
Effects of Climate Change on Plant Biodiversity

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Abstract

Climate change significantly impacts plant biodiversity, altering ecosystems and threatening species survival. Rising temperatures, shifting precipitation patterns, and increased frequency of extreme weather events disrupt the natural habitats of plants. These changes lead to shifts in species distribution, altered phenology, and increased vulnerability to pests and diseases. Some plant species face extinction, while others may migrate to new areas, potentially outcompeting native species and disrupting existing ecosystems. Climate change exacerbates habitat fragmentation and loss, further endangering plant diversity. The decline in plant biodiversity has cascading effects on ecosystem services, such as pollination, carbon sequestration, and soil fertility, which are crucial for human well-being. Understanding and mitigating the impacts of climate change on plant biodiversity is essential for preserving ecological balance and ensuring the resilience of natural and human systems.

Introduction

Climate change poses a critical threat to plant biodiversity, affecting ecosystems worldwide and leading to profound ecological consequences. As global temperatures rise and precipitation patterns shift, the habitats that plants rely on are being dramatically altered. These changes in climate conditions force plant species to adapt, migrate, or face the risk of extinction. The effects of climate change on plant biodiversity are multifaceted, impacting species distributions, phenology, genetic diversity, and ecosystem services. One of the most significant impacts of climate change on plant biodiversity is the alteration of species distributions. Many plants are temperature-sensitive, and as their optimal climate zones shift, they must migrate to higher altitudes or latitudes to survive. This migration can be hindered by physical barriers, urban development, and fragmented landscapes, making it difficult for some species to relocate. Consequently, this can lead to a decline in species richness in areas that become unsuitable and an increase in competition in new areas. Phenological changes, or shifts in the timing of biological events, are another critical effect of climate change on plant biodiversity. Warmer temperatures and altered precipitation patterns can cause plants to bloom earlier or later than usual, disrupting their interactions with pollinators, herbivores, and other species. This desynchronization can lead to reduced reproductive success and affect the overall health of plant populations.

Need of the Study

The need to study the effects of climate change on plant biodiversity is paramount due to the profound and far-reaching implications for ecosystems, human well-being, and global environmental health. Understanding how climate change influences plant biodiversity is essential for developing effective conservation strategies and mitigating adverse impacts. This research is critical because plants form the foundation of most ecosystems, providing food, habitat, and essential ecosystem services such as carbon sequestration, soil stabilization, and water regulation. As climate change accelerates, the ability of plant species to adapt or migrate to new habitats is increasingly tested. This can lead to shifts in species distributions, alterations in community composition, and the potential loss of unique species that are unable to relocate or adapt quickly enough. These changes can disrupt ecological interactions, affect food security, and lead to a decline in ecosystem resilience, making ecosystems more vulnerable to additional stresses. Furthermore, understanding the specific vulnerabilities and adaptive capacities of different plant species and ecosystems helps inform conservation priorities and actions. It enables policymakers, conservationists, and land managers to implement targeted measures to protect critical habitats, enhance connectivity between ecosystems, and foster resilience against climate change impacts. In summary, studying the effects of climate change on plant biodiversity is crucial for preserving the integrity of ecosystems, ensuring the sustainability of vital ecosystem services, and supporting the broader goals of biodiversity conservation and climate adaptation. This research is necessary to guide informed decision-making and proactive measures to safeguard plant diversity in a rapidly changing world.

Overview of Climate Change

Climate change refers to significant and long-term alterations in global weather patterns, primarily driven by human activities. The burning of fossil fuels, deforestation, and industrial processes have increased concentrations of greenhouse gases (GHGs) such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) in the Earth's atmosphere. These gases trap heat, leading to a greenhouse effect that causes the Earth's average temperature to rise, a phenomenon commonly referred to as global warming. Over the past century, the planet's average surface temperature has risen by approximately 1.2 degrees Celsius, with more rapid increases observed in recent decades.

