



# Climate Change and Its Impact on Plant Biodiversity and Ecosystem Services

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## Abstract

Climate change created considerable threat to global plant biodiversity and ecosystem services, altering species distributions, disrupting ecological interactions, and compromising human well-being. Climate change threatens plant biodiversity and ecosystem services. Rising temperatures and shifting precipitation patterns alter plant distributions, pushing species to extinction. This impacts ecosystem services like pollination, carbon sequestration, soil formation and nutrient cycling, affecting human wellbeing and food security. Predicted changes in plant communities may disrupt ecosystem functioning, exacerbating climate change. Protecting and restoring ecosystems, promoting sustainable land use, and supporting climate-resilient conservation can mitigate these effects. Preserving plant biodiversity safeguards ecosystem services essential for life on Earth. This review synthesizes present knowledge on the impacts of climate change on plant biodiversity and ecosystem services, highlighting key trends with future directions.

**Keywords:** Biodiversity, Climate change, Plant, Soil, Food security

## Introduction

Based on the publicly available information, climate change is actually happening right now and directly affects biodiversity, requiring organisms to adapt by shifting, modifying their phenotypic cycles, or acquiring new physiological characteristics. By the end of the current century, climate change is probably going to be one of the main causes of biodiversity loss, according to the Millennium Ecosystem Assessment (MEA, 2005). Numerous plants and animals in India are facing serious dangers from climate change, which is also having a noticeable effect on them (Ray *et al.*, 2014). With the aim to adapt to and counteract climate change, it is essential to safeguard and restore healthy ecosystems by way of biodiversity protection, sustainable use, and sustainable land management, which produce tremendous social, economic, and environmental benefits. In addition to natural variability, anthropogenic-caused rapid variations now poses a threat to intensify the biodiversity loss already occurring as a result of other human stresses. Therefore, there is an urgent requirement to compile and share information in order to aid in the creation of a strategic strategy for mitigating and adapting to climate change. This phenomenon has been primarily addressed up to this point in the context of biodiversity stabilizing ecosystems against climatic stressors, meaning that ecosystems' resilience to the effects of climate change is negatively impacted by biodiversity loss. In order to ensure that ecosystem services can be sustained in the face of climate change, it has been suggested that even functionally comparable species can differ in how well they tolerate climatic stresses. The great possibility of such compensatory effects in varied communities protects them against climate stressor-driven change. Such insurance effects of biodiversity are supported by some actual evidence; for instance, diversified grasslands are more resilient to drought and can continue to produce (Wang *et al.*, 2007).

## Impact on Plant Biodiversity

### Shifts in Species Distributions

A species' range refers to the geographic area where it can be found, shaped by factors like climate, soil, and interactions with other species. Over time, processes like adaptive radiation, speciation, and plate tectonics can also impact a species' range. Changes in climate, land use, and other factors can cause a species' range to shift. For example, climate warming can lead to changes in distribution, while land-use changes can drive shifts in multiple directions. Historically, climate change has led to significant changes in species' geographic distributions and

ecosystems. Climate change is driving shifts in plant species distributions, as species track changing climate conditions. This can lead to changes in community composition, ecosystem function, and biodiversity.

- Poleward Shifts: Numerous species are migrating their ranges poleward in response to warming temperatures (Parmesan & Yohe, 2003).
- Upslope Shifts: Plant species are also shifting their ranges to higher elevations, tracking cooler temperatures (Walther *et al.*, 2002).
- Changes in Habitat Suitability: Climate change is altering habitat suitability, leading to changes in plant community composition and structure.

Drivers of Shifts in Species Distributions:

- Temperature: Warmer temperatures are driving poleward and upslope shifts in plant species distributions.
- Precipitation: Changes in precipitation patterns are altering habitat suitability and driving changes in plant community composition.
- CO<sub>2</sub> Concentrations: Elevated CO<sub>2</sub> concentrations can stimulate plant growth, but may also alter plant chemistry and interactions with herbivores (Ziska & Dukes, 2011).

