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TEMPERATE AND MEDITERRANEAN FORESTS

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Northern Coniferous Forests

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Introduction

The northern coniferous forest or temperate needleleaf forest is restricted, essentially, to western North America. It also occurs in small elevational bands on mountain ranges of Europe, Asia, eastern North America, Mexico, Mesoamerica, and the coastal plains of the southeastern United States. The northern coniferous forest is conventionally a synonym for the boreal forest. Depending on the authority, the northern coniferous forest can be considered a southern offshoot of the boreal forest on the Rocky, Coast, Cascade, Appalachian, Alps, Carpathians, Urals, and Himalaya mountain ranges, as well as mountains in northern China, Korea, and Japan, or it can be restricted to montane coniferous forest. Pinaceae (pines, spruces, firs, and larches) are the major northern coniferous forest family and account for its economic importance. There are also mixed coniferous–deciduous stands in the western North American northern coniferous forest with trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*). Compared to the boreal forest, the northern coniferous forest is warmer and more productive: mature trees ≥ 25 m compared to ≤ 23 m. This article focuses on western North America because compared to other areas of the world, there are still large areas of natural northern coniferous forest.

Generally mountains become wetter, colder, and windier with increasing elevation. This results in distinct zones or bands of vegetation. A given vegetation zone tends to be found at higher elevations on drier sites compared to wetter, on south aspects compared to north, and at southern latitudes compared to northern. Low to mid elevation northern coniferous forests are rich in species diversity while the upper northern coniferous forest is less complex. The upper northern coniferous forest and lower subalpine have similar species composition and they are transitional to one another.

Distribution

Western North America

The northern coniferous forest includes the central plateaux of British Columbia and isolated Intermountain, mountain ranges between the Cascade–Sierra ranges as well as the Rocky Mountains. In the Rocky Mountains, it extends from the southern Yukon to south central New Mexico. Some consider it to include the Madrean (Mexican) section of the Rocky Mountains and the Coastal, Cascade, and Sierra Nevada ranges while others consider the Madrean and Sierra Nevada to be part of the southern coniferous forest. The Sierra Nevada is excluded from the northern coniferous forest as: (1) true coniferous forests are relatively rare in the northern hemisphere south of 40° N latitude; and (2) giant sequoias (*Sequoiadendron giganteum*) are present in the Sierra Nevada, which some authors consider to be members of the subtropical mountain system.

Rocky Mountains The Rocky Mountain (19–65° N latitude) northern coniferous forest has a subalpine forest above, characterized by subalpine fir (*Abies lasiocarpa*), white or Engelmann spruce (*Picea glauca,*

P. engelmannii), and depending on latitude other conifer species. Species diversity increases moving south from the boreal forest.

In the Boreal Rocky Mountains (53–65° N latitude), the northern coniferous forest is above the boreal forest dominated by aspen, balsam fir (*Abies balsamea*), white spruce, and jackpine (*Pinus banksiana*), with black spruce (*Picea mariana*) and tamarack (*Larix laricina*) in wetter areas (**Figure 1**). The northern coniferous forest is not complex having both boreal and subalpine species plus lodgepole pine (*Pinus contorta* var. *latifolia*). White spruce dominates at low and mid elevations. Common broadleaf trees are birch hybrids (*Betula* spp.), aspen, and balsam poplar (*Populus balsamifera*). The northern limit is marked by the absence of lodgepole pine and subalpine fir. The southern boundary is the transition between the Peace and Fraser River drainages. This roughly corresponds to Engelmann spruce and Douglas-fir's (*Pseudotsuga menziesii* var. *glauca*) northern distribution limit.

The Central Rocky Mountain (45–53° N latitude) northern coniferous forest is a rich productive forest rising to 1800 m in elevation above Rocky Mountain (western) juniper–ponderosa pine (*Juniperus scopulorum–Pinus ponderosa*) woodlands from 800 to 1500 m. It is dominated by cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), and Douglas-fir on the western slopes. Western white pine (*P. monticola*) and western larch (*Larix occidentalis*) are common on mesic and drier sites as are white–Engelmann (interior) spruce hybrids on wetter ecosystems (**Figure 2**). This is the most productive complex of the northern coniferous forest with site indices at 100 years (SI_{100}) of 40 m for spruce and 38 m for white pine and Douglas-fir. The eastern slopes are less diverse and not as productive. Aspen and paper birch are the dominant broadleaf species and are usually found in seral mixed species stands. The subalpine forest, in addition to *Abies* and *Picea*, has whitebark pine (*Pinus albicaulis*), limber pine (*P. flexilis*), mountain hemlock (*Tsuga mertensiana*), and subalpine larch (*Larix lyallii*). The Central sector is defined by the distribution of whitebark pine.

