



DISEASE-INDUCED CARBON LOSS IN FOREST ECOSYSTEMS

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Abstract:

Forests play a crucial role in the global carbon cycle by absorbing atmospheric carbon dioxide through photosynthesis and storing carbon stock in their biomass and soil. However, this capacity of our forest is increasingly threatened by invasions caused by microbes like fungi, bacteria, viruses, nematodes, and insect pests, alongside abiotic stressors such as drought and pollution. Disease-induced mortality reduces productivity, accelerates decomposition, and prematurely releases the stored carbon, reducing the role of forests as sink of carbon. This review systematically analysed peer-reviewed studies focusing on Indian forests with comparative global insights. Findings show that monoculture, foreign species (exotic species), poor silvicultural practices and climate change increase the severity and carbon emissions. Deadwood turnover, pest-pathogen interaction, and weak monitoring system makes carbon accounting more complicated. Integrated management, growing of resistant genotypes, mixed-species plantation, sanitation felling, and climate-resilient forestry is essential to safeguard carbon storage. In this paper we conclude that it is important to identify and incorporate disease-related mortality into carbon assessments is vital for India's climate commitments and global carbon balance.

Keywords: Invasions, Disease, Ecosystem, Pathogen, Climate-Resilient Forestry, Microbes.

1. Introduction

Forests are vital part of the Earth's carbon cycle. These forests absorb carbon dioxide (CO₂) from the atmosphere and store it in trees, inside the trunk, branches, leaves, and roots. This process is called carbon sequestration. It helps in reducing the amount of CO₂ in the atmosphere, which is important for controlling climate change. Trees absorb CO₂ via photosynthesis and store it as biomass. But when trees die due to ageing, fire, pests, or diseases, the stored carbon is slowly or quickly released back into the air. There are three main ways forests help in carbon sequestration, the most prominent is biological sequestration which involves the use of forest and vegetation to absorb CO₂ during photosynthesis and store it in their biomass and soil. Secondly, Geological sequestration where capturing and storing of CO₂ is done underground in geological formations (not common in forests). A third

method is chemical sequestration, where CO₂ is converted into stable compounds or useful products through various chemical processes. However, Trees are under threat from various pathogens. Pathogens such as fungi, bacteria, viruses, and pests etc. can cause mortality of trees. This in turn results in reduction of their productivity and diminishes their ability to sequester carbon. The carbon which is contained in their biological mass is frequently released back into the atmosphere. In India and around the world, tree diseases like *Shorea robusta*, *Tectona grands*, *Pinus roxburghii*, *Azadirachta indica* and *Acacia nilotica* are becoming more common (1,2). In this review we will learn about how such diseases affect carbon storage, especially in the Indian context.

2. Factors contributing to tree diseases in forest ecosystems

Tree diseases are caused by both living and non-living (Biotic and Abiotic) factors. These diseases reduce forest health, timber quality, biological diversity, and capacity to store carbon. Various researchers like Bakshi (1); Boyce and Bakshi (2) have studied these invasions in detail, highlighting microbes, environmental conditions, management practices, ecosystem dynamics, exotic species, and human influences. Common fungal diseases in India include root rot and butt rot in Sal and Indian Rosewood caused by 'Root Rot' fungus *Polyporus shoreae* and *Ganoderma lucidum* (1).