Consequences of Shifts in Species Distributions:

- Changes in Ecosystem Function: Shifts in plant species distributions can alter ecosystem function, including changes in carbon sequestration, nutrient cycling, and water regulation.
- Loss of Biodiversity: Shifts in plant species distributions can lead to loss of biodiversity, particularly for species with narrow ranges or specialized habitats.

### **Changes in Phenology**

Climate change is altering the timing of seasonal events in plants, a phenomenon known as phenology. Rising temperatures and changing precipitation patterns are causing plants to shift their growth cycles, including earlier springs and delayed autumns. This can disrupt delicate relationships between plants and their pollinators, as well as impact ecosystem processes. Warmer temperatures are advancing the timing of budburst, flowering, and leaf-out in many plant species, leading to changes in species composition and ecosystem function. For example, many tree species are leafing out earlier, while some herbaceous plants are flowering earlier in response to warmer winters (Menzelet *et al.*, 2006). These changes can have cascading effects on ecosystems, including altered species interactions and changes in carbon sequestration. Anticipating and minimizing the negative impacts of atmospheric warming on ecosystems requires an understanding of how it affects plant phenology. This can disrupt synchrony with pollinators, herbivores, and other species, impacting ecosystem function.

#### **Altered Timing of Flowering**

Climate change is altering the timing and duration of flowering in plants. Rising temperatures and changing precipitation patterns are causing many species to flower earlier, while others are experiencing delayed or disrupted flowering. This can impact pollinator interactions, seed production, and ecosystem processes. Warmer temperatures are also leading to changes in flower morphology and reduced flower longevity. Shifts in flowering times can have cascading effects on ecosystems, impacting species that rely on specific plants for food and habitat. Understanding these changes is crucial for predicting and mitigating climate change impacts on plant reproduction and ecosystem function. Warmer temperatures are altering the timing of flowering, which can disrupt synchrony with pollinators (Cleland *et al.*, 2007).

#### **Changes in Leafing and Senescence**

The timing of plant senescence and leaf emergence is changing due to environmental change. Warmer temperatures are causing earlier budburst and leaf-out, while delayed autumns are leading to prolonged growing seasons. However, this can also increase vulnerability to frost damage and disrupt ecosystem processes. Changes in leaf phenology can impact carbon sequestration, water cycling, and species interactions. Predicting how ecosystems will react to environmental degradation requires an understanding of these changes. (Richardson *et al.*, 2013).

#### **Drivers of Changes in Phenology**

Species have shifted their ranges throughout Earth's history, driven by factors like glaciation cycles. The Quaternary period saw 20 cycles of glaciation and deglaciation, impacting species distribution. Range shifts are influenced by resource availability, predation, competition, and symbioses. However, new ranges may not always provide suitable conditions, affecting establishment and reproduction. Climate change can disrupt evolutionary processes and initiate new ones. Human activities like land-use change can also drive range shifts, as seen in bird species like the Black-shouldered Kite, which expanded into Spain due to habitat changes.

- Temperature: Warmer temperatures are driving changes in plant phenology.
- Photoperiod: Changes in day length can also influence plant phenology.

- Precipitation: Changes in precipitation patterns can alter plant phenology, particularly in water-limited ecosystems.
- Consequences of Changes in Phenology:
- Disrupted Synchrony: Changes in phenology can disrupt synchrony with pollinators, herbivores, and other species, impacting ecosystem function.
- Changes in Ecosystem Function: Changes in phenology can alter ecosystem function, including changes in carbon sequestration, nutrient cycling, and water regulation.

### **Increased Extinction Risk**

The Western Ghats' native *Madhuca diplostemon* has been rediscovered after 184 years, with only one adult tree and fewer than 30 seedlings surviving (Jose *et al.*, 2023). Conservation efforts, including seed propagation and ex situ culture, are necessary due to limited regeneration and environmental pressures. Another endangered species, *Diospyros crumenata*, faces threats like predation and low seed viability. Around 2,000 seedlings are being raised for reintroduction to boost its survival chances. Globally, 38% of 47,282 assessed tree species are at risk of extinction, mainly due to deforestation, invasive species, diseases, and climate change.