Ponderosa pine parklands in the Southern Rocky Mountains (33–45° N latitude) are below two northern coniferous forest zones. The lower is a Douglas-fir forest with white fir (*Abies concolor*) and Colorado blue spruce (*Picea pungens*) and the upper is a lodgepole pine forest. Aspen is the primary broadleaf species. The subalpine, in addition to spruce and fir, has bristlecone pine (*Pinus aristata*).

The Madrean (19–35° N latitude) northern coniferous forest has complex topography and flora. About half of the world's pine species occur in Mexico. Fir forests (*Abies concolor*, *A. religiosa*, and *A. guatemalensis*) with codominant *Pinus*, *Quercus*, *Pseudotsuga*, and *Cupressus* species usually occur below *Pinus hartwegii* forests. Douglas-fir associated with *P. flexilis* and *Abies concolor* occurs below the fir-dominated forests. A ponderosa pine parkland is

Figure 1 Boreal Rocky Mountain northern coniferous forest rising above the boreal forest at 59° N.

Figure 2 Central Rocky Mountain northern coniferous forest at 54° N; mixed wood stands dominate recent cutovers.

below the Douglas-fir forest and above a mixed pine–oak (*P. edulis*, *P. cembroides–Quercus arizonica*, *Q. gambelii*) chaparral in southern regions and a pinyon–juniper (*P. edulis–Juniperus* spp.) pygmy conifer woodland in northern regions.

Plateau The Nechako and Fraser Plateaux comprise much of central British Columbia. The western portions are in the rainshadow of the Coast Mountains and are less productive than more easterly portions (**Figure 3**). Rain shadow areas are dominated by lodgepole pine with interior spruce occurring on rich, moist soils. The primary species, moving east away from the rainshadow, are interior spruce and subalpine fir with Douglas-fir occurring on drier sites. Lodgepole pine is a seral species on much of the plateau but it may be the climax species of the rainshadow region.

Intermountain From 37° to 45° N latitude, between the Rocky Mountains and the Cascade–Sierra complex are mountain chains, isolated like islands, in an otherwise very arid, high elevation environment. Above a pinyon–juniper woodland from 1500 to 2500 m is the northern coniferous forest. A white fir montane forest with lodgepole pine, ponderosa pine, and Douglas-fir on mesic sites characterizes the region. The subalpine is dominated by limber pine, subalpine fir, and the intermountain bristlecone pine (*Pinus longaeva*). On very arid ranges, the subalpine is absent and pinyon pine covers the slope.

Mesoamerica Low mountain pine forests of Guatemala, Belize, Honduras, and Nicaragua are usually stands of *Pinus oocarpa* although *P. caribaea* may be present. *Pinus hartwegii* and *Juniperus standleyi* are the major species of high mountain humid forests in northern Mesoamerica. *Abies guatemalensis* and *A. religiosa* continue southwards from Mexico and dominate the high mountain, perhumid forests of northern Mesoamerica.

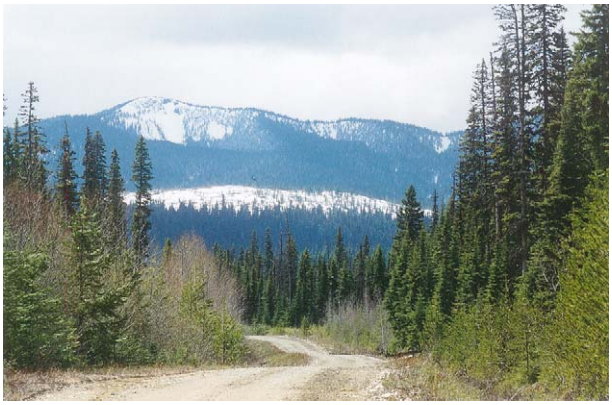

Figure 3 Northern coniferous forest on the rolling eastern Fraser Plateau; interior spruce and subalpine fir dominate on mesic and wetter sites.

