associated with climate change have profound effects on forests, affecting tree growth, ecosystem dynamics, and biodiversity. These temperature increases can also lead to more frequent and severe wildfires, further threatening forest health and carbon sequestration efforts. Climate change is associated with rising global temperatures, leading to increased heatwaves and extreme weather events. Studies show that elevated temperatures can result in physiological stress for trees, affecting growth rates and reproductive success. Anderegg et al., (2019) found that drought-induced tree mortality is more prevalent in drier populations, indicating that climate stress exceeds species' compensating mechanisms. This is consistent with the observations of widespread forest die-back and increased mortality rates due to drought and elevated temperatures (Hartmann, 2015). Heatwaves can also lead to widespread tree mortality, especially in drought-prone regions. Additionally, heat stress can weaken trees and make them more vulnerable to pests and diseases. High temperatures result in:

Thermal Stress: Higher temperatures can lead to thermal stress in trees, affecting growth rates, photosynthesis, and overall tree health. In addition, rising temperatures can also alter the timing of natural processes like flowering and fruiting, disrupting ecosystem functions. This can have cascading effects on other organisms within the ecosystem.

Shifts in Phenology: Changes in temperature regimes alter the timing of leaf emergence, flowering, and fruiting, disrupting ecological interactions and species synchronization. These shifts in phenology can lead to mismatches between species that rely on each other for survival, such as pollinators and plants. As a result, these disruptions can have negative impacts on biodiversity and ecosystem stability.

Range Shifts: Species may migrate to higher altitudes or latitudes in response to warming temperatures, leading to shifts in forest composition and distribution patterns, ultimately changing the structure.

8.2.2 Altered Precipitation Patterns:

Changes in precipitation patterns, such as altered rainfall amounts, timing, and intensity, have a significant impact on forest ecosystems. Changes in precipitation patterns can lead to drought conditions or increased flooding, which can affect the health and vitality of forest ecosystems. Additionally, shifts in precipitation patterns can also impact the distribution and abundance of species within forests. Changes in precipitation patterns, including shifts in timing, intensity, and frequency of rainfall, have profound effects on forest water balance.

Droughts, in particular, can weaken trees and make them more susceptible to pests and diseases. Forest stands with high sapling species diversity exhibited reduced vitality, suggesting a potential negative impact of diversity on sapling health under drought conditions (Beloiu et al., 2022). Conversely, heavy rainfall events can cause soil erosion and nutrient runoff, affecting ecosystem health (Lensing and Wise, 2007).

These impacts are likely to be more pronounced in drought-prone regions, such as the western Canadian interior and regions with Mediterranean-type climates (Nunes et al., 2021).

Lensing and Wise (2007) found that changes in rainfall, as predicted by climate-change models, significantly impact the rate of litter decay in deciduous forests with faster decay in high-rainfall and ambient plots compared to low-rainfall plots. The study suggests that predicted changes in rainfall due to global climate change will strongly affect rates of litter decay. These altered precipitation patterns can also lead to changes in forest composition and structure, impacting biodiversity and ecosystem services. It is important for forest managers to consider these factors when planning for sustainable forest management practices in the face of changing climate conditions. Changes in precipitation lead to:

Drought Stress: The increased frequency and severity of droughts result in water stress for trees, affecting their physiological functions and making them more susceptible to pests and diseases. This can lead to widespread tree mortality and negative impacts on forest biodiversity.

Water Availability: Changes in precipitation regimes influence soil moisture levels, stream flow patterns, and water availability for forest ecosystems, impacting plant growth and hydrological cycles. This can ultimately lead to shifts in species composition and ecosystem functions within forests.

Flood Risk: Intense rainfall events and flooding can lead to soil erosion, landslides, and habitat destruction in flood-prone forest areas. This can result in the displacement of wildlife and the loss of biodiversity within these ecosystems.

8.2.3 Increased Frequency and Intensity of Wildfires:

Climate change, by creating warmer and drier conditions, contributes to increased wildfire risks and impacts on forested areas. This can lead to the widespread destruction of forests and the loss of carbon storage capacity. Warmer and drier conditions associated with climate change contribute to more frequent and severe wildfires in forested areas (Liu et al., 2013).

