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Subalpine and Boreal Forests

N A Balliet and C D B Hawkins, University of Northern British Columbia, Prince George, BC, Canada

Table 1 Some species commonly occurring in subalpine and boreal forests, with their common names

Species	*Common name*
Abies balsamea	Balsam fir
Abies lasiocarpa	Subalpine fir
Abies sibirica	Siberian fir
Betula papyrifera	Paper birch
Juniperus spp.	Juniper spp.
Larix dahurica	Dahurian larch
Larix laricina	Tamarack
Larix lyallii	Subalpine larch
Larix sibirica	Siberian larch
Picea abies	Norway spruce
Picea engelmannii	Engelmann spruce
Picea glauca	White spruce
Picea mariana	Black spruce
Pinus albicaulis	Whitebark pine
Pinus aristata	Bristlecone pine
Pinus banksiana	Jack pine
Pinus contorta	Lodgepole pine
Pinus flexilis	Limber pine
Pinus sibirica	Siberian pine
Pinus sylvestris	Scots pine
Populus balsamifera	Balsam poplar
Populus tremuloides	Trembling aspen
Salix spp.	Willow spp.
Taxus spp.	Yew spp.
Thuja plicata	Western red cedar
Tsuga heterophylla	Western hemlock
Tsuga mertensiana	Mountain hemlock

Introduction

Many biogeographers consider boreal and subalpine forests as one biome, others separate them because, although boreal and subalpine forests share many similar attributes with respect to climate, vegetation, and soil, there are significant differences between the two. In this article the two will be treated separately.

Subalpine forests are high-elevation forests that occur in mountainous regions around the world. Coniferous subalpine forests, however, are largely limited to the northern hemisphere. These forests are found immediately above the northern coniferous forest in the European Alps, the mountains of east-central Europe, the Urals, the Himalayas, the mountains of northeast China, and the Appalachians, the Sierra Nevada, Cascade and Coastal Ranges and the Rocky Mountains of North America.

The majority of subalpine forests are dominated by *Picea*, *Abies*, *Pinus*, and *Larix* species; however, some variation does occur among regions (see **Table 1** for common names of these species). Subalpine forests of the European Alps are characterized by *Picea–Abies* forests at lower elevations and *Larix–Pinus* forests at higher elevations. The mountainous regions of Romania, Yugoslavia, and Bulgaria are characterized by *Abies*, *Larix*, *Picea*, and *Pinus* species, whereas the Urals are dominated by *Abies*, *Picea*, and *Pinus* species. The subalpine forests of the Himalayas are characterized by *Abies* and *Picea* at lower elevations and *Juniperus*, *Larix*, *Pinus*, and *Taxus* species at higher elevations, whereas the mountainous regions of northeast China support *Picea–Abies* species at elevations between 2500 m and 3500 m.

Due to distinct differences in species, climate, and soils, the subalpine forests of the Sierra Nevada and Cascade and Coastal Ranges in North America will be excluded from this description (*see* **Temperate and Mediterranean Forests**: Southern Coniferous Forests; Temperate Broadleaved Deciduous Forest). Additionally, because the Appalachians are often considered temperate and because subalpine forests are only found on the highest peaks, these forests will be covered elsewhere (*see* **Temperate and Mediterranean Forests**: Temperate Broadleaved Deciduous Forest).

In western North America, subalpine forests occur along the entire length of the Rocky Mountains. These subalpine forests will be the focus of this article, where, owing to their similarities with the boreal forest, they are often referred to as mountain, taiga, or boreal forests.

The boreal forest (separate from the subalpine forest) is commonly referred to as taiga (a Russian term), or northern coniferous forest. Although it is restricted to the northern hemisphere, it forms nearly a continuous belt of coniferous trees across portions of North America and Eurasia. In Canada, it extends from coast to coast. It is bordered by the northern coniferous forest, temperate forest, or prairie to the south and tundra to the north. In Eurasia, it extends across Norway, Sweden, Finland, Russia, and Siberia, where it is bordered by tundra to the north and steppe or northern temperate forest to the south.