Coast and Cascade Mountains In the Coast and Cascade Ranges (43–49.5° N latitude), the northern coniferous forest starts immediately above the temperate coniferous forest. Along the western slope of the Cascades and in the Coast Range, the northern coniferous forest has a lower amabilis fir (*A. amabilis*) zone and an upper mountain hemlock zone. These forests are nearly as productive as those of the Central Rocky Mountains. The northern coniferous forest consists of a ponderosa pine forest often with Douglas-fir, and a mesic *Abies* or mountain hemlock forest above 1500 m, but below the subalpine on the eastern Cascade slopes.

Other Northern Coniferous Forests

Appalachians Above the elevational limit of the deciduous forest along the Appalachian chain are dense, even-aged, red spruce (*Picea rubens*) stands. *Abies* increases in abundance with elevation (*A. balsamea* in the north, *A. fraseri* in the south). Pure subalpine stands can form if the mountain has sufficient elevation. In mixed spruce–fir stands, fir is shorter-lived and faster-growing than spruce. The Appalachian northern coniferous forest has been severely impacted by acid rain, woolly aphid, and unknown mortality agents over the past 25 years.

Southeastern USA Pre-European settlement pine forests were old and open, and contained a two-layered canopy and diverse groundcover. Upland pine forest of the southeastern USA can be classified into three general communities: northern pine barrens, xeric sand communities, and mesic pine communities. Pine–oak forests (*Pinus serotina–Quercus stellata*, *Q. marilandica*) of the northern pine barrens are confined to Delaware Bay. Longleaf pine (*P. palustris*) dominates the xeric, well-drained coarse sands of the southern coastal plain. Historically fire return intervals of 3–6 years maintained the open nature and facilitated reproduction of this forest. Mesic pine communities are generally dominated by an even-aged, closed canopy of longleaf, loblolly (*P. taeda*), pond (*P. serotina*), and/or slash (*P. elliottii*) pine. Species composition depends on site quality and disturbance frequency. Today's pine forest is young, dense, dominated by loblolly pine with a substantial hardwood component, has little or no groundcover, and accounts for nearly 60% of the USA's wood production.

Europe The northern coniferous forest is a significant component of mountain forests in France,

Germany, and Switzerland. Generally it is found above a beech–conifer (*Fagus sylvatica*–conifer) mixed wood, and is typified by a spruce–fir (*Abies alba–Picea abies*) forest below a pine–larch (*Pinus cembra*, *P. nigra*, *P. sylvestris–Larix decidua*) forest. In the Carpathian Mountains, a spruce northern coniferous forest lies above a broadleaf forest and below a mixed beech–fir forest. The northern coniferous forest of the Ural Mountains is a spruce–fir (*Picea obovata–Abies sibirica*) forest below a spruce–fir–Siberian stone pine (*Pinus sibirica*) forest.

Asian subcontinent The northern coniferous forest in northern and northwest Pakistan is diverse. It contains deodar (*Cedrus deodara*), kail (*Pinus wallichiana*), spruce (*Picea smithiana*), and silver fir (*Abies pindrow*), with chir (*Pinus longifolia*) at lower elevations and on hot southerly aspects. A subalpine spruce–fir forest again lies above the northern coniferous forest. The northern coniferous forest of the Himalayas continues eastward from Pakistan to Sikkim at high elevations: 1500–3300 m in the west, 2750–3350 m in Sikkim. Pencil juniper (*Juniperus macropoda*) and pine (*Pinus gerardiana*) are found throughout Kashmir while in moister valleys there are deodar and silver fir. In Nepal or the central Himalayas, northern coniferous forest species include silver fir, *Picea smithiana*, cedar, hemlock (*Tsuga dumosa*), and kail. Kail, *Picea spinulosa*, *Juniperus wallichiana*, hemlock, and *Larix griffithii* are the northern coniferous forest species at the eastern end of the Himalayas.

East Asia In China, the northern coniferous forest is a spruce–fir (*Picea brachytyla–Abies fabri*) forest with hemlock (*Tsuga chinensis*). Eastward to Korea, the northern coniferous forest is north of 40° N latitude. Species include *Picea jezoensis*, *Abies nephrolepis*, *Larix koreanna*, *Picea koyamae*, *Pinus koraiensis*, and *A. holophylla*. The northern coniferous forest decreases in elevation moving north along the Japanese island chain. The forest is fir–spruce (*A. homolepis–Picea jezoensis*) with a yew (*Taxus cuspidata*) component.