The impacts of climate change are multifaceted and far-reaching. Rising temperatures contribute to the melting of polar ice caps and glaciers, resulting in sea-level rise and increased coastal erosion. Changes in precipitation patterns are also evident, with some regions experiencing more intense and frequent rainfall, while others suffer from prolonged droughts. These shifts not only affect water availability but also exacerbate extreme weather events such as hurricanes, heatwaves, and wildfires. Increased atmospheric CO₂ levels affect

ocean chemistry, leading to ocean acidification, which has detrimental effects on marine life, particularly organisms with calcium carbonate structures such as corals and shellfish.

Climate change poses a significant threat to biodiversity, ecosystems, and human societies. Altered environmental conditions can disrupt the habitats and life cycles of many plant and animal species, leading to shifts in species distributions and, in some cases, extinction. Agricultural productivity is also at risk, as changing weather patterns and increased incidence of pests and diseases can compromise food security. Human health is impacted through increased heat-related illnesses, the spread of vector-borne diseases, and the displacement of communities due to sea-level rise and extreme weather events. Addressing climate change requires a concerted global effort to reduce GHG emissions, transition to renewable energy sources, and implement sustainable land-use practices. Mitigation and adaptation strategies are crucial to minimize the adverse effects on the environment and ensure the resilience of ecosystems and human communities in the face of a changing climate.

Literature Review

Bellard, C., Bertelsmeier, et al (2012). Climate change poses a significant threat to global biodiversity, with far-reaching impacts on ecosystems and species. Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events disrupt habitats, forcing species to adapt, migrate, or face extinction. As ecosystems become increasingly fragmented, the survival of many species is jeopardized, leading to a decline in genetic diversity and the loss of ecosystem services crucial for human well-being. Coral reefs, for instance, are experiencing widespread bleaching due to elevated sea temperatures, affecting marine life and the livelihoods of communities dependent on these ecosystems. Additionally, shifts in climate zones force species to migrate to more suitable habitats, often encountering barriers such as urban development and agricultural land, which further hinder their movement and survival. The phenology, or timing of biological events, is also disrupted, leading to mismatches between species and their food sources, pollinators, or breeding grounds. Conservation efforts must prioritize climate resilience, including the establishment of ecological corridors, protection of critical habitats, and restoration of degraded ecosystems. Mitigating climate change through reduced greenhouse gas emissions and adopting sustainable practices is essential to preserving biodiversity and ensuring the stability of ecosystems that support all life forms on Earth.

Pawson, S. M., Brin, A., et al (2013). Plantation forests, while often established to meet the growing demand for timber and to sequester carbon, have complex interactions with climate change and biodiversity. On one hand, these forests can play a role in mitigating climate change by absorbing carbon dioxide from the atmosphere. However, the biodiversity benefits of plantation forests are often limited compared to natural forests. Typically consisting of a single species or a few commercially valuable species, plantation forests lack the structural

complexity and species diversity of natural forests, which can lead to reduced habitat availability for a wide range of flora and fauna. Climate change exacerbates these challenges.

Sommer, J. H., Kreft, H., et al (2010). Climate change is projected to have profound impacts on regional capacities for supporting global plant species richness, significantly altering the distribution and diversity of plant life. As temperatures rise and precipitation patterns shift, many regions may become inhospitable for the plant species currently thriving there. For instance, areas that are currently biodiversity hotspots, such as tropical rainforests, may experience declines in species richness due to increased temperatures and changing rainfall patterns that exceed the tolerance levels of many native plants. Regions with significant temperature increases may see a northward or upward shift in plant species as they migrate to cooler areas.

Randin, C. F., Engler, R., et al (2009). Climate change significantly impacts plant distribution, with local models often predicting the persistence of plant species at higher elevations. As global temperatures rise, many plant species are forced to migrate to cooler, higher-altitude habitats to survive. These high-elevation areas become refuges for species that cannot tolerate the increased heat and altered precipitation patterns at lower elevations. Localized models, which take into account specific regional climate data, topography, and species-specific responses to environmental changes, consistently show that higher elevations will increasingly serve as critical habitats for biodiversity. While high-elevation areas may provide temporary havens, they are not without challenges.