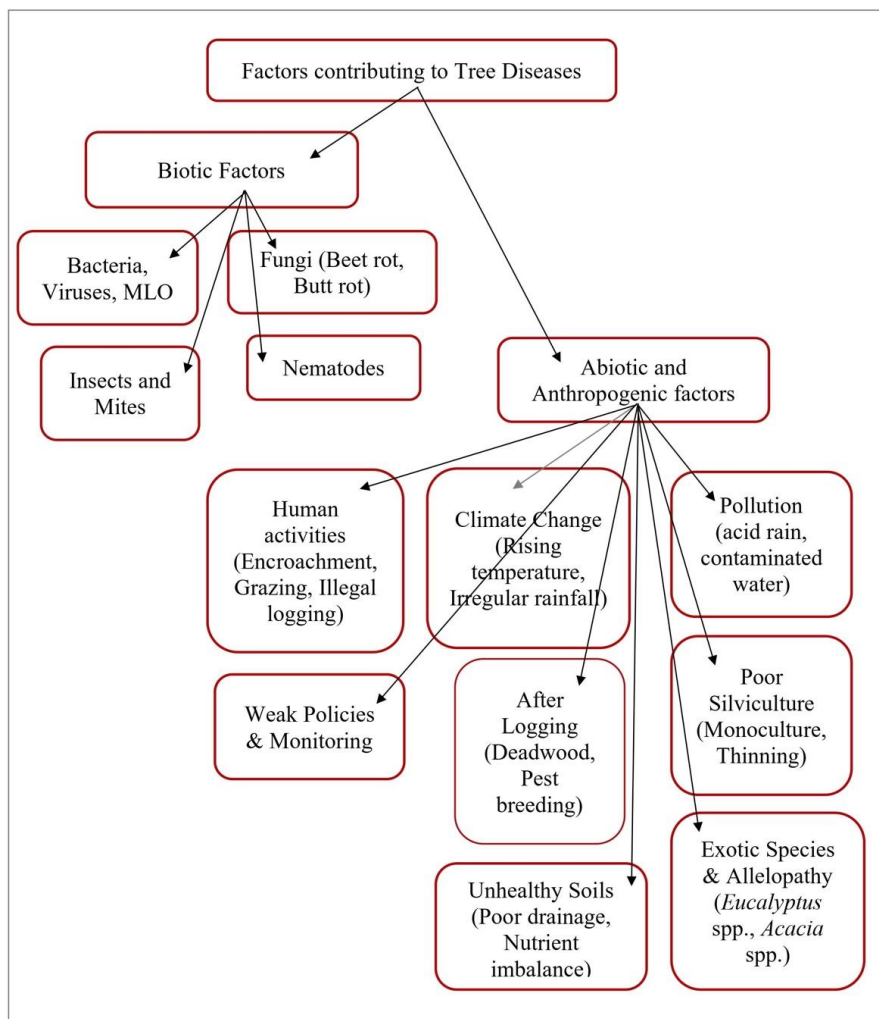


Figure 1: Flow diagram of factors contributing to tree diseases in forest ecosystems

The term Root Rot refers to decaying of roots due to over watering and fungal infections. The term butt rot refers to a disease caused by fungi which attack the base of tree trunk, leading to decay of wood in the context of forest pathology. Climate change like rising temperatures and irregular precipitation makes trees weaker and more prone to diseases (3). Poor 'silviculture' practices such as like monocultures, or improper thinning can make forests more vulnerable to diseases (4). The term Silviculture (latin word) refers to the science of controlling the growth, composition and quality of forest to achieve specific objectives like production of timber, wildlife habitat and many more. The term monoculture refers to a plantation or forest where only one type of tree (single tree species) is grown. The term thinning refers to a process where trees are strategically removed from a forest stand to improve growth and quality of remaining trees. After logging, leftover wood can become a breeding ground for pests and fungi (5,6).

Unhealthy soils with poor drainage or imbalance of nutrients can encourage root diseases like those caused by *Phytophthora* and *Fusarium* (7). In poplar plantations, too much or too little water can lead to disease outbreaks (8). Dead and decaying wood supports biological diversity but can also host pests, bacteria and fungi (9). Planting of non-native (alien or exotic) species like *Eucalyptus* (native of Australia and Tasmania) or *Acacia auriculiformis* (native of Northern Territory and Queensland, Papua New Guinea, and Indonesia) can harm native (indigenous) trees by allelopathy and by changing chemistry of soil and reducing its water availability. This can weaken native trees and make them more prone to diseases (10). The term Allelopathy in trees refers to an ecological phenomenon which involves the release of chemicals by the trees that inhibit or promote the growth of other trees and plants. Figure 1 below shows the flow diagram of factors contributing to tree disease in forest ecosystem.

