

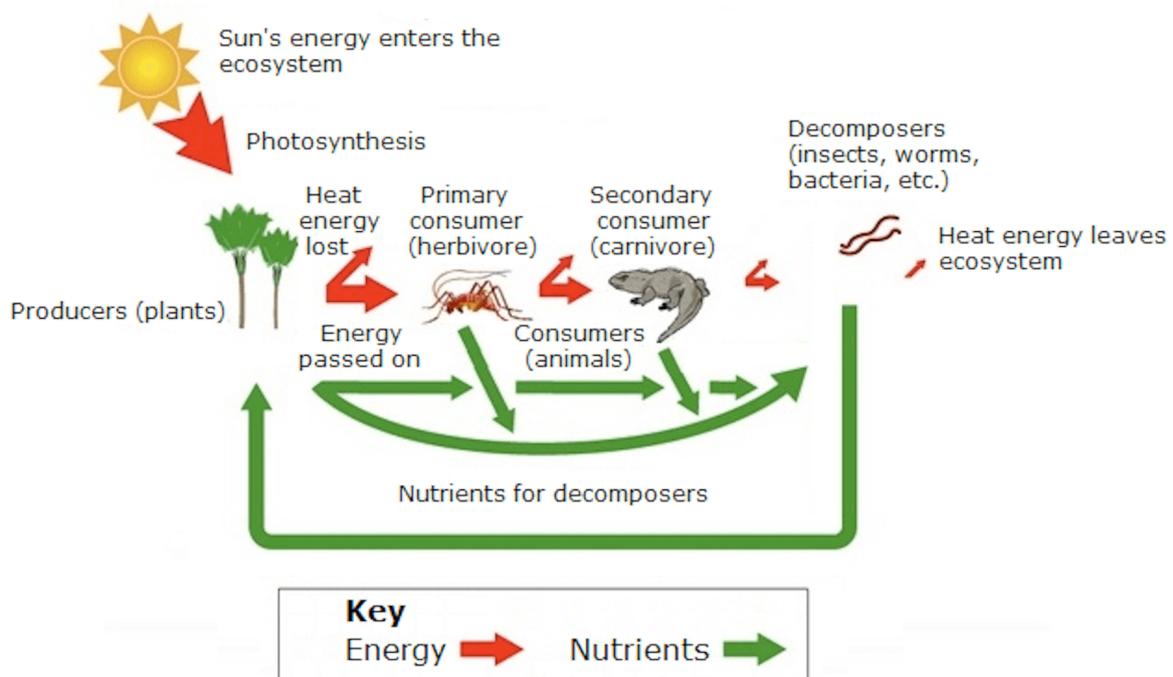
Different layers can have different physical and chemical properties, affecting how precipitation and nutrients are distributed and cycled through the forest.

2. Forest ecology

☞ Reminder

In ecology, an **ecosystem** is broadly defined as a biotic community together with its physical environment, functioning as a unit through the flow of energy and cycling of materials. For example, Yu et al. (2021) describe an ecosystem as “a fundamental organizational unit of the biosphere in which biological communities interact with their non-biological environment through energy flows and material cycles”. Likewise, Loreau (2010) defines an ecosystem as “the entire system of biotic and abiotic components that interact in some place,” emphasizing that an ecosystem includes all plants, animals, microbes, soils, water, atmosphere and other factors linked by ecological processes.

A simple ecosystem



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In practice, ecosystems are dynamic systems: solar energy enters via photosynthesis, nutrients are recycled through food webs and decomposition, and the structure of the community can change over time (succession). This definition applies at many scales (from a pond to a forest to a desert), but always involves the key features of living communities interacting with their abiotic surroundings under the laws of ecology.