The boreal forest is characterized by a mosaic of coniferous genera including *Abies*, *Larix*, *Picea*, and *Pinus*, and broadleaf genera including *Betula*, *Populus*, and *Salix*. These genera occur as both pure and mixed stands across the landscape.

Subalpine Forests

While the following description focuses on subalpine forests of the Rocky Mountains, many of the characteristics are common to subalpine forests around the world.

Distribution

In Western North America, subalpine forests are found along the Rocky Mountains from as far south as Mexico to north of the Arctic Circle. The subalpine forests of the Rocky Mountains can be divided into four regional groups: Boreal, Central, Southern, and Mexican. The most northerly section, the Boreal Rocky Mountain forest (**Figure 1**), extends from Alaska south to the Peace River in Northern British Columbia. The Central Rocky Mountain forest extend south from the Peace River to Wyoming. The Southern Rocky Mountain forest extend south from Wyoming to New Mexico. The most southerly group, the Mexican Rocky Mountain forest (also sometimes called the Madrean Rocky Mountain forest), extend south from New Mexico into southern Mexico and even into the mountains of Guatemala. Most consider the Mexican or Madrean Rocky Mountain forest to be part of the southern coniferous forest, however (*see* **Temperate and Mediterranean Forests**: Southern Coniferous Forests).

Postglacial Development

Currently there is very little information on the postglacial development of subalpine forests. Although pollen cores taken from lakes reveal that pioneer species such as *Betula*, *Juniperus*, *Populus*, and *Salix* were followed after glaciation by coniferous species such as *Abies*, *Larix*, *Picea*, and *Pinus*, it is unknown whether the present forest is a recent development or has been in existence for some time. It is believed the subalpine forest reached its modern state between 6000 and 5000 years ago.

With the retreat of glaciers, *Betula* and *Picea* spp. migrated west and northwest across Canada from refugia south and southeast of the continental ice sheet. *Larix* and *Populus* spp. may have followed the

Figure 1 Subalpine forests of the Boreal Rocky Mountains.

same migration pattern. In the west, *Pinus* spp. migrated from refugia south of the ice up the Rocky Mountain Trench as the Cordilleran and Laurentide ice sheets separated. Today, the Rocky Mountain subalpine forest occurs in the steep mountainous terrain of western North America above the northern coniferous forest.

Climate

The subalpine forest is characterized by a short growing season (less than 90 growing degree days); winters are generally long with heavy snow, while summers are short, dry, and cool. The climate varies somewhat with elevation and slope position (i.e., windward versus leeward slopes); temperatures drop while precipitation, solar radiation, wind, and snow depth and duration increase with increasing elevation. As such, the subalpine forest is often divided into two subzones: the lower subalpine area (1200–1800 m elevation), which is defined by a closed forest and a relatively favorable climate, and the upper subalpine area (1800–2300 m), which is characterized by open parkland or woodland and a harsher climate. These zones are found at lower elevations in the north and at higher elevations in the south.

Soil

Subalpine forests are most frequently associated with luvisols, brunisols, and regosols. Luvisols are characterized by an accumulation of clay; conversely, brunisols and regosols are poorly developed soils. Soils of the subalpine forest are typically shallow and generally poor in nutrients. They can also be acidic, and erosion is common due to frost heaving and steep slopes.

Vegetation

Rocky Mountain subalpine forests consist mainly of conifers with a few hardy deciduous species. These forests are often viewed as a southern extension of the boreal forest, particularly in the most northerly zone, the Boreal Rocky Mountain Forest, where it is often difficult to separate the boreal forest from the subalpine forest and the northern coniferous forest. Although vegetation varies somewhat with elevation, slope position, and soil, particularly from north to south and east to west, the Rocky Mountain coniferous forests are remarkably similar in species composition and stand structure along their entire length.