History of the Northern Coniferous Forest in Western North America and Europe

Expansion of high montane and mixed coniferous forest at high latitudes and high elevations began 35 to 11 million years before present (BP). This coincided with a significant drop in North American temperature. Cooling continued from 10 to 2 million years BP concomitant with a retreat in hardwood forests from mid and high latitudes and a continental expansion of coniferous forest. The present day Boreal and Central Rocky Mountain northern coniferous forest regions were covered with ice when the Cordilleran and Laurentide ice sheets joined at the last glacial maximum (LGM) about 18 000 years BP. The LGM defined present North American distributions of plant communities. Glacial refugia existed in the Queen Charlotte Islands, the exposed Coastal Plain, and areas to the south of the ice sheet (e.g., Clearwater River drainage in Idaho). The ice sheets separated and retreated from 13 500 to 11 000 years BP. This resulted in a corridor, the Rocky Mountain Trench, for northern coniferous forest species migration from refugia. It is predicted that with climate change the northern coniferous forest will expand into boreal and subalpine forests in coming centuries.

Much of northern Europe was covered by large ice sheets at the LGM, about 22 000 to 14 000 years BP. Forests and woodlands were nonexistent except for isolated pockets of woody vegetation in southern European mountains. Birch and conifers (open woodland) were present in European Russia 13 000 years BP. Open woodland returned to much of Europe by 12 000 years BP. Open woodland retreated during the younger Dryas and forest returned to much of Europe by 9000 to 8000 years BP. A warm period persisted from 7000 to 5000 years BP and forests spread northward. Present-day northern coniferous forest was established about 4500 years BP.

Environment

Climate

Climate is the most important determinant of natural terrestrial ecosystems. In western North America, the northern coniferous forest has a continental climate with a moderating maritime influence. Similar to the boreal forest, winters are cold and summers are short: growing degree days average about 90 in the north to more than 120 in the south. Mean annual temperature ranges from 0.5°C in the north and at high elevations to 9°C in the south. The average temperature drops below 0°C for approximately 4 months (range 1–5) of the year, and rises above 10°C for 2–5 months. Generally, frost can occur in any month. Precipitation varies by locality; it is least in valleys and increases with slope position. It ranges from 300 to 1650 mm, of which 25–50% falls as snow.

Soils

Over time, soils develop as a function of parent material, climate, biota, and topography. Generally northern coniferous forest soils are young. In the Central Rocky Mountains, mesic soils are humo–feric

podzols and brunisolic or orthic gray luvisols. Podzolic soils are typical of the northern coniferous forest but given the complex topography and variety of parent materials, many soil types can develop. Podzols are well drained and are leached of clay and organic matter. The lack of calcium in these soils makes them susceptible to erosion and weathering. Brunisolic soils result from slow weathering and/or restricted development due to long winters and low temperatures in cold climates and lack of soil moisture in dry climates. Brunisols are found primarily in forested areas such as lodgepole pine forests. Luvisolic soils are characterized by a horizon of clay in the subsoil resulting from leaching which may restrict root penetration. Luvisols form under forest cover having either high rainfall or low temperature. The northern coniferous forest organic soil layer arises through slow humification of forest litter low in nutrients and high in resins, waxes, and lignins. Climate warming may promote a change in soil type due to increased respiration and accelerated loss of organic matter.

Disturbance

Historically, fire has been the most important and conspicuous disturbance agent of the Rocky Mountains. European settlement and fire suppression reduced fire frequency in the northern coniferous forest in the twentieth century. Consequences include altered species composition, increased insect and pathogen epidemics, and enhanced probability of catastrophic fires due to increased fuel loading. The fire cycle or fire return interval lengthens with increased elevation. Fire intensity decreases with increased fire frequency: low-intensity fires every 5–12 years in ponderosa pine woodlands versus stand-replacing fires every 100 years in lodgepole pine forests to every 200–400 years in higher elevation forests.

Insect and pathogen outbreaks are also primary northern coniferous forest disturbance agents. The spruce beetle (*Dendroctonus rufipennis*) killed virtually all spruce in northwestern Colorado during the 1940s. The mountain pine beetle (*D. ponderosae*) infested 2 million ha in the western USA from 1979 to 1983. On the Fraser and Nechako plateaux in British Columbia, in excess of 5 million ha of the northern coniferous forest were infested with mountain pine beetle in the spring of 2003. Many have attributed serious pest outbreaks in the northern coniferous forest to the success of wildfire control programs and climate change. Fungal pathogens such as *Armillaria*, *Phellinus*, and *Tomentosis* can also be significant disturbance agents.