Johnson et al., (2007) highlight the significant impact of wildfires on forest ecosystems, particularly in terms of carbon and nutrient budgets. Wildfires not only pose direct threats to forest health and biodiversity but also release large amounts of CO_2 into the atmosphere, exacerbating climate change. The increase in atmospheric CO_2 levels can have both positive and negative impacts on forest growth and production. It is crucial for forest managers to incorporate strategies for wildfire prevention and management into their sustainable forest management plans (Brecka et al., 2020). By mitigating the heightened wildfire risk associated with climate change, forests can be safeguarded and conserved for future generations. Wildfires and climate change are likely to increase fire risk and severity in the Great Lakes region. Future climate conditions may lead to longer periods of high fire risk and an earlier peak wildfire season. Severe drought conditions have been observed in the Laurentian Mixed Forest, contributing to wildfire occurrences (Miesel et al., 2018). Wildfire results in:

Extended Fire Seasons: Warmer and drier conditions lengthen the fire season, increasing the frequency and intensity of wildfires in many forested regions. Additionally, wildfires can also result in air pollution and harm to human health.

Ecosystem Disturbance: Severe wildfires can cause extensive ecosystem damage, including loss of vegetation, soil erosion, habitat fragmentation, and altered nutrient cycling. Wildfires can also have long-lasting impacts on biodiversity and ecosystem resilience.

Carbon Emissions: Forest fires release significant amounts of carbon dioxide into the atmosphere, exacerbating climate change and contributing to feedback loops. This could result in continued warming and an increase in the frequency and intensity of wildfires in the future.

8.2.4 Species Distribution Shifts:

Climate change influences species distribution and biodiversity in forests by altering habitat suitability and ecological interactions. Climate change can lead to shifts in the distribution of tree species as they respond to changing environmental conditions (Guo et al., 2022).

They have documented changes in species composition and migration patterns, with implications for forest structure and ecosystem dynamics. These changes underscore the necessity of continuous monitoring and conservation efforts to safeguard biodiversity and maintain ecosystem stability. Many Chinese tree species will be seriously threatened by climate change, with a significant percentage vulnerable or threatened by 2070 and high local extinction risks even under the most conservative scenario. Species distribution leads to:

Range Contractions/Expansions: Species may experience range contractions as suitable habitats shrink or expand into new areas as climates shift, leading to changes in species assemblages and community dynamics.

Invasive Species: Climate change can facilitate the spread of invasive species into new areas, impacting native vegetation, disrupting ecosystems, and altering ecological processes.

8.2.5 Pest and Disease Outbreaks:

Climate change influences the occurrence and severity of pest and disease outbreaks in forests by creating favorable conditions for pest proliferation and pathogen spread. This can result in significant damage to forest ecosystems and economic losses for industries reliant on healthy forests. For example, the mountain pine beetle outbreak in North America has caused widespread tree mortality and billions of dollars in lost timber revenue. Warmer temperatures and altered precipitation patterns can create favorable conditions for pest and disease outbreaks in forests. Native species may face increased threats from invasive pests, leading to economic losses and ecological disruptions. These impacts can have cascading effects on biodiversity and ecosystem health. Climate change is a significant driver of pest and disease outbreaks in agricultural and forest ecosystems (Goebel and Cilas, 2015).

It can lead to the expansion of pest and disease ranges, increased infestation pressure, and changes in the spectrum of harmful organisms. The impact of climate change on pests and diseases is particularly pronounced in tropical environments, where it can lead to the spread of major pests and diseases such as coffee leaf rust and sugarcane stem borers (Goebel and Cilas, 2015). Pests and diseases outbreak leads to:

Pest Expansion: Warmer temperatures and altered climatic conditions enable pests like bark beetles and defoliating insects to thrive, causing widespread damage to forest ecosystems. This can ultimately lead to increased unemployment and reduced revenue for industries that rely on healthy forests, impacting local economies and communities.

Pathogen Dynamics: Changes in temperature and moisture regimes affect the prevalence and spread of forest pathogens, leading to increased disease outbreaks in susceptible tree species. This can result in significant economic losses and ecological impacts. In addition, the loss of tree species can also disrupt the delicate balance of forest ecosystems, leading to further ecological consequences. Forest managers must vigilantly monitor and address these pathogen dynamics to uphold forest health and sustainability.

8.3 Strategies for Forest Management:

Forests are shifting from carbon sinks to carbon sources due to global change, emitting additional greenhouse gases. Developing efficient adaptation strategies to climate change is a worldwide challenge to prevent the decline of forest ecosystems. Strategies for forest conservation involves.

