Biomes of the Future: Temperate Coniferous and Broadleaf Forests

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1. Description of biome

The temperate coniferous and broadleaf forests constitute a biome distinguished by their moderate temperatures and distinct seasons. Seasonal changes introduce fluctuations in temperature, precipitation, and snowfall, thereby influencing the distribution of flora and fauna (Gilliam, 2016). The flora of the temperate coniferous forest biome is dominated by needle-leaved, evergreen trees like pine, spruce, fir, and larches. In contrast, the flora of the temperate broadleaf forest biome is dominated by broadleaf, deciduous trees like oak, maple, birch and beech (Currie, 2008). The fauna inhabiting temperate coniferous and broadleaf forests exhibit rich diversity, including mammals like deer, various bird species, amphibians, reptiles, and insects (Caviedes, 2017). Some temperate forests border rivers, streams, or lakes, providing habitat for fish and serving as an additional habitat and water source for other wildlife. However, the temperate coniferous and broadleaf forests also differ in terms of dominant species, biodiversity, the presence of amphibians and reptiles, and the specially adapted invertebrates, reflecting their distinct ecological characteristics. The soils in temperate coniferous forests tend to be highly acidic due to the conifer litter and nutrient-poor, while in temperate broadleaf forests, they are slightly acidic and often more fertile. (Adams, M. B., 2019). Currently, temperate forests are found in various temperate regions of the world, primarily in North America, Eurasia, New Zealand, Australia, parts of Asia, Europe, and South America (Rawat, 2022; Gilliam, 2016).

2. Description of each organismal group within the biome

Temperate coniferous and broadleaf forests are distinct types of temperate ecosystems found across the globe. Coniferous forests are characterized by dominant coniferous trees like pine, spruce, fir, cedar, and hemlock, which have needle-like leaves and cones (Korboulewsky et al., 2021). Under their canopy, lush ferns, mosses, and occasional shrubs thrive due to limited sunlight. The forest floor is often covered with fallen needles, cones, and fungi, contributing to nutrient cycling. These forests support a variety of wildlife adapted to their dense canopies, including deer, elk, owls, and songbirds. In temperate broadleaf forests feature deciduous trees such as oak, maple, beech, birch, and hickory, known for their broad, seasonal leaves (Silander, 2001). The understory is rich with wildflowers, ferns, and shrubs like rhododendrons and witch hazel, making the most of seasonal sunlight (Awad et al., 2019). Fall brings a carpet of fallen leaves, enriching the soil with nutrients, alongside herbaceous plants like ferns and mosses. The diverse plant life in these forests sustains a wide range of wildlife, including deer, raccoons, squirrels, rabbits, and a multitude of bird species, as well as abundant insects and amphibians (Silander, 2001). Both forest types play vital roles in biodiversity and ecosystem services, from carbon sequestration to wildlife habitat provision.

Avian fitness and speciation on a global scale is relatively prosperous in a time of global biodiversity loss. The success of avian species in temperate forests shows a linear relationship

between age of tree species, number of tree species and tree size correlated to more bird species and population counts (Poulsen, 2002). While more static factors affect avian fitness in these regions, such as latitude or elevation, which seemed to facilitate the large avian biodiversity we see today. It is in large part the avians ability to migrate between temperate and tropical regions that facilitate biodiversity to avians that have a high individual plasticity (Charmantier & Gienapp, 2013). While some regions are being more affected by temperature change, the force that diminishes the quality of temperate ecosystems and lowers avian fitness is lesser than the ability for avians to migrate and adapt to other more preferable latitudes. This is why globally we see an increase in avian biodiversity yet a lowering of biodiversity in this biome (Cox, 1985).

Temperate forests provide habitats for diverse fish species by way of various water systems such as lakes, rivers, and streams. This is evident on the Tibetan Plateau in southwest China, a region made up of predominantly temperate forest. Fish lineages on the Tibetan Plateau consist of three major groups: Triplophysa, Siluriformes, and Schizothoracines (Ma et al., 2015). Common species in this area include cavefish, zebrafish, loaches, snow trout, and various catfish. Due to the higher altitudes of many temperate forests, the fish must be adapted to the subsequent conditions and hypoxia that comes with higher elevations. This can be seen in the most common genus of fish on the Tibetan Plateau, Triplophysa, as there is recent evidence of their accelerated evolution and better response to hypoxia when compared with that of fish living at lower altitudes (Wang et al., 2015). Other regions of temperate coniferous and broadleaf forests contain similar species of fish as well as species unique to the area. Various species of catfish and trout can be found in the Southern Appalachian region, but the central stoneroller is an important fish unique to North America (Simbeck, 1990). The diverse species of fish in all regions of temperate forests provide ecological balance by serving as a primary food source for many larger animals and even humans.