The lower subalpine area is typified by a closed forest of productive *Picea engelmannii* (south of 54° N), *P. glauca* (north of 54° N), *Abies lasiocarpa*, *Pinus contorta*, and *Populus tremuloides*, whereas the upper subalpine area is typified by shorter, open grown *Abies lasiocarpa*, *Picea engelmannii*, and *P. glauca*. *Picea* and *Abies* species tend to dominate the mature forests, whereas *Pinus contorta* dominates in the drier parts of the zone where fire disturbance has occurred. At the timberline, harsh climatic conditions affect tree growth. These trees grow in clumps and are often stunted, flagged or krummholz. In the Northern Rockies, the treeline is dominated by *Larix lyallii*, whereas in the Central Rockies *P. albicaulis* and *Pinus flexilis* dominate. This area is dominated by *P. aristata* in the Southern Rockies.

Ecosystem Dynamics

Subalpine forests are disturbance driven, with a mean disturbance return interval of 150 to 350 years. Although fire is the most important form of natural disturbance in these forests, wind, insects, disease, ungulate browsing, avalanches, landslides, extreme weather, and volcanism also play a role.

Successional patterns vary from north to south along the Rocky Mountains. In the Boreal Rocky Mountain Forest, *Betula papyrifera*, *P. balsamifera*, and *Populus tremuloides* are successional following fire disturbance. *Abies* spp and *Picea glauca*. follow. The Central Rocky Mountain Forest is somewhat more variable. In general, *Pinus contorta*, *Populus tremuloides*, and *P. balsamifera* are successional following fire, whereas, *Picea engelmannii* dominates older forests, although *Abies lasiocarpa*, *Betula papyrifera*, *Larix* spp., and *P. mariana*, and are also present. *Picea engelmannii* appears on the south eastern slopes of the Central Rocky Mountain forest, while *Larix lyallii*, *Pinus albicaulis*, and *P. flexilis* appear near the timberline. On the southwestern slopes of the Central Rocky Mountain Forest, *Abies* spp., *Tsuga heterophylla*, and *Thuja plicata* are associated with *Larix lyallii*, *Picea* spp., *Pinus albicaulis*, and *Tsuga mertensiana* appear at higher elevations. The subalpine forests of the Southern Rocky Mountain forest are dominated by *Abies lasiocarpa* and *Picea engelmannii*.

Damaging Agents

Insects and disease Many species of insect and disease impact trees in the subalpine forest. Although insects such as spruce budworm (*Choristoneura* spp.), bark beetles (*Dendroctonus* spp.) and white pine weevil (*Pissodes strobi*), are the major pests to conifers of the subalpine forest, diseases such as mistletoe (*Arceuthobium* spp.), western gall rust (*Endocronartium harkenssii*), and broom rusts are also present.

Fire and wind Fires in the subalpine forest are infrequent but tend to be stand destroying, making them an important part of the successional pattern in these forests. Shallow soils are common in the subalpine forest, which make for a poor rooting medium leaving trees susceptible to windthrow.

Avalanche paths Avalanche paths are common in the subalpine forest. Recurrent slides leave many of these paths devoid of trees and dense with shrubs and herbaceous species.

Climate change Global climate change may have serious implications for subalpine forests. Although temperatures are not expected to rise higher than they have historically, the rate of change appears to be much faster than it has been in the past. Global warming of 1.0–4.5°C over the next 100 years is anticipated. It is likely that changes in precipitation patterns and carbon dioxide levels will also accompany changes in temperature. All of these changes may result in latitudinal or, to a limited extent, elevational shift in species ranges. Differences in dispersal ability may also result in changes in plant communities and competition between 'exotic' species, which could result in extinction for some species. Extinction may also occur because species cannot adapt or move fast enough under the changing conditions.