8.3.1 Conservation Strategies:

Conservation strategies aim to preserve and protect existing forest ecosystems, safeguarding biodiversity and ecosystem services for future generations. A range of strategies have been proposed for forest management to mitigate climate change. Kline (2020) emphasizes the need to address deforestation drivers and protect high conservation-value forests. Kraxner (2011) suggests responsible forest management can contribute to climate change mitigation through conservation, sequestration, and substitution. Hylander (2021) introduces resistance and transformation strategies, including the identification and protection of forest climate refugia and the enhancement of conditions for forest species favored by the new climate. Africa (2011) discusses the role of forest management in reducing deforestation and degradation, conserving forests, and increasing sequestration potential through afforestation and reforestation. Conservation strategies includes:

Protected Areas: Establishing and managing protected areas such as national parks, wildlife reserves, and conservation easements to safeguard critical habitats and biodiversity, reducing deforestation, promoting sustainable logging practices, and restoring degraded forests.

Forest Certification: Using certification schemes like the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) is crucial to promoting environmentally and socially responsible forest management.

These certification schemes ensure that forests are managed in an environmentally and socially responsible manner, helping to protect biodiversity and ecosystem services. Additionally, promoting sustainable logging practices can help mitigate the negative impacts of deforestation on ecosystems and wildlife.

Community-based conservation: It involves engaging local communities in forest management decisions, promoting stewardship, and supporting sustainable livelihoods through programs like community forestry and indigenous land rights.

Biodiversity Conservation: Implementing strategies to safeguard and enhance biodiversity, which include habitat restoration, species conservation programs, and integrated landscape management, is crucial for maintaining ecosystem balance and preserving valuable plant and animal species. These efforts can help preserve the delicate balance of ecosystems and prevent the loss of valuable plant and animal species.

8.3.2 Restoration Strategies:

Restoration strategies focus on rehabilitating degraded forests and enhancing their ecological functions. Forest restoration has gained attention from scientists and policymakers for its potential to help mitigate climate change (FAO, 2020). Forest restoration also has important links to biodiversity, as the restoration of stable forests that provide multiple ecosystem services requires a functional understanding of the biodiversity that underpins ecosystem functioning. Forest restoration is thus included along with conservation in the decisions and targets of the Sustainable Development Goals, the Convention on Biological Diversity, the UN Decade on Ecosystem Restoration, and the Bonn Challenge. Forest restoration follows processes of forest degradation and deforestation, which are dealt with in separate modules in the Sustainable Forest Management Toolbox. Key approaches include:

Reforestation: Restoration efforts, including reforestation and afforestation projects, are essential for enhancing biodiversity and ecosystem services in degraded forest landscapes. Restoring native species and habitats can improve resilience to climate-related stressors (Tepe and Meretsky, 2010). Planting native tree species to restore deforested or degraded areas, improve soil fertility, and sequester carbon dioxide from the atmosphere, forests can regain their natural equilibrium and functionality.

Forest Landscape Restoration: Another important restoration strategy is habitat restoration, which involves recreating natural habitats for plant and animal species to thrive. Implementing integrated restoration projects at the landscape scale, combining reforestation, agroforestry, and sustainable land use practices to enhance ecosystem resilience and biodiversity. By strategically selecting native tree species that support local wildlife habitats, restoration efforts can promote a healthy ecosystem and enhance biodiversity. Additionally, involving local communities in restoration projects can create a sense of ownership and stewardship, ensuring long-term success and sustainability. Diggins et al., 2010 reported that planned restoration treatments in the Four Forests Restoration Initiative can significantly reduce growth declines, with full implementation leading to even lower declines and fewer years with extremely low growth.

Restoration treatments increased resilience to climate stressors, reduced tree mortality, and promoted forest growth. Managing fire regimes at longer intervals can sustain forest resilience in the face of climate change (Stoddard et al., 2021).

Forest restoration impacts biodiversity by focusing on restoring the relationship between biodiversity and ecosystem functioning. The BEF framework provides a comprehensive framework to evaluate the consequences of biodiversity loss caused by human activities and offers a powerful incentive for biodiversity conservation and ecological restoration. The duration since the start of restoration and the type of disturbance are critical ecological factors influencing the success of forest restoration, especially concerning invertebrates, plant biodiversity, and vegetation structure (Olivier, 2011; Hua et al., 2022).

Natural Regeneration: Permitting the natural processes of seed dispersal and regeneration to facilitate forest restoration, particularly in regions with existing forest remnants or secondary growth, is a cost-effective and minimally invasive approach to restoring diverse and resilient ecosystems. Additionally, natural regeneration can help restore important ecosystem functions and services, such as carbon sequestration and water regulation.

Watershed Management: Implementing watershed restoration projects to improve water quality, regulate streamflow, and prevent erosion, benefiting both forests and downstream communities. These projects often involve activities such as reforestation, erosion control, and stream-bank stabilization to enhance the health of the watershed. Implementing practices like erosion control and stream-bank stabilization through effective watershed management ensures the long-term sustainability of forests and improves the health of surrounding ecosystems.