2.1 Forest Ecology

Forest ecology is the subfield of ecology that focuses on forest ecosystems – that is, on communities of trees and associated plants, animals, microbes, and their abiotic environment. It seeks to understand

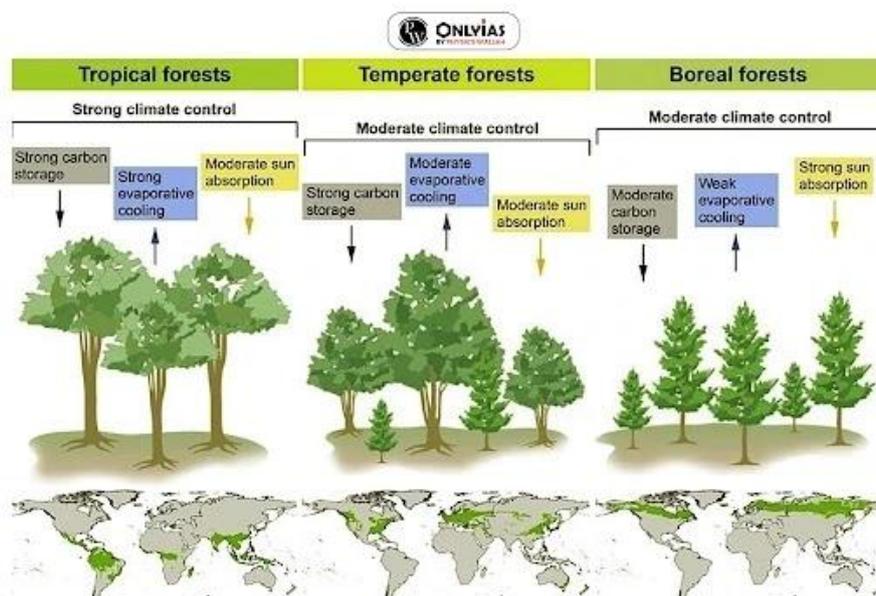
the patterns and processes that control the distribution, structure, composition, and functioning of forests. Forest ecologists study how forests develop over time (succession), how nutrients and water cycle through trees and soils, how forests respond to disturbances (fire, pests, storms) and management, and how interactions among species (competition, mutualism, predation) shape forest dynamics. In essence, forest ecology treats forests as complex systems and asks how the many components of a forest (from roots and fungi in the soil to canopy trees and understory plants) interact with each other and with climate and other physical factors.

The scientific significance of forest ecology is very high because forests play a major role in the Earth’s biosphere. For example, Maréchaux et al. (2021) note that forests cover roughly 30% of the Earth’s land surface, store almost half of all terrestrial carbon, and are habitat for more than half of the planet’s known species. These figures underscore why understanding forests is critical: forests provide vast ecosystem services to humanity and the climate system. As Liu et al. (2021) emphasize, forests (the “lungs of the Earth”) are key regulators of the global carbon cycle and climate; they supply timber and fuel, regulate water and climate, prevent soil erosion and flooding, and harbor rich genetic and species diversity.

In practical terms, forest ecology informs climate-change mitigation (via carbon sequestration in forests), biodiversity conservation, sustainable forestry and land management. Because forests influence climate, water resources, and biodiversity on a global scale, the science of forest ecology is crucial for predicting the effects of environmental change and guiding conservation and policy decisions.

2.2 Forest Ecosystems Across Biomes (Tropical, Temperate, Boreal)

A **forest ecosystem** may be defined as any ecosystem dominated by trees and woody vegetation, together with its associated plants, animals, microbes, soils, and climate. Across the globe, forest ecosystems are commonly classified into three broad types – *tropical*, *temperate*, and *boreal* – each with distinct climates and communities, but all sharing the core ecosystem processes of energy flow and nutrient cycling. In all cases, a forest ecosystem includes the living organisms (producers, consumers, decomposers) and the nonliving environment (soil, water, air) interacting as a functional unit. The dominant tree species and ecological dynamics, however, depend on latitude, temperature, and precipitation patterns.