3. Disease-driven carbon release in indian forest ecosystems

Tree disease is a major threat to forest health and carbon sequestration. The reason behind this is they suppress the growth of trees, enhance mortality, enhance decomposition, and transfer the stored carbon released back into the atmosphere. In Uttar Pradesh and Madhya Pradesh, for instance, the Sal tree (*Shorea robusta*) is critically impacted by root and butt rot (tree diseases) caused by the fungus *Polyporus shoreae* (2). Clear-cutting of Sal forests not only diminishes timber yield and biodiversity but also suppresses the long-term carbon sequestration potential of these forests (4). Dead Sal trees tend to be infested by fungi and insects, perpetuating a cycle of infection; while deadwood promotes biodiversity, over-accumulation enhances disease risk (11), and it promotes more release of carbon as infected tissue decomposes. Chir pine (*Pinus roxburghii*), being a major Himalayan species, is subjected to various biotic and abiotic stresses that in turn reduce its productivity and ecosystem services. Needle blight, which is caused by *Dothistroma septosporum* and *Lophodermium* spp., decreases photosynthesis in Chir pine trees, whereas resin tapping injuries allow invasion of stem canker fungi (such as *Diplodia pinea*), thus causing decreased resin yield and wood rot (1,2). *Armillaria mellea* root rot, especially in infertile soils, induces decline and windthrow, while insects such as *Ips longifolia* weaken trees and hasten tree mortality. These mechanisms in turn lead to premature release of carbon because fallen trees and decomposing biomass return sequestered carbon back into the atmosphere.

Indian rosewood (*Dalbergia sissoo*), having valuable timber and application in agroforestry, is ravaged by root rot (caused by *Ganoderma lucidum*), particularly in flooded soils (1,4). The symptoms of the disease include yellowing of leaves, defoliation, dieback, and tree mortality, with the timber becoming useless due to internal decay (Sharma et al. 1983). Since monoculture plantations have poor resilience, pathogens remain in soils and infect quickly (10).

Death of rosewood trees erodes carbon storage in natural and agroforestry systems. The decomposition of their (rosewood trees) infected biomass hastens the release of carbon. Preventive measures like enhancement of drainage, planting of mixed species, and utilisation of resistant genotypes enhance their productivity as well as conserve carbon stock. Margosa (*Azadirachta indica*) is also affected by disease-related loss of carbon, and vascular wilt due to *Fusarium* spp. results in yellowing and wilting of leaves, and sap-sucking scale insects (*Aonidiella orientalis*) lead to weakening of trees (13,14). Weakened tree vigour reduces the accumulation of biomass, but pest damage increases susceptibility to other infections, resulting in premature death and carbon emission as a result of decaying material. Gum Arabic trees (*Acacia* spp.), which are planted for soil enrichment and livelihood, frequently experience dieback on waterlogged or saline soils. Root-attacking microbes like *Fusarium* spp. and *Phytophthora* spp. and stem borers like *Xystrocera festiva* cause damage to the roots and stems, decline carbon sequestration and increase mortality (1). Seed borers (*Bruchidius albizziae*) weaken the regeneration (15) by inhibiting the ability of the *Acacia* stands to restore the carbon stock. Photosynthetic capacity in Eucalyptus trees is decreased due to leaf blights by *Teratosphaeria destructans* and *Mycosphaerella* species. Damping-off by *Pythium* spp. and *Rhizoctonia solani* kills seeds in nurseries (1). Root and stem rots by *Armillaria mellea* and *Ganoderma philippii* and wilts by *Ceratocystis fimbriata* result in extensive canopy mortality and stand collapse (2). Abiotic stresses such as drought and infertile soils exacerbate infection further lowering their productivity because each tree mortality is a direct decrease in carbon storage (3,16). Teak (*Tectona grandis*) is a top tropical hardwood, harmed by vascular wilt (possibly due to *Ceratocystis fimbriata*), resulting in yellowing, wilting, and stem discolouration. These infections quickly propagate in monocultures, which causes extensive carbon stock loss. Moreover, the teak defoliator *Hyblaea puera* is seen prior to monsoon, causing leaf stripping and stunted growth (1). Widespread infection lowers carbon fixation and, in severe cases, kills trees and releases stored carbon through decomposition.