The temperate coniferous and deciduous forest biomes boast considerable species richness and diversity, featuring a wide array of mammalian taxa (Currie, 2008). Examples of these mammals include rodents, ungulates, carnivores, lagomorphs, bats, and small mammals, all of which significantly enhance the biodiversity of these ecosystems. Within the mammal group, rodents typically stand out as the most numerous and varied, they have complex effects on the environment as herbivores and seed dispersers in the ecosystem (Li, 2023). Meanwhile, ungulates are important prey for predators, playing a crucial role in shaping vegetation dynamics through herbivory (Kuijper, 2014). Bats, abundant and diverse in this biome, hold a crucial ecological position as insectivores, actively contributing to insect control and facilitating pollination (Beilke, 2023). The biodiversity found within temperate forests results from the intricate interactions among various mammalian taxa, each playing a role in shaping the ecological functioning and overall diversity of these ecosystems.

Amphibians, especially those of the salamander family, fulfill several important ecological functions within the temperate forest biomes. The terrestrial woodland salamanders of Plethodontidae are among the most abundant vertebrate animals within temperate forests, mostly

living within specific moist microhabitats in the undergrowth, leaf litter and coarse woody debris (Baecher & Richter, 2018; O'Donnel et al., 2014). Within these microhabitats, salamanders act a key top-down predator species by preying upon detritivores and fungivores, which in turn regulates the rate of litter decomposition, the makeup of bacteria and fungi within the soil and leaf litter, which in turn impacts the rates of nutrient and energy cycling within the forests (Hickerson et al., 2017). The abundance of salamanders also provides a key prey resource for a variety of predatory species including invertebrates like spiders and centipedes, other amphibians and snakes, mammals like shrews and racoons, and birds including jays, thrushes, hawks, and owls (Semlitsch et al., 2014). Frogs, while less numerous in species type and overall population within temperate forests also provide many of the same ecological functions, but with their balance between terrestrial and aquatic life history they also provide movement of nutrients and energy between the terrestrial and aquatic systems of the forests (Baecher & Richter, 2018). Reptile species within temperate forests are mostly composed of various turtles which can be found in aquatic habitats like rivers, lakes and streams, snakes, and some small lizards of the skink and Agamidae species and are fewer in species type and populations when compared to the amphibians (Rajpar et al., 2020). Reptiles act as predators within the temperate forests and tend to specialize in behavior and location by utilizing different habitat niches including shrubs, trees and rock crevices for shelter and foraging, and are a major food source for birds (Rajpar et al., 2020).

3. Conservation threats faced by biome and by communities of organismal groups

Temperate coniferous and broadleaf forests, often referred to as vital biomes, face a multitude of conservation threats that endanger not only the ecosystems themselves but also the diverse communities of flora, fauna, and humans that rely on them for their well-being and sustenance. Deforestation poses a significant threat to temperate coniferous forests, in particular. This harmful activity is caused by a number of factors, including the relentless demand for lumber, agricultural development, and urban sprawl. Due to these activities, vital forest ecosystems are lost, contributing to ecological imbalances and upsetting the delicate balance that has developed over millennia (Korboulewsky et al., 2021). The difficulties experienced by temperate coniferous forests are made worse by climate change which has caused the distribution of tree species to be altered by changes in temperature and precipitation patterns, making it impossible for some to flourish in their native habitats. The ecosystems of forests may be damaged as a result, making them more susceptible to other dangers. Extreme weather events like droughts and storms, which can have devastating effects on these forests, are on the rise as a result of climate change (Benke, 2015). Particularly challenging are the increasing frequency and severity of wildfires. These wildfires not only burn off substantial portions of forests, but they also threaten the lives of various wildlife species and release a significant quantity of carbon dioxide into the atmosphere, exacerbating climate change (Korboulewsky et al., 2021). An additional threat to the health of temperate coniferous forests is air pollution. Acid rain, which is caused by the atmospheric emission of sulfur and nitrogen compounds from industrial and agricultural processes, can harm a tree's leaves and needles, making it more susceptible to further stressors. Smog, which is frequently associated with urban areas, has a negative impact on photosynthesis and can reduce light

penetration in forests (Awad et al., 2019). These ecosystems become less resilient overall as a result of this type of pollution, which increases their susceptibility to other environmental stressors.

