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The Boreal Forest Biome

The boreal forest biome spans two large belts from Alaska to Labrador in North America and from Scandinavia through Siberia to the Pacific in Northern Eurasia (Figure 1). Latitudes of 45°N to 75°N closely corresponds with the boreal forest climate (Stahler, 2013). This biome is located mostly in high latitude regions of Canada, Russia, and Alaska (Bernier, et al, 2015) This vast ecosystem covers around 17% of the Earth's total land surface (Kasischke, 2000) and accounts for approximately 30% of all forest coverage on Earth (Bernier, et al, 2015). Since the boreal forest is located at such high latitudes, it receives less solar energy annually than lower latitudes. The low angle of the sun causes the biome to receive around double the sunlight in peak summer compared to winter and as it is closer to poles, it experiences large variations in insolation (Figure 2). This seasonal difference also results from the Earth's orbital pattern around the sun, causing the sun to appear at a low angle.

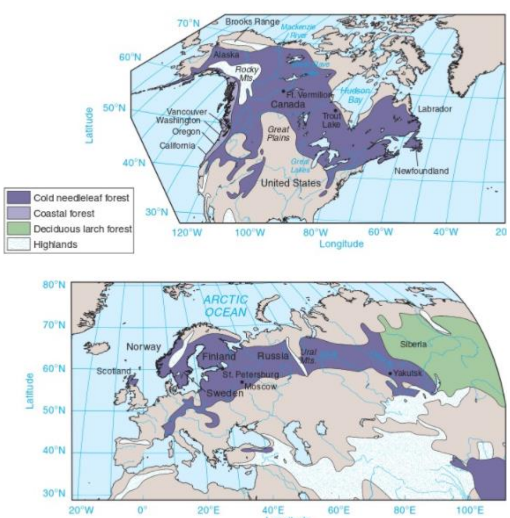

Figure 2: Geological distribution of the boreal forest biome.

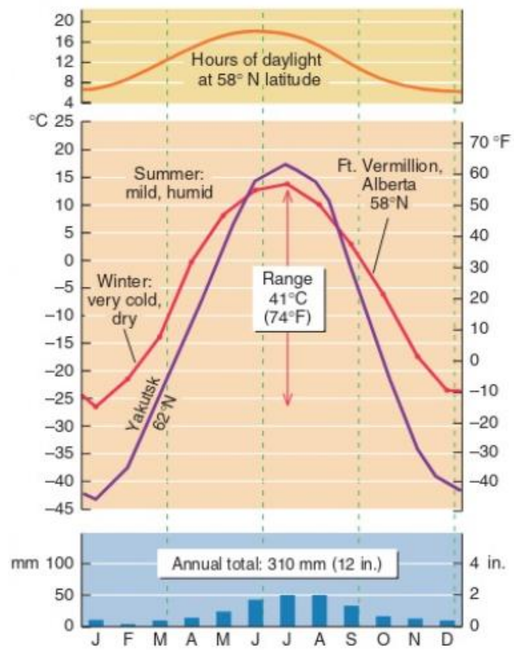

Figure 1: Climatic chart of Ft. Vermillion, Alberta (58° N).

The boreal forest's climate is characterized by intense seasonal variation with short, moist, and moderate summers along with long, dry, freezing winters (Bonan, 1989). This seasonal variation results in a short growing season and severe winters with freezing temperatures occurring for 6-8 months and long-lasting snow cover (Benier, et al, 2015). The variation is controlled by continental polar, maritime air, and continental arctic air masses and since the air masses affecting the biome's climate come from the arctic, the region experiences the largest annual temperature ranges out of all climates (Stahler, 2013). Acting as a major source for cold, dry and stable continental polar air masses result in low precipitation and short, cool summers as well as long, cold, bitter winters. The region's climate is frequently influenced by even colder continental arctic air masses, otherwise known as polar vortexes (Stahler, 2013). This causes disturbances in the jet stream of westerly flow that circles the poles so warm, moist air begins to push north while lobes of cold arctic air pushes south, creating wave cyclones around the arctic front. Precipitation in this biome is affected by maritime air masses in the summer, when this air penetrates the continent through wave cyclones (Stahler, 2013). However, some regions of the biome still experience low annual precipitation when they are far inland, such as western Canada and Siberia (Stahler, 2013). In general, precipitation ranges from 40-100 cm per year, depending on distance from the sea (WWF, 2021).