There are other northern coniferous forest disturbance agents. Wind destroys patches of old, high-elevation stands with increased bole rot. Avalanches can be significant disturbance events on a local scale. In some areas, indiscriminate grazing by native and domestic ungulates can impact regenerating vegetation or lead to forest degradation.

Global Warming

Past changes in climate were natural processes that probably drove species extinction as well as speciation. The current concern surrounding climate change is relevant because (1) the rate of change appears to be greater than most previous changes, (2) ecosystems are often more fragmented, except perhaps in the boreal forest, resulting in barriers to species migration, and (3) most ecosystems serve multiple needs and loss – damage to forests will have significant environmental, economic, and social impacts.

Warming is expected to be more significant at higher latitudes. To accommodate changing climate patterns, species will shift to more northern latitudes and higher elevations. This will alter the northern coniferous forest distribution. In addition to increased temperature and precipitation, frequency of extreme weather events will increase.

Temperature is hypothesized to increase by 1° to 4.5°C within the present century. With a temperature change of 3°C, species would have to move about 250 km in latitude or 500 m in elevation to maintain the same temperature. Tree species have variable rates of migration, 1 to 45 km per century. Predicted temperature shifts requiring migrations of over 100 km per century are beyond the dispersal abilities of coniferous species. If species cannot migrate, they will: (1) exist at current locations with reduced productivity and presence, (2) adapt slowly to changing conditions, or (3) become extinct. Where there are obligate community relationships, e.g., deer and forest type, deer will only be able to migrate at the same speed as the tree species unless an alternate forest type is found. This could lead to local extinctions.

Forest Dynamics, Management, and Utilization

Stand Dynamics

Stand development following disturbance is a function of local elevation, moisture gradients, and soil. Mesic stands in the northern coniferous forest exhibit developmental stages widely encountered in boreal and montane conifer forests. The first stage or establishment stage is characterized by little competition and significant seedling establishment and growth. The second, stem exclusion stage is typified

by competition among trees resulting in mortality and increased tree size. Little, if any, recruitment occurs. The third, understory reinitiation stage results when gaps occur in the canopy allowing new regeneration. The fourth, equilibrium or old-growth stage is when, simplistically, tree mortality is balanced by tree recruitment. Due to frequent disturbances, stands rarely reach the equilibrium stage in the northern coniferous forest; a noted exception is the Central Rocky Mountain's hemlock–cedar-dominated forests.

Where competition is minimal and seed supply is abundant, establishment occurs in 10 years. However, establishment is typically prolonged, 40–70 years, particularly on severe or very good sites where herbs can overtop seedlings. At higher elevations, tree establishment is slower and results in multiple age classes. Consequently the stem exclusion stage is bypassed, and tree mortality and recruitment of the third stage follow stand establishment. At lower elevations where fires are not detrimental to the canopy trees, seedling regeneration occurs in waves assisted by a good seed year, favorable weather, and no fire. Stand dynamics can also vary along environmental gradients: on a mesic north-facing slope an even-aged Douglas-fir stand will develop while on the adjacent south-facing slope an uneven-aged, open Douglas-fir stand will establish with understory lodgepole pine.

Productivity

In the Rocky Mountain northern coniferous forest, biomass peaks early in stem exclusion, declines as mortality increases and then increases as recruitment proceeds. Species diversity tends to track resource availability, dropping dramatically at the start of stem exclusion and staying low until understory reinitiating. The northern coniferous forest is a moderate carbon store compared to temperate rainforest and boreal forests. The northern coniferous forest produces 6–18 tonnes ha^{-1} $year^{-1}$ compared to 4–12 tonnes ha^{-1} $year^{-1}$ on upland boreal sites and 15–25 tonnes ha^{-1} $year^{-1}$ in the temperate rainforest.

Nontimber forest products and environmental services can be classified as being market or nonmarket regulated. Market products and services include grazing, medicinal plants, edible products (mushrooms, wild rice), decorative products, trapping, and outfitting. Nonmarket items include traditional first nation's uses, hunting, fishing, birdwatching, and ecotourism. In order to provide timber, nontimber forest products, and environmental services, northern coniferous forest seral stage diversity must be maintained.