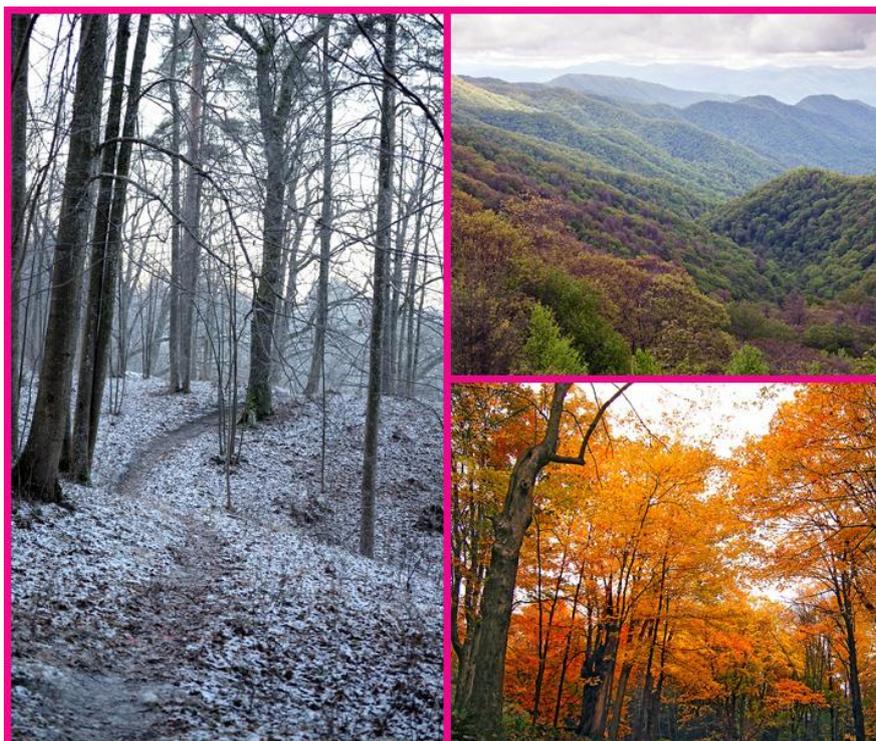


- **Tropical Forests:** Tropical rainforests occur near the equator in warm, wet climates. These forests have year-round growing conditions, extremely high biodiversity (rich communities of trees, plants, insects, birds, mammals, etc.), and very dense, multi-layered canopies. Tropical forests are highly productive and store large amounts of carbon aboveground. Because tropical regions often experience intense rainfall and sunlight, decomposition and nutrient cycling are rapid.



Recent studies (e.g. Forzieri et al. 2022) indicate that tropical forests are already showing significant declines in resilience under climate change, likely due to increased drought stress and climate variability.

- **Temperate Forests:** Temperate forests occupy mid-latitudes with four seasons (cold winters and warm summers). They can be deciduous (e.g. eastern North America, Europe) or evergreen (e.g. Pacific Northwest), and host moderate species diversity compared to the tropics. Understory light availability, soil fertility, and seasonal climate strongly influence these forests. Temperate forests have intermediate productivity and a mix of tree genera. Forzieri et al. (2022) similarly find that temperate forests are experiencing a significant decline in resilience with recent climatic anomalies, suggesting increased vulnerability to drought and extreme events.



- **Boreal Forests (Taiga):** Boreal forests dominate high northern latitudes (Canada, Russia, Scandinavia) and are characterized by cold climates, short growing seasons, and coniferous trees (spruce, pine, fir). Biodiversity is lower than in tropical or temperate forests, and soils tend to be colder and less fertile (often with permafrost). Boreal forests store enormous carbon stocks in biomass and peat. Interestingly, recent global analyses show that many boreal regions have seen an *increase* in ecosystem resilience in the past decades, likely because warmer temperatures and higher CO₂ levels can extend the growing season and stimulate growth. However, local boreal forests may suffer severe disturbances (e.g. wildfires, pest outbreaks) that can rapidly change forest structure.



- ❖ **As a conclusion**, and despite these differences in climate and species, all forest ecosystems perform similar ecological functions – they fix carbon via photosynthesis, cycle nutrients through plant and soil processes, regulate hydrology and climate, and undergo succession and disturbance regimes. A unified definition is that a forest ecosystem is any tree-dominated ecosystem functioning as an integrated community–environment unit, with tropical, temperate, and boreal forests representing variations on this theme adapted to their climatic zone.