The northern range of the boreal forest correlates with regions that were covered in ice sheets during the previous Ice Age. However, when the ice retreated, it eroded the ground, revealing underdeveloped and young soils as well as creating shallow basins of bedrock which would become bogs and lakes in present-day Canada and Siberia (Stahler, 2013). These lakes make the boreal forest have more surface freshwater than any other biome (Bernier, et al, 2015). The flatter stretches of land in boreal forests surround these lakes, but elevated regions within and around the forests play a large role in the climate of the region. In hilled regions, south facing slopes have thinner permafrost and thicker active soil layers than north facing slopes due to the increased insolation south facing slopes receive at higher latitudes (Bonan, 1989). As seen in the boreal forests of Alaska, mountains encompass the forest, restricting the inland flow of moist maritime air, reducing annual precipitation. This phenomenon can be observed in the Eurasian belt of the boreal forest as well. In Scandinavia, west of the Ural Mountains, there are no mountain ranges to restrict air from the North Atlantic Ocean, leading to more precipitation and a smaller annual range in temperature compared to its counterparts in Siberia. Siberia is east of the Ural Mountains and North of the Altai Mountains, amplifying the already continental climate of the region, where some places receive as low as 13 cm of precipitation annually (Bonan, 1989).

Due to the location of the boreal forests and the subsequent cold that comes with it, vegetation is forced to adapt to intense winters and short growing seasons. This leads to boreal forests having a relatively low diversity of plant species, as only a few kinds of vegetation can survive the environment. Most trees found in boreal forests are needleleaf, or conifer trees, as their leaves are ideal for surviving harsh winters and dense snowfalls, though some broadleaf and flowering trees are found in small, isolated groups (Bernier, et al, 2015). Boreal forests found in North America, Europe, and Western Siberia are dominated mainly by *picea* (spruce) and *abies* (fir) trees, while Northern, Southern, and Eastern Siberia are populated mostly with *larix* (larch) trees (Stahler, 2013). Due to the relatively small layer of unfrozen soil above the permafrost, trees, as well as ground covering plants, tend to have shallow, but wide-reaching roots to avoid the permafrost layer (Alaska Department of Fish & Game, 2017). Because of this, deep-rooted grassland would not be able to survive, as roots would not be able to grow past the permafrost. This leads to the ground being covered in mainly patches of moss or lichens (WWF, 2021).

The soils of the boreal forest are shaped by the biome's history, climate, and vegetation. While there are a class of alfisols present in the biome, known as boralfs, that are distinguished by a grey surface horizon and brownish subsoil, the dominant soil order is spodosols. Spodosols' soil profile typically consists of an O horizon and A horizon followed by an albic E horizon that was bleached white or grey by organic acid from the slowly decomposing O horizon. Then, the minerals from the E horizon are eluviated down to the spodosols' defining feature, a spodic B horizon that has a dense accumulation of iron and aluminum oxides and organic matter, followed by a C horizon (Stahler, 2013). Spodosols are typically associated with regions that were recently covered in ice sheets, such as the boreal forest, so they tend to be young with a coarse parent soil mostly composed of quartz which does not weather into clay minerals conducive to agriculture (Stahler, 2013). Furthering spodsol's productivity challenges are the large presence of hydrogen and aluminum cations which make it strongly acidic, but the needleleaf trees native to these soils have adapted a way of recycling the bases in the soil (Stahler, 2013).

These needleleaf trees also play a role in the spodosol's properties. The trees act as regulators on the soil by reducing wind speed in winters and providing shade in summers, allowing permafrost to remain year-round in some locations despite the biome's large temperature range (Bonan, 1989). Besides vegetation, the climate is a major factor in the properties of spodosols. Alaskan and Canadian boreal forests demonstrate how the climate of the region creates a positive feedback loop regarding permafrost. The presence of cold air is a determining factor in the distribution of permafrost by lowering soil temperature, in turn reducing the decomposition of organic matter and nutrient cycling. As organic matter accumulates due to its slow decomposition, its low thermal conductivity and bulk density allow for the continuation of a high permafrost table (Bonan, 1989).