Poplar (*Populus deltoids*) is grown extensively for paper, plywood and energy and is particularly vulnerable due to monoculture cultivation. Root rot in poplar is caused by species of *Phytophthora* and *Fusarium* that in turn results in a decrease of carbon stock and poor economic productivity. Poorly dried soil results in general mortality, while stress due to drought reaches the trees and proceeds to the dieback (12). *Ceratocystis fimbriata* and *Botryodiplodia theobromae* result in stem canker and decrease of wood quality (Boyce, Bakshi 1959). *Melampsora* rust and *Alternaria alternata* blight are foliar diseases which decrease photosynthesis, leading to defoliation and poor growth. As the poplar tree is extensively used in agroforestry, its defoliation decreases not only economic productivity but also carbon storage capacity. Australian pine (*Casuarina equisetifolia*) planted in coastal shelterbelts and fuelwood tree plantations is threatened by wilt caused by *Fusarium oxysporum* f. sp. *casuarinae*, which in turn inhibits vascular transport and causes mortality. The *Ganoderma* and *Armillaria* root rot is prevalent in saline or poor nutrient soil (7), whereas air or sand mechanical injury brings about entry for opportunistic fungi. Disease mortality in *Casuarina* spp. not only diminishes carbon sequestration but also diminishes its contribution to coastal protection, enhancing susceptibility due to erosion and hurricane development. Figure 2 below shows the graphical diagram of disease-driven carbon release in forest ecosystems.

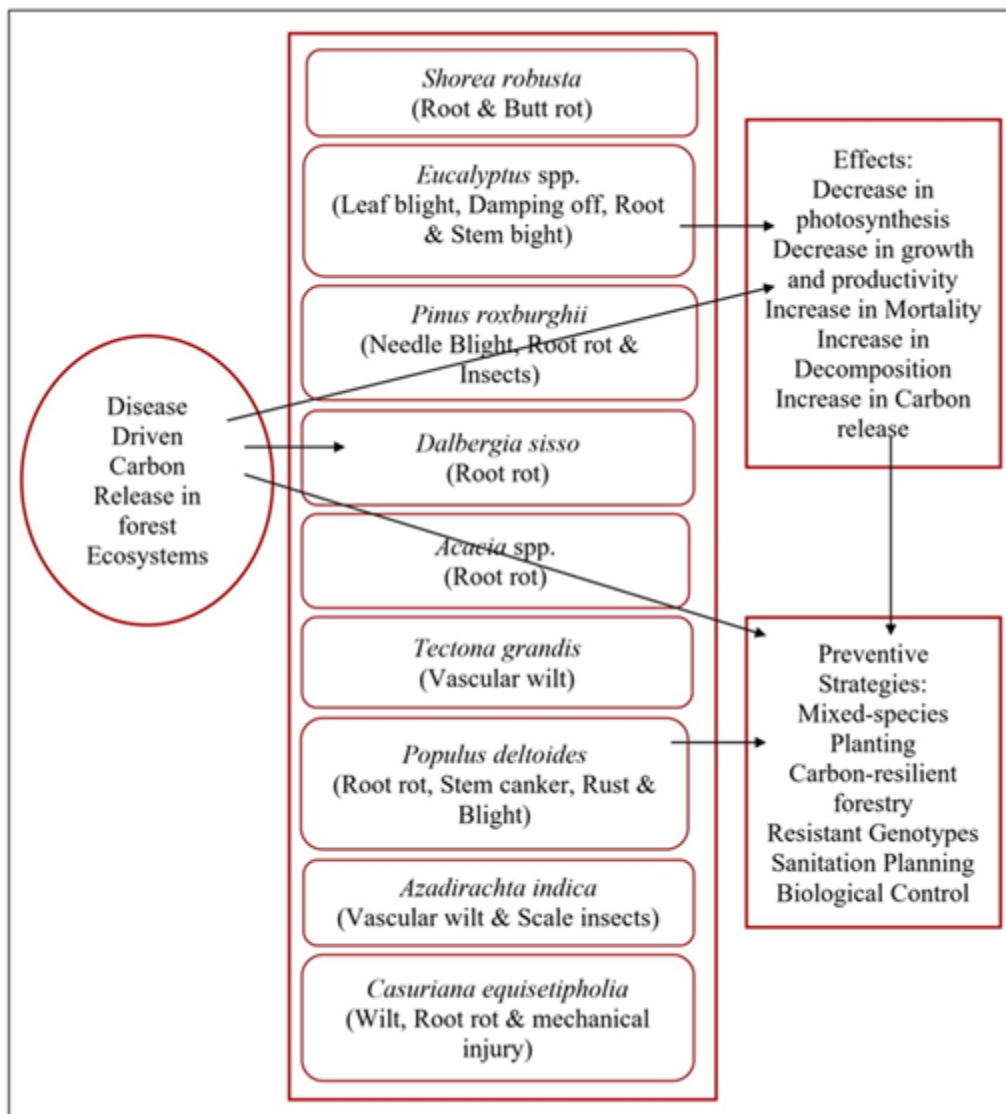


Figure 2: Graphical Diagram of Disease-driven Carbon Release in Forest Ecosystems.