8.3.3 Adaptive Management Strategies:

Adaptive management strategies involve iterative learning and adjustment based on monitoring feedback and changing conditions. A range of adaptive management strategies have been proposed to address the impact of climate change on forest ecosystems. Pach (2021) emphasizes the importance of silvicultural measures, such as changes in species composition, forest structure, and thinning intensity, in enhancing forest resilience and climate smartness. Nagel (2017) further underscores the need for on-the-ground research and the integration of climate change considerations into forest management tools and training. This is echoed by Nagel (2010), who highlights the importance of providing training on the ecological impacts of climate change and incorporating adaptive techniques into forest management strategies. Adaptive strategies, such as assisted migration and assisted gene flow, can support species survival and adaptation in rapidly changing environments. Furthermore, incorporating diverse tree species and promoting genetic diversity can enhance resilience to climate change impacts. Collaborating with stakeholders and sharing knowledge on climate-smart practices can also improve overall forest health and productivity (Tepe and Meretsky, 2010). Adaptive management strategies include:

Climate-Smart Forestry: Incorporating climate change considerations into forest management practices, such as implementing drought-resistant tree species, adjusting harvesting regimes, and promoting carbon sequestration.

Adaptive Silviculture: Adaptive silviculture involves adjusting forest management practices to respond to changing environmental conditions. By promoting diverse tree species and age structures, forest managers can enhance resilience and adaptability in the face of climate change. Adaptive silviculture also supports long-term sustainability by promoting healthy ecosystems and diverse habitats for wildlife. Adaptive silviculture can promote biodiversity conservation by implementing conservation strategies for peripheral populations, integrating habitat and genetic conservation objectives, and recognizing the value of genetic planning and monitoring. Ex-situ conservation may be necessary for peripheral populations facing extinction threats, but it should be a last resort option due to lower genetic diversity and limited adaptation potential compared to in-situ conservation. Silvicultural interventions for gene conservation may be needed, especially in areas where habitat quality is declining and extinction risks are high (Fady, 2016) . Adaptive strategies, such as assisted migration and assisted gene flow, can support species survival and adaptation in rapidly changing environments. Furthermore, incorporating diverse tree species and promoting genetic diversity can enhance resilience to climate change impacts. Collaborating with stakeholders and sharing knowledge on climate-smart practices can also improve overall forest health and productivity (Tepe and Meretsky, 2010).

Fire Management: Developing fire management plans that balance wildfire prevention, controlled burning for ecological benefits, and community safety measures, considering changing fire regimes due to climate change. These plans should also incorporate strategies for restoring fire-adapted ecosystems and reducing the risk of catastrophic wildfires. By integrating fire management into overall forest management practices, we can better protect forests and the communities that depend on them. Integrated fire management approaches, including prescribed burning and wildfire suppression techniques, are critical for reducing wildfire risks and protecting forest ecosystems. Collaboration between stakeholders and communities is key to effective fire management strategies.

Integrated Pest and Disease Management: Implementing integrated pest management (IPM) strategies to address pest and disease outbreaks, including biological controls, cultural practices, and selective use of pesticides. By taking a holistic approach to pest and disease management, we can minimize the impact on ecosystems and reduce the need for harmful chemicals. This proactive approach can help maintain the health and resilience of forests in the face of changing environmental conditions.

Stakeholder Engagement: Engaging stakeholders, including government agencies, NGOs, industry stakeholders, and local communities, in collaborative decision-making processes to address diverse forest management challenges and priorities. By including diverse perspectives and expertise, stakeholders can collaborate to develop creative solutions that address economic, social, and environmental goals. This inclusive approach can lead to more sustainable and effective forest management practices.

Invasive Species Management: Controlling invasive species through monitoring, early detection, and eradication measures is crucial for maintaining forest health and resilience. Integrated pest management strategies can help minimize the impact of invasive pests on native flora and fauna. Additionally, promoting native species restoration can help out-compete invasive species and restore ecological balance in forests.

Implementing bio-security measures can also prevent the introduction and spread of invasive species in forested areas.

8.4 Conclusion:

Climate change poses significant challenges to forest ecosystems, impacting their structure, composition, and functioning. Sustainable forest management practices, informed by recent research and scientific evidence, are crucial for mitigating these impacts and promoting resilience in the face of changing climatic conditions. By integrating adaptive strategies, restoration efforts, and collaborative approaches, forest managers can enhance ecosystem health and contribute to global efforts to address climate change. Implementing sustainable forest management practices, such as promoting habitat restoration and species conservation, can help maintain biodiversity, enhance ecosystem services, and ensure the overall health of forests.

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