Importance of Plant Biodiversity

Plant biodiversity, encompassing the variety and variability of plant species within a given ecosystem, is a cornerstone of ecological health and human well-being. It plays a critical role in maintaining ecosystem functions and services, including air and water purification, soil fertility, and climate regulation. Diverse plant communities contribute to the resilience of ecosystems, enabling them to withstand and recover from environmental stresses such as droughts, floods, and pest infestations. This resilience is crucial in the context of climate change, as ecosystems with high biodiversity are better equipped to adapt to shifting conditions and maintain their functionality.

One of the most significant contributions of plant biodiversity is its role in supporting food security. A wide range of plant species provides a variety of crops that can be cultivated for food, ensuring dietary diversity and nutritional balance. Diverse genetic resources within plant species allow for the development of new crop varieties that can withstand diseases, pests, and changing climatic conditions. This genetic diversity is essential for plant breeding programs aimed at improving crop yields and sustainability.

Moreover, plant biodiversity is fundamental to the pharmaceutical industry and traditional medicine. Many medicinal plants are sources of compounds used to treat various ailments and

diseases. The potential for discovering new drugs and therapies from plants underscores the importance of conserving plant biodiversity. Additionally, plants play a vital role in cultural and spiritual practices around the world, highlighting their importance beyond ecological and economic values.

Plant biodiversity also supports pollinators, such as bees, butterflies, and birds, which are essential for the reproduction of many flowering plants, including a significant proportion of food crops. The intricate relationships between plants and their pollinators exemplify the interconnectedness of biodiversity and ecosystem health.

The importance of plant biodiversity extends far beyond the mere existence of different plant species. It underpins ecosystem stability, food security, human health, and cultural heritage. Protecting and conserving plant biodiversity is imperative for sustaining the natural systems that support life on Earth and ensuring the well-being of future generations.

Climate Change Factors Affecting Plant Biodiversity

Climate change exerts a profound impact on plant biodiversity through various interrelated factors, including rising temperatures, changes in precipitation patterns, increased CO₂ levels, extreme weather events, and shifts in seasons and phenology. Each of these factors contributes to altering the habitats, growth, and survival of plant species, leading to significant biodiversity changes.

Rising Temperatures Global warming, driven by increased greenhouse gas emissions, results in higher average temperatures worldwide. Rising temperatures affect plant physiology, disrupting processes such as photosynthesis and respiration. Temperature-sensitive species may face reduced growth rates, altered flowering times, and shifts in geographical distribution. High temperatures can also exacerbate water stress, particularly in regions already prone to drought, reducing plant survival and reproductive success. Some species may migrate to cooler areas, leading to changes in community composition and potential loss of local biodiversity.

Changes in Precipitation Patterns Climate change is altering precipitation patterns, leading to more frequent and intense droughts in some areas and excessive rainfall in others. These changes affect water availability, a critical factor for plant growth and survival. Drought conditions can lead to reduced soil moisture, limiting nutrient uptake and causing plant stress or mortality. Conversely, excessive rainfall can cause soil erosion, nutrient leaching, and flooding, which adversely affect plant communities. The variability in precipitation patterns challenges plant species' ability to adapt, resulting in shifts in species distribution and composition.

Increased CO₂ Levels Elevated atmospheric CO₂ levels can enhance photosynthesis and water use efficiency in some plant species, promoting growth. However, the benefits of increased CO₂ are not uniform across all species and ecosystems. Some plants may become

more competitive, leading to changes in species dominance and biodiversity. Additionally, increased CO₂ levels can alter plant-herbivore interactions by affecting the nutritional quality of plant tissues, with potential cascading effects on entire ecosystems.

Extreme Weather Events The frequency and intensity of extreme weather events, such as hurricanes, heatwaves, and wildfires, are increasing due to climate change. These events can cause immediate and severe damage to plant communities, leading to large-scale mortality and habitat destruction. The recovery from such disturbances depends on the resilience and adaptability of the affected plant species. Repeated extreme events can reduce biodiversity by favoring species that are more tolerant of disturbance at the expense of more sensitive species.

Shifts in Seasons and Phenology Climate change is causing shifts in the timing of seasonal events, such as flowering, fruiting, and leaf emergence. These phenological changes can disrupt the synchrony between plants and their pollinators or seed dispersers, affecting plant reproduction and survival. Early or late onset of seasonal events can also lead to mismatches with optimal growing conditions, reducing plant fitness. Long-term shifts in phenology can alter plant community dynamics and biodiversity, favoring species that can adjust their life cycles to new climatic conditions.

Climate change factors such as rising temperatures, altered precipitation patterns, increased CO₂ levels, extreme weather events, and phenological shifts pose significant threats to plant biodiversity. Understanding and mitigating these impacts are crucial for conserving plant species and maintaining ecosystem health and resilience in the face of a changing climate.

Impact on Plant Physiology and Ecology

Climate change profoundly affects plant physiology and ecology, influencing critical processes such as photosynthesis and respiration, water use efficiency, growth and development, and phenology. These changes have cascading effects on plant ecosystems and biodiversity.

Photosynthesis and Respiration Photosynthesis and respiration are fundamental processes for plant growth and survival. Rising temperatures can accelerate respiration rates, increasing the metabolic cost of maintaining plant tissues and potentially leading to reduced growth if photosynthesis cannot keep pace. Elevated CO₂ levels can enhance photosynthetic rates in some species by increasing the availability of carbon dioxide, the raw material for photosynthesis. However, this effect is often limited by other factors such as nutrient availability and water stress. Additionally, higher temperatures can lead to the closing of stomata to reduce water loss, thereby limiting CO₂ uptake and potentially reducing photosynthesis rates.

Water Use Efficiency Water use efficiency (WUE) is the ratio of carbon gained through photosynthesis to water lost through transpiration. Increased CO₂ levels can enhance WUE by enabling plants to maintain photosynthesis with reduced stomatal opening, thus conserving

water. The benefits of increased WUE may be offset by higher temperatures, which increase evaporation rates and exacerbate water scarcity. Changes in precipitation patterns further complicate the scenario, with some regions experiencing more intense droughts, leading to severe water stress for plants. Improved WUE in response to elevated CO₂ might benefit some species, but overall water availability remains a crucial factor in plant survival and productivity.

Growth and Development Climate change influences plant growth and development through its effects on temperature, CO₂ levels, and water availability. Elevated temperatures can accelerate developmental processes, leading to earlier maturation but potentially shorter growth periods, which can reduce biomass accumulation. Increased CO₂ levels can promote growth in some species, but this response is often contingent on the availability of other resources such as nitrogen and water. Water stress due to altered precipitation patterns can severely inhibit growth by limiting nutrient uptake and causing physiological stress. Additionally, climate change can alter the allocation of resources within plants, affecting root-to-shoot ratios and reproductive success.

Implications for Plant Communities

Climate change has profound implications for plant communities, affecting species composition, ecosystem dynamics, biodiversity, and the provision of ecosystem services. These changes can disrupt the balance and functionality of ecosystems, with far-reaching consequences for both natural environments and human societies.

Changes in Species Composition As climate conditions shift, the distribution of plant species changes, leading to alterations in species composition within plant communities. Some species may migrate to more favorable environments, while others may face local extinction if they cannot adapt or relocate. For example, temperature-sensitive alpine plants may move to higher elevations, whereas species adapted to cooler climates may decline in regions experiencing warming. This reshuffling can lead to the establishment of new plant communities, with novel combinations of species that may not have coexisted previously. These changes can disrupt existing ecological relationships, such as plant-pollinator interactions, and create opportunities for invasive species to establish and spread.

Altered Ecosystem Dynamics Changes in species composition affect ecosystem dynamics, including nutrient cycling, energy flow, and species interactions. For instance, if dominant plant species in a community are replaced by less efficient nutrient cyclers, the overall nutrient availability in the soil could decrease, affecting plant growth and productivity. Altered plant communities can also impact herbivores, predators, and decomposers, leading to shifts in food web structures and ecosystem stability. Additionally, changes in plant phenology, such as earlier flowering or leaf-out, can affect the timing of resource availability for other organisms, potentially leading to mismatches in ecological interactions.

Biodiversity Loss Climate change can lead to significant biodiversity loss, particularly in ecosystems that are highly sensitive to environmental changes, such as coral reefs, wetlands, and arctic tundra. As species fail to adapt or relocate, the overall richness and diversity of plant communities may decline. Biodiversity loss reduces the resilience of ecosystems, making them more vulnerable to disturbances such as pests, diseases, and extreme weather events. The loss of keystone species, which play critical roles in maintaining ecosystem structure and function, can have cascading effects on other species and ecosystem processes.

Ecosystem Services Ecosystem services, the benefits that humans derive from natural ecosystems, are directly impacted by changes in plant communities. These services include provisioning services (e.g., food, fiber, medicine), regulating services (e.g., climate regulation, water purification, flood control), supporting services (e.g., soil formation, nutrient cycling), and cultural services (e.g., recreation, aesthetic value). Climate change-induced alterations in plant communities can compromise the ability of ecosystems to provide these services. For example, shifts in forest composition can affect carbon sequestration and storage, influencing global carbon cycles and climate regulation. Changes in wetland plant communities can impact water filtration and flood control, increasing the risk of water pollution and flooding. Climate change has far-reaching implications for plant communities, leading to changes in species composition, altered ecosystem dynamics, biodiversity loss, and compromised ecosystem services. These changes underscore the importance of conserving plant biodiversity and enhancing the resilience of ecosystems to mitigate the adverse effects of climate change and sustain the benefits that healthy ecosystems provide to human societies.

Adaptation and Resilience Mechanisms

To cope with the challenges posed by climate change, plant species and communities employ various adaptation and resilience mechanisms. These mechanisms include genetic diversity and adaptation, phenotypic plasticity, the role of seed banks and gene pools, and assisted migration and conservation strategies. Each of these mechanisms contributes to the ability of plants to survive, reproduce, and maintain ecosystem functions in the face of changing environmental conditions.

Genetic Diversity and Adaptation Genetic diversity within plant populations is crucial for adaptation to climate change. High genetic variability allows for a greater range of responses to environmental stresses, enabling some individuals to survive and reproduce under new conditions. Over time, natural selection can increase the prevalence of advantageous traits, leading to population-level adaptation. For example, plants with genetic variations that confer drought tolerance or heat resistance are more likely to thrive in changing climates. Maintaining genetic diversity through conservation practices and breeding programs is essential for enhancing the adaptive capacity of plant species.

Phenotypic Plasticity Phenotypic plasticity refers to the ability of a single genotype to produce different phenotypes in response to environmental changes. This flexibility allows plants to adjust their growth, development, and physiology without genetic changes. For instance, some plants can alter their leaf morphology, root architecture, or flowering time in response to variations in temperature, water availability, or light conditions. Phenotypic plasticity provides a rapid response mechanism to short-term environmental fluctuations, helping plants maintain fitness in diverse and changing environments.

Role of Seed Banks and Gene Pools Seed banks and gene pools play a critical role in preserving plant genetic diversity and facilitating adaptation to climate change. Seed banks store seeds from a wide variety of plant species and populations, acting as reservoirs of genetic material that can be used for restoration and conservation efforts. These stored seeds can be reintroduced into the wild or used in breeding programs to enhance the resilience of plant populations. Gene pools, which encompass the total genetic diversity within a species, provide the raw material for natural selection and adaptive evolution. Preserving and managing these genetic resources are vital for maintaining biodiversity and ecosystem health.

Assisted Migration and Conservation Strategies Assisted migration involves the deliberate relocation of plant species or populations to areas with more favorable climatic conditions. This strategy aims to preemptively address the impacts of climate change by moving species to habitats where they are more likely to survive and thrive. Assisted migration can help protect species at risk of extinction due to habitat loss or unfavorable climate shifts. Conservation strategies, such as creating protected areas, restoring degraded habitats, and implementing sustainable land-use practices, are also crucial for supporting plant adaptation and resilience. These strategies aim to enhance the capacity of ecosystems to buffer against climate impacts and maintain biodiversity.