As harsh winters wrack the ecosystem, wildlife has adapted a variety of solutions to surviving. With intense snow covering the landscape, finding a source of food for birds can prove difficult. This leads to most bird species migrating south during the long winter in search of a warmer climate and food. When winter ends, and the short growing season begins, these birds return to nest in the abundant trees, and feed on the newly awakening insect population (Alaska Department of Fish & Game, 2017). Warm blooded mammals, however, have a choice to make when it comes to their winter plans. Both brown and black bears, as well as marmots and even small mice, will store fat during the growing season to fall into a long hibernation (Alaska Department of Fish & Game, 2017). Other mammals, such as wolf packs or the endangered Canadian Lynx will, instead, remain active throughout the year, hunting stoats and hares, which have adapted to change the color of their coat to blend in with the white snow, or the previously mentioned small hibernating mammals (WWF, 2021).

Boreal forest ecosystems serve as great carbon sinks and oxygen sources due to how extensive the biome is. Although it covers less than 17% of Earth's land surface, it contains about 30% of total forest carbon sinks, in both vegetation and soil (Kasischke, 2000). Since the boreal forest is so extensive, it plays a huge role in oxygen production and carbon cycling, contributing to 8% of global soil respiration (Angert, et al, 2003). In fact, the boreal forest's carbon content is comparable to, if not greater than, that of tropical rainforests (Bernier, et al, 2015). A thick, organic layer of moss and lichen controls energy flow and nutrient cycling by controlling decomposition rates. Additionally, cyanobacteria present in mosses are crucial nitrogen fixers in regions such as interior Alaska (Bonan, 1989). This moss layer adds to the accumulation of organic matter in the forest and aids in forest development. As soil temperatures decline, the moss layer slows decomposition of organic matter in the forest until it dies and decomposes, allowing the forest floor to become the principal reservoir for nutrients (Bonan, 1989). Unfortunately, due to deforestation and an increase in disturbances such as fire and disease, the boreal forest may become a source of carbon as opposed to a sink (Kasischke, 2000). This shift would cause the region to become a large contributor of greenhouse gases and a net release of carbon.

While currently being in a relatively good shape compared to other biomes wracked by human interference, the boreal forest is not without its threats. More specifically, global climate change and the lumber industry threaten to thin the species diversity and possibly eradicate the forests altogether. As of 2015, over ⅔ of boreal forest land has been harvested by the lumber industry in Canada, Finland, Sweden, and Russia (Bernier, et al, 2015). The industry is so pervasive, and the rate of harvesting is so high, that an estimated 33% of all lumber, as well as 25% of all paper products originate in a boreal forest (Bernier, et al, 2015). Harvesting trees has a negative effect on the region's biodiversity as a whole and with certain species of trees being culled for the lumber industry, wildlife struggles to maintain its habitat. Migrating birds lose nesting sites and wolf packs are forced to make new dens away from industrial areas.

Global climate change has also had a hand in thinning these forests and shrinking their land coverage. Boreal forests have seen the most drastic temperature increase because of climate change out of any other global biome (Bernier, et al, 2015). The average annual temperature of the boreal forest has increased 1.5°C since the 1970's and is projected to increase 4°C more by the end of the century (Schuur, et al, 2018). As temperatures climb and air becomes drier, most notably in the southern regions of the forests, tree lines begin to thin (Bernier, et al, 2015), meaning that the forest is slowly receding north as temperatures increase.

The combined efforts of deforestation and climate change are slowly shrinking the boreal forest. Being a large carbon sink, it is our responsibility to maintain it, or else our carbon emission problem will only worsen. Unless efforts are made to stop harvesting of the trees, the effects of our carbon emission and climate change could create a snowball effect, ending with the boreal forest being nearly eradicated.

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