- Climate-Driven Extinctions: Climate change is exacerbating extinction risk for many plant species, particularly those with narrow ranges or specialized habitats (Thomas *et al.*, 2004).
- Loss of Genetic Diversity: Climate change can lead to loss of genetic diversity, reducing the ability of plant populations to adapt to changing conditions (Jump & Peñuelas, 2005).

### **Changes in Community Composition**

Shifts in Dominance: Climate change is altering the dominance of plant species, leading to changes in community composition and ecosystem function (Klanderud & Totland, 2005).

Invasive Species: Climate change is facilitating the spread of invasive plant species, which can outcompete native species and alter ecosystem function (Ziska & Dukes, 2011).

### **Impact on Ecosystem Services**

Ecosystem services, the benefits humans get from nature, are feeling the heat of climate change. The concept's not new, but it's gained traction over the last 30 years. The Millennium Ecosystem Assessment defines these services as benefits society gets from ecosystems, breaking them down into provisioning, cultural, regulating, and supporting services. These benefits fall into two camps: utilitarian (provisioning, regulating, supporting) and non-utilitarian values (ethical, religious, cultural, philosophical). Utilitarian values can be split into direct use values, like consuming fish or enjoying scenic views, indirect use values like water and climate regulation, and option values, like preserving species for future generations (Lele *et al.*, 2013). Climate change is hitting ecosystem services hard, with both direct and indirect impacts. Rising CO<sub>2</sub> levels, land use changes, pollution, and loss of biodiversity are all taking a toll. These changes affect the very foundation of ecosystems, driven by factors like population growth and resource depletion. Understanding climate change's impact on ecosystem services is crucial for adapting and mitigating its effects (De Groot *et al.*, 2002). Key stressors like population growth, overexploitation, urban expansion, pollution, land use change, and climate change are reshaping our ecosystems.

### **Effect on provisioning services**

Provisioning services in cities refer to the tangible goods we get from urban ecosystems, like food, water, and raw materials. Think food grown locally, water for homes, timber, energy from biomass, and plants used for medicine and clothing. Food provision is a big deal, it comes from urban agriculture, fishing, and even hunting. Cities might not be the first thing that comes to mind, but urban farming, green spaces, and smart water management are key to keeping people supplied.

### **Food production**

Rising temperatures are messing with food provision globally. At moderate levels, the impact's manageable, but hit 1°C and things start going downhill. If temperature rise above 2°C, the effects get seriously bad. Expect more competition for food and water resources as climate change bites. Changing rainfall patterns are throwing urban food production and water resources off balance, leading to droughts or floods. This can tank agricultural productivity, hike prices, and leave cities scrambling. Extreme weather's also taking a toll on urban trees and crops, disrupting supply chains, and causing food losses. As climate change bites, food prices rise, hitting low-income households hardest. Farmers might switch crops, which could change what's on urban plates. Agriculture are the interconnected with Animal husbandry, livestock, fisheries and dairy sector. Due to climate change the substantial effects also observed on animal reproduction efficiency, milk quality, feeding pattern, pest and disease outbreak and mortality of animals (Bett *et al.*, 2017).