Similar difficulties are faced by temperate broadleaf forests. Urbanization and agricultural growth continue to be major threats that cause deforestation. Due to habitat degradation and fragmentation brought on by the conversion of forests into cropland or urban areas, populations of plants and animals are isolated, making it more difficult for them to interact and exchange genetic material. This process can ultimately reduce genetic diversity and weaken the ability of species to adapt to changing conditions (Silander, 2001). Modified precipitation patterns and an increase in extreme weather events are two effects of climate change in temperate broadleaf forests. Different species' life cycles may be disturbed by these changes, which may have an impact on their chances of reproducing and surviving (Korboulewsky et al., 2021). Broadleaf and coniferous temperate forests are also threatened by invasive species. Native ecosystems can be affected by invasive plants, animals, and pathogens, which also reduce biodiversity by outcompeting native species. This may change how these forests function through accumulating impacts on the food chain and environmental processes (Pallardy, 2008). Additionally, temperate broadleaf woods continue to be encroached upon by urbanization. As cities and towns grow, pollution from industrial, agricultural, and urban sources follows them. The health of both plant and animal species is hampered by this pollution, which has a severe impact on the quality of the air, water, and soil (Awad et al., 2019). It also affects how ecosystems work, which causes imbalances in the cycling of nutrients and other crucial processes (Pallardy, 2008).

Alteration of waterways by way of dams remains a significant conservation threat to fish in temperate forests as it changes the flow of the water, and therefore alters the habitats of fish species, as well as the predator and prey interactions between fish and their predators. Chemical contamination of water can be detrimental to fish and cause mass fish kills. These chemicals generally come from agricultural or industrial runoff, in addition to acid rain. Lastly, overfishing is a well-known threat to fish species everywhere, including in temperate forests. Rivers in various temperate forest biomes provide a significant food source to the local populations of people. However, commercial overfishing can quickly deplete populations of fish without allowing them sufficient time to recover their numbers. This can easily lead to endangerment and eventually extinction of important fish species in the biome (Simbeck, 1990).

Amphibians within the temperate forest biomes are sensitive to changes in the landscape structure and sensitive to habitat destruction and degradation (Baecher & Richter, 2018). Habitat loss from human activities including agriculture and urbanization, along with silviculture practices are the leading causes of population decline for amphibians, while urbanization and habitat loss or alteration from cattle-raising are leading causes for the decline of reptile populations (Cordier et al., 2021). Increases in disturbance events caused by climate change, like forest fires, show a reduction of overall species richness for both amphibians and reptiles, even in fire-prone vegetation communities and with species that have adapted and evolved with regular fire disturbances

(Beranek et al., 2022; Hu et al., 2013). Disturbances like wildfires, prescribed burns, silviculture and livestock that damage or destroy leaf litter and coarse woody debris, causes the destruction of the moist microhabitats used by salamanders and frogs within the forests (O'Donnell et al., 2014). The loss of salamander species within the forest can alter the litter decomposition, nutrient cycles and soil composition (Hickerson et al., 2017).

The temperate biome is vast and diverse, and as a result offers much range and potential for specific scenarios in which the fitness and biodiversity of avian species can be assessed. The mutualistic relationship between timing and latitudinal patterns of fruits is critical for bird species migratory patterns and presents both an ecological pressure in which bird species are tied to as well as a mechanism for bird species to have massive migratory and dispersal potential (Stiles, 1980). Forests that experience deforestation also have a direct impact on local avian fitness, wherein deforestation impact is varied by forest type and latitude which affects local species richness, diversity, foraging and breeding habits (LaManna & Martin, 2016). The avian species are not only dependent on its surrounding ecosystem, but also are a key component in a healthy local ecosystem, where avian presence in an area affects invertebrate herbivory and sapling growth more than tree species in sections of temperate forest. This complicates the relationship between overstory, understory and shrub relationships that were once considered (Dekeukeleire et al., 2019).

Human activities like deforestation have the potential to disrupt the ecological balance of temperate forests, resulting in significant effects on the habitat and behavior of mammals (Zhang, 2016). Given that mammals have specific habitat requirements and compete for limited resources, forest thinning can contribute to a decline in the functional diversity of mammals (Zhang, 2016). The loss of forests can trigger shifts in mammal community composition and may result in the decline or extinction of certain species or lineages (Echeverria, 2006). These shifts can affect the phylogenetic diversity within the community. In addition, climate changes impact the distribution and population sizes of plant species, consequently altering the accessibility of food sources for herbivorous mammals. Altered phenology such as flowering and movement of migratory animals, plays a key role in the structure and function of temperate forest ecosystems (Gilliam, 2016). Exotic plant invasions and persistent, elevated levels of herbivory represent two significant biotic stressors that exert substantial impacts on temperate forest ecosystems in eastern North America (Shen, 2016). Invasive species can disrupt resource availability, competition, and trophic interactions, leading to changes in the ecological roles and evolutionary lineages within the biome (Betras, 2022).

4. Prognosis: Biomes of the future

The variability of temperate forests has no doubt established many environmental pressures that have facilitated the evolution of coniferous and broadleaf species. These regions' successes are dependent on several conditions including topographic, biotic and edaphic factors (Wang et al., 2018). As human activities have accelerated the rate at which climatic changes occur, there are

varied projections for this highly variable biome. However, one thing remains consistent across them, which is the projected loss of biodiversity. This is guaranteed across all temperate forests due to the relationship between soil CO2 respiration and atmospheric CO2; as well as climate change-induced tree mortality (Yuste et al., 2019). The relationships between local ecosystems remain complex and highly tangential, with each ecological component having its own specific factors but still affect other components. Understory vegetation, but not shrubs, are dependent on above ground biomass and overstory stratum and decrease with elevation. The dominant drivers for shrub and herbs are elevation, access to water and slope, but not overstory species. Overstory species play a crucial role in facilitating biodiversity, in at least conifer forests, to which a mutualistic relationship between overstory and understory strata, and to a lesser extent shrubs (Wang et al., 2018). As climate changes occur, we see a steady loss of tree populations which will have a cascading effect on understory and shrub biodiversity and biomass. In addition to the static latitudinal and elevational preferences of these trees, and that they obviously lack mobility, will see a steep decline in conditions preferable for those tree species.

Most reptiles and amphibians are habitat-specialists, and their diversity and species richness is highly negatively impacted by disturbance events that often create local extinction events for the specialist species (Hu et al., 2013). The fewer generalist herpetofauna species are more able to take advantage to adapt to the altered habitats, but the low number of generalist species shows that a large amount of diversity and richness is lost with disturbances (Hu et al., 2013; Cordier et al., 2021). While avians experience population decline in some areas, globally due to their high speciation rates and biodiversity, does relatively well in terms of lineage count and can persist in adapting to new environments or migrating to more preferable climates (Jetz et al, 2012). Fish have shown to be adaptable to changing environmental conditions, as seen by certain species evolving to survive in hypoxic environments (Wang et al., 2015). However, it is less likely that fish will be able to overcome the threats of overfishing as it often happens at faster rates than fish are able to recover their lost population. Mammalian functional and phylogenetic diversity was impacted by conservation threats, which may result in population declines, distributional changes, and even disrupt ecological interactions between mammals and other species in the future. For example, a decline in seed-dispersing mammals, such as rodents, could lead to reduced plant regeneration and altered forest composition (Zhang, 2016). Only mammal species with the capacity to adapt to changing environmental conditions or exhibit flexibility in their behavior may have a higher chance of enduring. Conversely, those that are less adaptable or specialized species may experience a greater risk and an increased likelihood of extinction.

Climate change mitigation strategies should therefore focus on reducing tree mortality, as well as many other related factors such as tree resistance, resilience as well as performing strategies for acclimatizing populations as rapidly as the temperature shifts (Park et al., 2014). Conservation measures including the establishment of protected areas, reforestation initiatives, and habitat restoration projects, as well as sustainable land-use practices, such as selective logging and agroforestry, can help balance human needs with the preservation of these invaluable ecosystems

(Awad et al., 2019). Additionally, community engagement and education are crucial for fostering a sense of stewardship among local populations and encouraging responsible forest management practices.

5. **Prognosis: Global Health**

The health of temperate coniferous and broadleaf forests is not only important for the vast amount of biodiversity within it, but it is also crucial for the rest of the world. Temperate forests are found globally and it is argued that climate change and anthropogenic disturbance have potentially affected these forests the most when compared with other biomes (Gilliam, 2016). Since forests in general provide resources for lumber, power generation, and agricultural land, temperate forests are heavily relied on around the world for these industries. One significant global impact would be the shortages of the products produced by such industries (wood, electricity, food) due to the destruction of temperate forests by way of climate change and human activity. From an ecological aspect, temperate forests provide a service that benefits the environmental health of the globe as well. These forests are particularly good at carbon sequestration due to their biomass and soils (Lal & Lorenz, 2012). This could be a positive or negative trait depending on the future outlook of the biome. If temperature forests continue to be deforested and succumb to anthropogenic climate change, the world would be losing an important carbon sink. This would ultimately contribute to the imbalance of the overall carbon cycle of the globe. However, if strong regenerative efforts are made to restore temperate forests and protect old growth, the forests could actually lead to a globally positive effect by drawing more carbon out of the atmosphere. The fate of temperate coniferous and broadleaf forests and its impacts on global health truly depends on the rate of climate change and anthropogenic activity, as well as the success or failure of all current and future efforts being made to conserve and regenerate these forests.

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