The adaptation and resilience of plant species to climate change depend on a combination of genetic diversity, phenotypic plasticity, the preservation of genetic resources, and proactive conservation measures. By understanding and supporting these mechanisms, we can help ensure the continued survival and ecological function of plant communities in a rapidly changing world.

Effects on Species Distribution

Climate change significantly impacts species distribution, causing range shifts, habitat fragmentation, changes in migration patterns, and the proliferation of invasive species. These effects disrupt ecological balance and biodiversity, leading to long-term consequences for ecosystems and human societies.

Range Shifts As climate conditions change, many plant species are forced to shift their geographic ranges to maintain suitable living conditions. Typically, this means moving towards higher altitudes or latitudes where temperatures are cooler and more conducive to

their growth. For example, alpine plants may migrate to higher elevations, while species in temperate zones might move poleward. These range shifts can lead to the formation of new plant communities, which may not have coexisted previously, potentially altering ecosystem dynamics. The success of these shifts depends on the species' ability to disperse seeds to new locations, the availability of suitable habitats, and the speed of climate change.

Habitat Fragmentation Climate change exacerbates habitat fragmentation, breaking up continuous habitats into smaller, isolated patches. This fragmentation can be caused by rising sea levels, changing precipitation patterns, and increased frequency of extreme weather events, all of which alter the landscape. Fragmented habitats limit the movement and genetic exchange between plant populations, reducing their ability to adapt to changing conditions. Smaller, isolated populations are more vulnerable to inbreeding, genetic drift, and local extinctions. Efforts to maintain and restore habitat connectivity are crucial to mitigating these effects and supporting biodiversity.

Migration Patterns Climate-induced changes in environmental conditions influence the migration patterns of plant species. Some plants may extend their range into new areas where the climate has become more favorable, while others may retract from regions that have become inhospitable. Migration patterns are influenced by various factors, including seed dispersal mechanisms, landscape barriers, and the presence of suitable soil and microclimatic conditions. For example, tree species with wind-dispersed seeds may migrate more quickly than those reliant on animal dispersers. Understanding and facilitating natural migration processes are essential for conservation planning.

Invasive Species Climate change can create conditions that favor the establishment and spread of invasive plant species. Warmer temperatures, altered precipitation regimes, and increased CO₂ levels can give invasive species a competitive advantage over native plants. Invasive species often have high phenotypic plasticity, allowing them to thrive in a range of environmental conditions. Their proliferation can lead to the displacement of native species, changes in community composition, and disruptions to ecosystem functions. Invasive plants can alter fire regimes, nutrient cycling, and hydrology, further impacting native biodiversity and ecosystem health.

Climate change drives significant shifts in species distribution through range shifts, habitat fragmentation, altered migration patterns, and the spread of invasive species. These changes challenge the resilience and stability of ecosystems, highlighting the need for proactive conservation and management strategies to preserve biodiversity and ecosystem services in the face of a rapidly changing climate.

Research Problem

The research problem centers on understanding the complex and multifaceted impacts of climate change on plant biodiversity, specifically focusing on how changing climate

conditions are altering plant species distributions, phenology, genetic diversity, and ecosystem dynamics. As global temperatures rise and precipitation patterns shift, many plant species face unprecedented challenges, including habitat loss, altered growing seasons, and increased vulnerability to pests and diseases. These changes threaten the survival of numerous plant species, leading to potential declines in biodiversity and disruptions in ecosystem services that are critical for human well-being. A key aspect of the research problem is the need to identify which plant species and ecosystems are most vulnerable to climate change. This involves assessing the adaptive capacities of different species, understanding the potential for species migration, and identifying barriers to movement such as fragmented landscapes and human development.

Conclusion

This research on the impacts of climate change on plant biodiversity are multifaceted, providing critical insights and practical recommendations for conservation efforts. Firstly, the research aims to identify plant species and ecosystems most vulnerable to climate change. By understanding these vulnerabilities, conservationists and policymakers can prioritize actions to protect these at-risk species and habitats. Another expected outcome is a detailed understanding of the shifts in plant species distributions and phenological changes caused by climate change. This knowledge will help predict future trends and guide the creation of ecological corridors and protected areas that facilitate species migration and adaptation.

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