### **Timber provision**

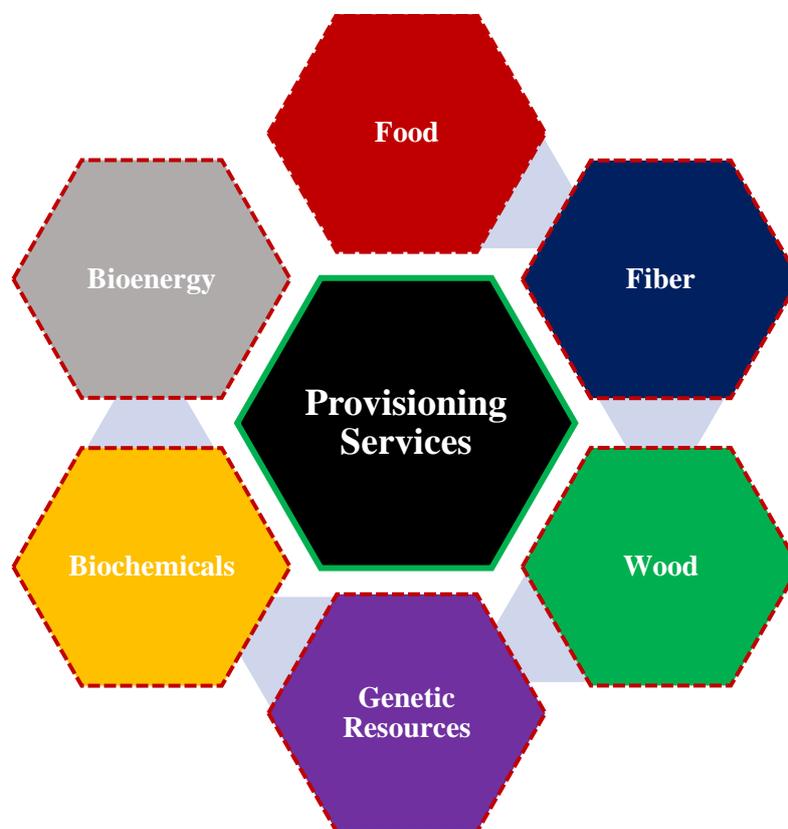
Climate change is throwing a spanner in timber production, affecting developing countries that rely on it for construction and industry. Most timber now comes from plantations, with firewood from plantations expected to hit three-quarters of production by mid-century. Managed forests are a good way to conserve traditional landscapes, but production rates vary wildly across regions.

### **Water provision**

Water is the essential components for humans-domestic use, industry, power, agriculture and sanitation. But climate change is messing with freshwater quantity and quality. Warmer water and more nutrients are breeding algae and pathogens. Nutrient runoff from land use changes and biome shifts isn't helping. Add extreme weather and intensive water use, and water provision's in trouble.

### **Energy provision**

Ecosystems are the ultimate energy storage and source, with biomass like wood and charcoal being a major energy supply globally. In serious climate change mitigation scenarios, biomass energy's role gets even bigger. Plants, especially forests and woody ones, are key for carbon sequestration and storage, making them a hot commodity for short-rotation farming. Furthermore, ecosystems provide other energy heavy-hitters like hydropower and wind energy.



### **Effect on supporting services**

Supporting services, invisible things enchantment that keeps communities running effectively, are essential to urban ecosystems. Consider the water cycle, soil formation, biomass production, nutrient cycling, and oxygen production. Other ecosystem services would not be present without these processes, which are the basis of life.

### **Nutrient cycling and soil formation**

Nutrient cycling and soil formation are the unsung heroes of ecosystems, moving nutrients through the food chain and storing them in biomass. Climate change is messing with these processes, affecting the cycle of carbon, nitrogen, sulfur and phosphorus. These minerals (element) are crucial for the ecosystem services. If nutrient cycling and soil formation slow down, ecosystem services might be threatening and causes loss of soil fertility.

### **Biomass production**

Biomass production is the foundation of ecosystems, relying on photosynthesis to convert light energy into chemical energy. Climate change messes with photosynthesis rates, affecting biomass production and rippling up the food chain. This impacts essential ecosystem services like food, water, and clean air (Colvin *et al.*, 2019). Primary productivity's all about how much biomass primary producers like plants and algae crank out per area and time. The concept is that more diverse producer species are the more efficient biomass conversion. This biomass fuels

everything from food to biofuels, but climate change is hitting biodiversity hard, which in turn hits biomass production.

### **Effect on regulating services**

Ecosystems regulating services, like pollination, flood control and climate regulation, rely heavily on biodiversity and ecosystem health. Climate change and human activities are disrupting this balance, making these services vulnerable to degradation. Think seed dispersal, water quality, and carbon storage are all the under threatening stage.

### **Regulation of climate**

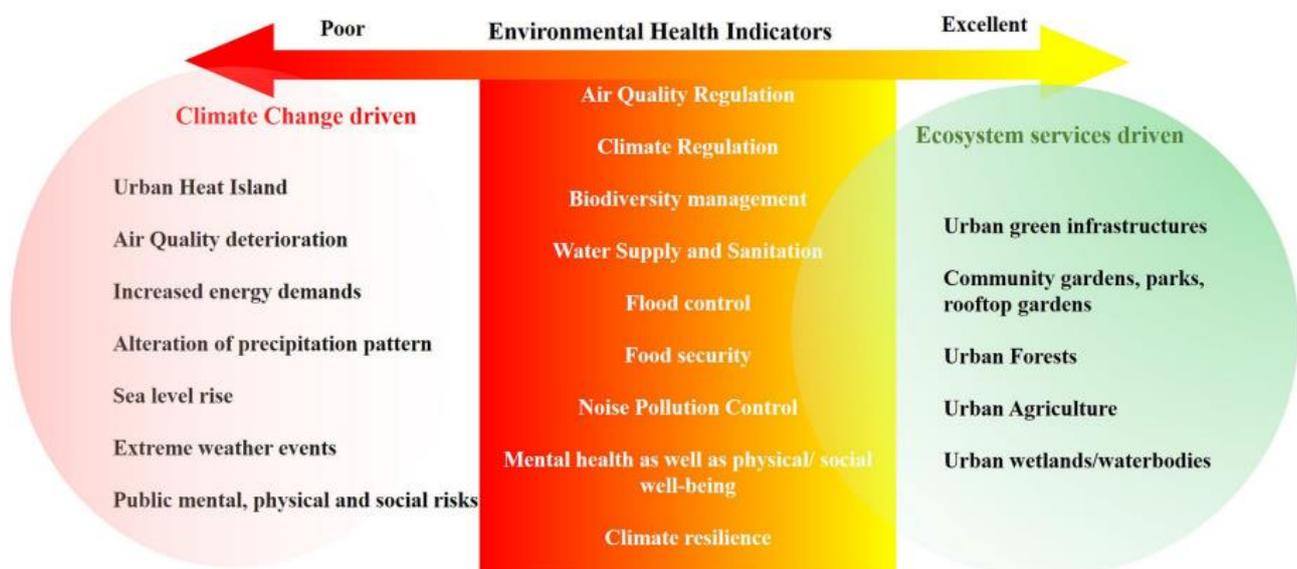
Ecosystems play a crucial role in regulating climate by controlling atmospheric composition, temperature, and weather patterns. They sequester carbon, trap pollutants, and maintain air quality. But climate change's messing with these abilities, affecting ecosystems' capacity to regulate the atmosphere and maintain balance. Still, both land and water ecosystems are helping mitigate climate change by absorbing CO<sub>2</sub> emissions. The rate of respiration slightly increasing with temperature, whereas sequestration rate saturates with rising CO<sub>2</sub> concentration and decrease as temperature fall (Patterson and Coelho, 2009).

### **Regulation of health and wellbeing**

Climate change is reshaping ecosystem services, impacting human health and wellbeing. Ecosystems regulate air and water quality, moderating climate-related health risks like heat stress and disease spread. But rising temperatures and extreme weather disrupt these services, increasing health vulnerabilities. For example, droughts compromise water security, while floods contaminate water sources. Coastal ecosystems like mangroves protect against storms, but sea-level rise threatens these natural barriers. As ecosystems degrade, communities face heightened health risks, emphasizing the need to protect these vital services.

### **Pollination**

Pollination, a crucial ecosystem service is vulnerable to climate change. Many pollinating insects are sensitive to temperature shifts, threatening food security, biodiversity, and ecosystem health. Pollinator decline's been reported globally, linked to climate change, insecticides, disease, and habitat loss. As pollinators and plants respond differently to climate stress, their relationships can break down. Changes in flowering times are already showing climate change's impact. Pollination can be made rarely by introduced/reared species, artificially by human-being, wild animals; but mostly preferred by insects like honeybees, bumble bees, , wasp, butterflies, beetles and birds other invertebrates (Häussleret *al.*, 2017).



**Fig. 1.** Urban ecosystem services and climate change factors interaction (Source: Pandey and Ghosh, 2023)

### **Effect on Cultural Services**

Climate change is reshaping cultural ecosystem services, impacting the spiritual, recreational, and aesthetic values we derive from nature. Rising temperatures and changing landscapes are altering the character of iconic landscapes, threatening cultural heritage sites, and disrupting traditional practices. In many indigenous communities, cultural identity is deeply tied to specific ecosystems. As climate change alters these environments, it erodes cultural knowledge and practices. For example, melting glaciers and shifting seasons disrupt traditional hunting and gathering practices, compromising food security and cultural continuity. Tourism, a significant economic driver for many regions, is also under threat. Coral bleaching, melting glaciers, and changing wildlife

distributions are just a few examples of climate-related impacts that deter tourists and undermine local economies. Beyond economic impacts, climate change affects human wellbeing by altering landscapes with spiritual or aesthetic significance. Sacred sites, whether natural features or cultural monuments, are being degraded or lost, causing profound cultural and psychological distress. Urban ecosystems aren't immune either. As green spaces shrink and urban heat islands intensify, cities lose their cultural and recreational value, impacting mental health and community cohesion. Adaptation strategies are crucial. Protecting and restoring ecosystems can help preserve cultural values, while supporting community-led initiatives can safeguard cultural heritage. Integrating traditional knowledge into climate planning ensures that responses are culturally sensitive and effective. The intertwined nature of cultural and ecological systems means that preserving one often depends on preserving the other. By valuing and protecting cultural ecosystem services, we safeguard not just biodiversity, but the richness of human experience. Nature's spiritual and religious significance is gaining attention, recognized as a key part of cultural ecosystem services. Experts discuss how these values can drive conservation, but there's a risk of oversimplifying complex relationships between spirituality and the environment. Many religious groups and conservationists promote "environmental stewardship", linking faith to conservation efforts. These relationships involve moral, symbolic, and practical concerns, like land claims or resource management.

### **Future prospects**

The future of plant biodiversity and ecosystem services hangs in the balance as climate change intensifies. Rising temperatures and shifting precipitation patterns threaten plant species, potentially pushing many to extinction. This loss will cascade through ecosystems, impacting services like pollination, pest control, and nutrient cycling. Predicted changes in plant communities may alter ecosystem functioning, affecting carbon sequestration, soil health, and water cycles. This, in turn, will impact human wellbeing, food security, and economic stability. To mitigate these effects, we must protect and restore ecosystems, promote sustainable land use, and support climate-resilient conservation strategies. By preserving plant biodiversity, we safeguard ecosystem services essential for life on Earth.

### **Conclusion**

Ecosystem services are affected either directly or indirectly by climate change. These include changes in land use, increased CO<sub>2</sub>, pollution of the air and water, increased exploitation of natural resources, and biodiversity loss. Therefore, in order for adaptation and mitigate the impact, it became crucial that everyone understand the manner in which ecosystem services are affected by climate change. Climate change's messing with ecosystem's supporting services - biomass production, nutrient cycling, soil formation, oxygen production, and water cycle. Without these, the whole ecosystem collapses. But there's hope: adaptation and mitigation strategies can help. Protecting, restoring, and managing ecosystems can reduce climate change's impact, helping people cope with the loss of essential services.

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#### Author Contributions

Krishna M., Ramachandra Naik M., Rajat M. Suseelamma M conceived the concept, wrote and approved the manuscript.

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