Forest management Forests in the lower subalpine area are highly productive. *Abies lasiocarpa*, *Picea glauca*, *P. engelmannii*, and *Pinus contorta* are the largest and most productive species in the subalpine forest. As such, these species are a highly valuable resource where timber harvesting is the major economic activity. These large, nature forests, however, are also highly valuable caribou habitat. In recent years, efforts have been made through alternative silviculture systems such as variable retention, shelterwoods, or group selection, to protect the structural and functional integrity of caribou habitat in these high elevation forests.

Boreal Forests

Distribution

The boreal forest (**Figure 2**) forms a circumpolar forest belt in the northern hemisphere and as such it is one of the world's largest forested areas, and a major carbon reservoir.

Postglacial Development

The majority of the area covered by the boreal forest today was once completely covered by ice. As the ice sheets melted, the land was slowly invaded by herbaceous plants and shrubs, followed by conifers. Although the distribution of boreal species was

Figure 2 The boreal forest in northeastern British Columbia.

largely a response to climate and soil, species dispersal rates and locations of refugia played a large role following glaciation. In North America, refugia existed south, west, and east of the ice. Species migration in the boreal region was similar to that of the subalpine region, with *Picea*, *Betula*, *Populus*, and *Larix* spp. migrating west and northwest across Canada and *Pinus* spp. migrating north up the Rocky Mountain Trench as the Cordilleran and Laurentide ice sheets separated. Due to the lingering ice sheets, the boreal forest in eastern Canada is believed to be younger than the boreal forest in western Canada.

Climate

The climate of the boreal forest varies somewhat between coastal and continental regions. In continental regions, winters are long, cold, and dry, while summers are short, moderately warm, and moist, whereas in coastal regions, such as eastern Canada and Scandinavia, the climate tends to be warmer and moister. In general, however, an average of 100–900 mm of precipitation falls annually and the mean annual temperature does not rise above -0.5°C.

Terrain and Soil

The terrain of the boreal forest is diverse. Rolling uplands are interspersed with lakes of varying sizes, bogs, and wetland communities. Bogs or peatlands are thick deposits of peat and organic soils often saturated with water that cover vast areas of the boreal forest. Bedrock outcrops, eskers, and moraines are also common.

Boreal forests are most frequently associated with podzols (spodosols). These soils are characterized by an accumulation of organic matter as well as iron and aluminum deposits. They are acidic and have low nutrient status. Other soil types commonly found in the boreal include luvisols and organics. Luvisols are defined by an accumulation of clay, whereas organic soils are composed largely of organic matter and tend to be poorly drained. Pockets of continuous and discontinuous permafrost exist throughout the boreal forest, chilling the soil above and slowing decomposition. Permafrost also forms an impenetrable layer, retarding drainage.

Vegetation

Coniferous trees dominate the boreal forest; however, hardy deciduous species such as *Betula papyrifera*, *Populus balsamifera*, and *P. tremuloides* are also common. Shrub willow (*Salix* spp.) is also very common on the wetter areas. In western North America, *Picea glauca*, *P. mariana*, *Larix laricina*, *P. banksiana*, *P. contorta*, *A. lasiocarpa*, and *A. balsamea* dominate the boreal forest, whereas, in eastern North America, *A. balsamea* forms the climax species. In Scandinavia and western Russia, *Picea abies* and *Pinus sylvestris* dominate, whereas *Abies sibirica*, *L. dahurica*, *Larix sibirica*, and *Pinus sibirica* dominate in Siberia.

The boreal forest is often divided into three latitudinal zones: closed forest, lichen woodland, and forest–tundra. The closed forest at lower latitudes is characterized by continuous northern coniferous forest with *Betula* and *Populus* spp. intermixed. Maximum tree height in these forests is about 23 m. The trees of the lichen woodland at mid latitudes are shorter and more open than those of the closed forest; however, they are not as scattered as the trees of the forest–tundra. The treeline is often found at the northern limit of the forest–tundra zone and is analogous to the treeline above subalpine forests. Temperature appears to regulate the northern and southern bounds of the boreal forest: respectively, the boundaries correspond roughly to 13°C and 18°C July mean temperatures.

The mosaic of forest communities found in the boreal forest is largely due to a response to climate, topography, the presence or absence of permafrost, soils, fire activity, as well as the reproductive capacity, vigor, and distribution of boreal tree species.

Productivity Productivity of the boreal forest is limited by low atmospheric temperatures, the presence of permafrost and low soil temperatures, thick organic layers with slow rates of decomposition, and poorly drained acidic soils with low nutrient availability. This is why it is one of the major carbon reservoirs on earth. Consequently, productivity of the boreal forest varies widely with latitude, proximity to the coast, topography, and seral stage. In general, however, productivity differs greatly from the lowlands to the uplands. The most productive sites are the lowland floodplains. These sites are dominated by *Populus balsamifera*. In contrast, *Picea mariana* sites are the least productive.

Ecosystem Dynamics

The boreal forest is disturbance driven with a mean disturbance return interval of 50–200 years in North America and 50–270 years in Sweden. Although fire is the main disturbance factor, insect outbreaks and windthrow also play a key role. These frequent and diverse disturbance regimes in conjunction with a varied environment are thought to

contribute to the diversity of forest types and the range in stand productivity typical of the boreal forest.

Most boreal species have evolved with fire and have adapted their growth and reproductive strategies accordingly. These diverse responses have led to a variety of successional pathways, and a diverse landscape.

Many boreal species have adapted an even-aged growth strategy. For instance, *Pinus banksiana* and *P. contorta* have adapted to poor dry sites, whereas *Picea mariana* has adapted to poor wet sites. In both cases, the extreme environmental conditions under which these species grow and reproduce leaves them relatively free of interspecific competition.

Boreal species also vary widely in their shade tolerance, longevity, and regeneration strategies. For example, *Betula papyrifera*, *Populus balsamifera*, and *P. tremuloides* are early successional species, regenerating quickly following disturbance. As a result, however, these species are short-lived and shade-intolerant. Conversely, *Picea glauca* and *Abies* spp. are long-lived and shade-tolerant, making them keystone species in late successional and climax boreal forest types.

Indigenous Use

The indigenous people of Canada's boreal forest region have been harvesting a wide variety of natural products from the forest, to maintain their culture, for thousands of years. These products were used for a wide variety of purposes including (but not limited to) medicine, food (e.g., berries, roots, bark, small and large mammals), shelter, baskets, and clothing.

Damaging Agents

Insects and disease Insects and disease, are important components of forest ecosystem dynamics in the boreal forest. For boreal conifer species, the major pests include spruce budworm (*Choristoneura* spp.), bark beetles (*Dendroctonus* spp.), and Siberian silkworm (*Dendrolimus sibericus*), all of which can cause widespread damage. For instance, the spruce budworm has been an extensive and extended problem in northeastern British Columbia as well as in eastern Canada. White pine weevil (*Pissodes strobi*), mistletoe (*Arceuthobium* spp.), western gall rust (*Endocronartium harkenssii*), and broom rusts are also present; however, these are minor pests compared to those mentioned above.

Fire and wind Fire is an important aspect of ecosystem dynamics in the boreal forest. Fires destroy mature and overmature forests which are then replaced by new forests. Although stand-destroying fires are frequent, they tend to be small. Due to shallow rooting, boreal trees tend to be susceptible to windthrow, which opens up small gaps allowing species to regenerate in the openings.

Pollution and climate change The boreal forests of eastern North America and Europe have been severely impacted by acid deposition (i.e., acid rain). Acid rain acidifies the soil which makes it toxic to plant roots, leaving the trees more susceptible to damage from insects and disease.

As discussed for subalpine forests, global climate change may also have serious implications for boreal forests. Change may result in a northward latitudinal shift in species ranges. However, in some areas, barriers such as urban areas may limit migration. The increase in temperature could enhance soil respiration and accelerate carbon emissions from the vast stored pool of the boreal forest.

Changes in temperature and precipitation will also have an impact on disturbance mechanisms such as insects, drought, and fire, influencing their occurrence, timing, frequency, duration, extent, and intensity. For example, extended periods of drought may result in fires burning more frequently, over larger areas, and at higher intensity, further reducing carbon storage in the boreal forest.

Industrial activities Historically, boreal forests have played an important role in the economic development of northern countries. Resource extraction (e.g., trapping and forestry activities) began in the nineteenth century in Scandinavia and the twentieth century in Canada. Today, the boreal forests of North America and Europe continue to be an important region for the production of minerals, petroleum, hydroelectricity, and timber. The Siberian boreal forest is currently undergoing rapid development.

Although the majority of the boreal forest is suitable for sustainable resource extraction, industrial activities can result in the destruction of permafrost and the surrounding landscape. In Scandinavia, for example, large-scale forestry operations have transformed virtually all forested land into intensively managed secondary forests.

This emphasis on large-scale industrial resource extraction has resulted in conflicts between traditional resource users and industrial users world wide. The Temagami region of Ontario, for example, has been in dispute since the mid nineteenth century. The Teme-Augama Anishnabai people seek land claim settlements, the government seeks to establish industrial logging and mining operations in the area,

and environmental groups seek to protect old-growth forests.

Subalpine and Boreal Forests: A Comparison

There are some distinct differences between subalpine and boreal forests even though in many ways they are similar. Subalpine and boreal forests both occur in the northern hemisphere, but subalpine forests are restricted to high elevation mountainous regions, while boreal forests occur at northerly latitudes. Subalpine and boreal forests likely shared similar postglacial development patterns. As the ice sheets retracted, species migrated northward and upward with continued warming and species migration from southern refugia; the northern coniferous forest established below the subalpine forest. Subalpine and boreal forests both have short growing seasons due to long winters. As the boreal is a cold biome, organic matter decays slowly and it is a major carbon sink along with the coastal temperate forest.

Subalpine forests are characterized by dry summers and snowy winters, whereas boreal forests are characterized by warm moist summers and cold dry winters. Subalpine forests occur in mountainous terrain, where soils tend to be shallow and low in nutrients. Boreal forests occur in rolling terrain with many lakes, bogs, and wetlands interspersed. Soils are also low in nutrients and permafrost can be continuous or discontinuous. This too contributes to the slow decay processes in the boreal forest. Both subalpine and boreal forests are dominated by coniferous trees with some hardy deciduous species. *Abies* and *Picea* species dominate the subalpine forest with *Pinus* species occupying the higher elevations near timberline and drier microsites. The boreal forest is characterized by a mosaic of *Abies*, *Betula*, *Larix*, *Picea*, *Pinus*, and *Populus* species. Subalpine forests become more open with increasing elevation as boreal forests do with increasing latitude. Both subalpine and boreal forests are disturbance driven, largely by fire which occurs at intervals of 150–350 years in subalpine forests and at slightly shorter intervals of 50–270 years in boreal forests. Insects, diseases, and wind also play a role in the ecosystem dynamics of both forests. Climate change is also a concern for both forest types. Changes in temperature, precipitation, and carbon dioxide levels may lead to shifts in species ranges, either latitudinally or elevationally.

Both forests are valued for their timber resources, while the boreal forest region is also valued for minerals, petroleum, and hydroelectricity, as well as for indigenous peoples' needs. Consequently, environmental groups are increasingly interested in protecting the boreal forest from such industrial activity as well as implementing actions to minimize the effects of global warming. Loss of the boreal forest could have serious global consequences, including impacts on the economy, the atmosphere, and the water supply.

See also: **Ecology**: Natural Disturbance in Forest Environments. **Environment**: Impacts of Elevated CO_2 and Climate Change. **Temperate and Mediterranean Forests**: Northern Coniferous Forests. **Temperate and Mediterranean Forests**: Southern Coniferous Forests; Temperate Broadleaved Deciduous Forest. **Temperate Ecosystems**: Alders, Birches and Willows; Pines; Spruces, Firs and Larches.

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