Environmental Services

The northern coniferous forest provides many important values or services in addition to fiber production for subsistence and industrial uses. Watershed quality and water production is a function of a healthy, intact forest cover. Forest cover regulates snow storage and snowmelting rates by snow interception, shading, and wind amelioration. Peak flow and soil erosion are reduced by intact forest cover. Erosion is further reduced when groundcover vegetation is present. Maintenance of northern coniferous forest forested slopes helps regulate stream temperature and stabilize steep slopes.

Wildlife species diversity is a function of the complexity of tree species and associated understory vegetation. Wildlife is directly linked to seral stages of the northern coniferous forest (or any plant community). As wildlife species have different preferences for different plant species, they have different life or stand developmental stage (seral) needs. Time of year (season) may also result in different habitat needs for a species. Maintenance of riparian areas is crucial for fish survival and mature forest habitat is critical to some species' survival. Therefore, it is important to have seral stage (structural) diversity, including standing and fallen dead wood, to maintain northern coniferous forest species diversity.

Forests in the northern coniferous forest are increasingly managed to provide leisure and recreational services. They include hiking, photography, birdwatching, hunting, and fishing. This places leisure and recreational management in conflict with traditional forest product management. In addition to parks and wilderness areas for recreational services, managing for northern coniferous forest seral stage diversity will provide ongoing recreational opportunities.

Management and Utilization

Industrial activity in the northern coniferous forest varies by locale. About half of the world's pulp comes from the northern coniferous forest. In Canada, there is significant harvesting activity as the northern coniferous forest is second in productivity only to the northern temperate coastal forest. In the western USA, logging activities have fallen during the 1990s due to a focus on forest services rather than forest products: 57 million m^3 were cut on US National Forests in 1986 and 23 million m^3 were cut in 1996. The northern coniferous forest is part of the industrial forest of Europe while on the Asian subcontinent it provides fuel and subsistence for local peoples as well as industrial wood.

Depending on northern coniferous forest locale, even- or uneven-aged management may be utilized.

Silvicultural system selection dictates harvesting systems and equipment (if any). Steep slopes in much of the northern coniferous forest also influence equipment selection. In general, cable systems are required on steeper ground while ground-based systems can be used if slopes do not exceed 30–50%. Soils of the northern coniferous forest are young and often thin, which influences equipment selection. The risk of soil degradation is generally greater with ground-based systems. Harvesting is highly mechanized on large-scale western North American operations whereas in Eastern and Central Europe, power saws and small tractors are used in small-scale forestry operations. In Asia, past forestry practices have significantly compromised the productivity of the northern coniferous forest due to flooding and erosion. Small-scale fuelwood collection and mechanized harvesting are both practiced in the Asian northern coniferous forest.

Significance

The northern coniferous forest provides a significant proportion of the world's industrial forest products as well as nontimber forest products and environmental services. It helps to maintain the social fabric of indigenous peoples and preserve aboriginal culture. The northern coniferous forest also provides services such as watershed integrity, habitat, and recreational and leisure opportunities. Compared to boreal and subalpine forest, the northern coniferous forest is diverse and productive. A challenge for northern coniferous forest managers, worldwide, is to maintain structural and species diversity without compromising the potential of the northern coniferous forest to provide its products and environmental services.

See also: **Operations**: Forest Operations Management. **Temperate and Mediterranean Forests**: Southern Coniferous Forests; Subalpine and Boreal Forests; Temperate Broadleaved Deciduous Forest. **Temperate Ecosystems**: Pines; Spruces, Firs and Larches

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Southern Coniferous Forests

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Introduction

When referring to coniferous forests, an image comes to mind of the great boreal forests of the northern hemisphere or carefully managed and regular pine plantations. The native conifer forests of the southern hemisphere rarely conform to this image. In fact, except in a few cases, the term 'coniferous forest' is a misnomer and most of the associations described in this section might more properly be called 'forests with a coniferous element.' Most of the southern hemisphere conifers are of exclusively southern hemisphere families or, in the case of those families which are represented in both hemispheres, are of genera which are represented only in the southern hemisphere. In a total of 67 conifer genera and 557 species worldwide, 31 genera and some 200 species are largely southern and 160 species are totally southern. Of those genera that are found in both hemispheres only one 'northern' genus is found in the southern hemisphere while 12 'southern' species extend into the northern hemisphere mainly into