Collectively, rots, wilts, blights, cankers, and insect phase changes terminate the potential of forests by lowering photosynthetic effectiveness, slowing growth, and killing carbon by lowering growth rates. Severe infections lower carbon fixation and, in extreme infestation, kill trees, releasing stored carbon through breakdown. Poplar (*Populus deltoides*), which is grown intensively for paper, plywood, and energy, is particularly susceptible due to monocultural cultivation. Root rot, which is caused by *Phytophthora* and *Fusarium* spp., induces widespread mortality in poorly drained soils Bakshi (1), whereas drought stress makes these trees susceptible to cankers and dieback (12). Stem cankers are induced by *Ceratocystis fimbriata* and *Botryodiplodia theobromae* which results in lowering of quality of timber (2). Foliar diseases like *Melampsora* rust and *Alternaria alternata* blight inhibit photosynthesis, causing defoliation and stunted growth. Australian pine (*Casuarina equisetifolia*), cultivated in coastal shelterbelts and fuelwood plantations is menaced by wilt (induced by *Fusarium oxysporum* f. sp. *casuarinae*), which causes death by impeding vascular transport. Root rot from *Ganoderma* and *Armillaria* spp. is prevalent in saline or poor soils (7), and mechanical injury from wind or sand opens the way to opportunistic

fungi. Mortality caused by disease not only diminishes carbon sequestration but also compromises its coastal protective function by making it more susceptible to erosion and storm surges.

4. Carbon loss pathways and mitigation in disease-induced tree mortality

To manage the impact of tree disease on forest carbon, understanding of how deadwood turnover works is important. To keep forests acting as carbon sinks, we must monitor the health of trees and include multiple impacts in the accounting of carbon. Studies like Heath *et al.* (17) and Ward (18) say that forest carbon estimates should include tree mortality rates, decay stages of deadwood, and species-specific decomposition rates. For monitoring of carbon stock, a national tree disease surveillance system should be developed, especially for sensitive tree species like Sal, Margosa, Pine, and Indian Rosewood tree. We have observed that improper forest management practices significantly increase the spread of tree diseases. Plantation of monocultures increases vulnerability of trees, while poor sanitation and excessive deadwood provide breeding grounds for pathogens. Exotic species often alter the chemistry of soil and weaken the nearby growing native flora by making them susceptible to pathogens. Improper harvesting of trees and unmanaged deadwood accelerate emission of CO₂ through rapid decay and risk of forest fire.

Accounting of carbon stock often ignores the role of disease-related mortality of trees and their decomposition. Tools like remote sensing, Geographical Information System (GIS), plantation of mixed-species, sanitation felling, and climate-resilient forestry strategies, and participatory forest management offer promising solutions. By complementing both forest conservation and sustainable management, the International Union for Conservation of Nature (IUCN) and the World Wide Fund for Nature (WWF) have coined the term forest landscape restoration in 2000 as a framework for managing landscapes Bonn Challenge (2025). Ultimately, if we protect forest health from biotic and abiotic stressors, we can safeguard their role as long-term carbon sinks.

Conclusion

Finally, this review highlights that tree diseases represent a significant but often identified passage of carbon loss in the forest ecosystem. Pathogens such as fungi, bacteria, nematodes, insects, and abiotic stress not only reduced tree growth and productivity, but also accelerated mortality and decomposition which led to premature release of the stored carbon. Indian references, with their diverse forest types, indicate how monoculture, poor silviculture practice, exotic species and climate change intensifies these dangers. The study of tree diseases clearly shows that the disease-induced mortality disrupts long-term carbon storage and weakens the flexibility ecosystem. For the protection of forests as a carbon sink, integrated strategies require-alternative system, resistant genotypes, mixed-species planting, sanitation felling, and climate-resilient forestry practices. Ultimately, protecting forest health from pathogens is not only necessary for conservation of biodiversity but it is also important to maintain terrestrial carbon balance and climate mitigation.

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