2.3 Major Factors Influencing Forest Ecosystems

Forest ecosystems are shaped by many factors, but in the current era four interacting drivers are especially important: **climate change**, **biodiversity loss**, **deforestation (land-use change)**, and other direct **human impacts**. These forces often act together, creating feedbacks that can degrade forest structure and function. For instance, Loreau (2010) notes that anthropogenic pressures like habitat destruction, fragmentation, pollution, climate change, **resource overexploitation**, and biotic homogenization affect species and ecosystems simultaneously. Likewise, Liu et al. (2021) list climate change, extreme weather, insect invasions, fire, and deforestation as key disturbances that have already damaged forests worldwide. In summary, human activities are increasing the frequency and intensity of stressors on forests at the same time that forests' natural resilience is being challenged. Key factors include:

- **Climate Change:** Global warming and associated shifts in precipitation and storm patterns are major forces altering forests. Higher temperatures and changing rainfall regimes can stress trees (e.g. through increased drought frequency), shift species' suitable ranges, and change disturbance regimes (fires, storms). For example, satellite analyses show that tropical and temperate forests are already experiencing *declines in resilience* that correlate with water stress and climate variability. Climate change can also exacerbate **pest outbreaks** and ice/wind damage. As Loreau (2010) points out, climate change is likely to cause additional biodiversity loss, and in turn biodiversity loss will reduce ecosystems' ability to resist climate impacts. Thus, warming and extreme events are pushing many forest ecosystems toward critical thresholds (tipping points).



- **Biodiversity Loss:** Reductions in species and genetic diversity weaken forest ecosystems. When tree and animal species disappear or become rare (due to hunting, disease, fragmentation, etc.), key processes like pollination, seed dispersal, and nutrient cycling can be impaired. Loreau (2010) emphasizes that losing biodiversity can decrease an ecosystem's resistance and resilience, making forests less able to buffer disturbances such as climate extremes. Empirical studies confirm that forests with lower plant diversity often have reduced productivity and stability, and become more prone to invasion and collapse. In summary, maintaining biodiversity is crucial to sustain forest function; its loss acts synergistically with other stresses to degrade forests.



- **Deforestation and Land-Use Change:** The direct removal of forests for agriculture, logging, or development is one of the single greatest impacts on forest ecosystems. Cutting or burning

trees not only releases stored carbon (driving climate change) but also fragments habitats and interrupts water and nutrient cycles.

- Liu et al. (2021) report that selective logging and deforestation have significantly lowered canopy cover and soil protection, thereby reducing forest resilience. Habitat loss forces forest species into smaller fragments, often reducing biodiversity and enabling invasive species. Deforestation also alters the regional climate and hydrology (e.g. reducing rainfall). In short, land-use change converts dynamic forest ecosystems into degraded landscapes or agricultural lands, fundamentally altering ecosystem services.
- **Other Human Impacts:** Beyond deforestation, numerous human actions influence forests. These include overharvesting of timber or non-timber forest products, pollution (acid rain, ozone, nitrogen deposition) that stresses vegetation, road-building and fragmentation, and introduction of invasive species. For example, Loreau (2010) lists overexploitation of resources and biotic homogenization as major pressures on ecosystems. Changes in fire management (suppression or excess burning) can also disrupt natural disturbance regimes. Each of these factors – alone and in combination – can lead to nutrient imbalances, soil degradation, and altered species interactions. Collectively, they increase forest vulnerability by compounding the effects of climate change and biodiversity loss.

In summary, current research shows that forest ecosystems are increasingly affected by global changes. Climate change and its feedbacks, combined with habitat destruction and biodiversity loss, are pushing many forests into new regimes. Understanding these drivers and their interactions (a central goal of forest ecology) is critical for predicting and managing forest change in the Anthropocene.

3. Forest dendrology

3.1 Introduction to Dendrology

Def. –Dendrology (also called **xylology** or forest dendrology) is the scientific study of **woody plants** – trees, shrubs and lianas – with an emphasis on their taxonomy, characteristics and uses.

As a specialized branch of systematic botany and forestry, dendrology focuses on identifying and classifying forest trees and other woody species. Historically it also encompassed the natural history of trees in a region, but today ecological aspects (e.g. tree-environment interactions) are treated separately under ecology.

In practice, dendrologists use morphological keys (based on leaves, bark, buds, fruits, etc.) to distinguish species. This knowledge is **vital for forestry and conservation** – for example, selecting the best tree species for timber or reforestation, recognizing invasive species, and protecting rare or endangered trees. In short, dendrology provides the foundational tree identification skills and taxonomic framework used in forestry, ecology and natural resource management.

3.2 Forest Species Categories

Forest plants are often classified by their origin and behavior in an ecosystem. Key categories include: