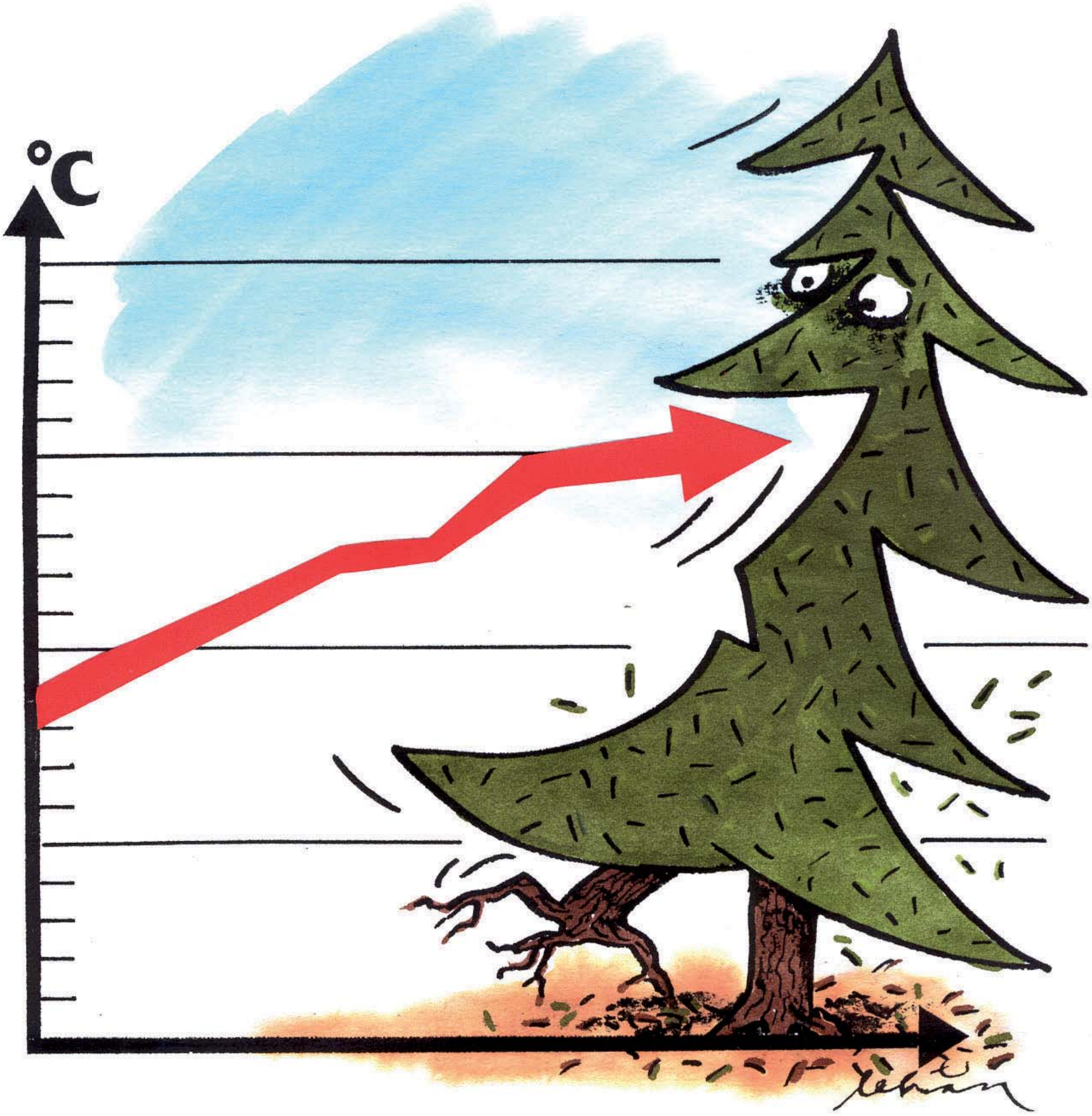

Boreal Forest and Climate Change

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Boreal Forest and Climate Change

By Roger Olsson

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Contents

About the author: Roger Olsson is a Swedish journalist and science writer. He has for many years worked as an expert for environment NGOs and other institutions and has published several books on, among other things, forest management and biodiversity.

Executive summary

About one third of the world' s forest is boreal, and about half of the boreal forest is still primary, i. e. largely unaffected by forestry and other human activities. This is the largest remaining intact forest ecosystem on earth. The fate of this forest over the 21st century will largely be governed by natural dynamics and their responses to climate change.

The boreal forest has a heavy impact on the global climate through its effect on radiation balance and the carbon cycle. The boreal forest holds almost one third of the world´s vegetation and soil carbon.

The long-standing view that forests must be managed and regenerated to serve as carbon sinks has recently been challenged. Old-growth forests accumulate carbon for centuries (up to 800 years of age) and thus contain vast quantities of it. Much of this carbon will be lost to the atmosphere if they are disturbed.

If global warming exceeds 1.5-2.5°C forests globally face the risk of major vegetation changes. The boreal forest is likely to be especially affected because of its sensitivity to temperature and the high rates of warming in the Arctic region.

This far, warming has either increased or decreased tree growth in the boreal forest. As global warming increases, negative effects on tree and forest growth are likely to be more widespread.

A straightforward response of the boreal forest to a warmer climate would be for the vegetation in any present zone to migrate northward and eventually reconstitute the zone further north. However, this is not likely to happen. One obvious reason for this is that even with warming of just 2°C climate zones will shift northwards at a rate of five kilometres per year, which exceeds the recorded migration responses of trees by a factor of ten. A more likely scenario is a non-linear forest response resulting in the creation of new ecosystems.

On the tundra, north of the boreal forest zone, the treeline has advanced polewards in response to recent warming, but this does not mean that boreal forest is about to colonize tundra on a broad front. Due to climatic factors there is probably a time-lag of 100-200 years, and parts of the tundra may well remain treeless.

In addition, permafrost thawing is likely to affect boreal forest distribution. One possible outcome of permafrost collapse is the transformation of forest into peatland.

Disturbance – wildfire, windthrow and insect attacks – is the driving force behind vegetation dynamics in the boreal biome. Climate, disturbance, and vegetation interact and affect each other, and together they influence the rate and pattern of changes in vegetation, the rate of future disturbance, and the pattern of new forest development. Nevertheless, current projections of vegetation response to climate change either assume that the disturbance regime does not change or use globally averaged disturbance rates.

Over the last few decades, forest fires have become more frequent and the area burned has increased all over the boreal region. In North America the area increased by a factor of 2.5 between the 1960s and the 1990s. As temperature increases, forest fires will be even more common and fires will tend to be more severe. Even at 2°C warming large increases in the areal extent of extreme fire danger is projected. If global warming exceeds 4°C the area burned in North American boreal forest could double. Windthrow and insect outbreaks are also expected to increase in frequency and intensity with projected changes in global climate.

It has been suggested that forest ecosystems in Canada recently shifted from a carbon sink to a carbon source as a result of the increase in disturbance regimes (fire and insect attacks). The positive feedback of carbon losses from forest fires has the potential to be a major factor in climate change. Increased carbon emissions result in a warmer and drier climate, which will create conditions conducive to more fires.

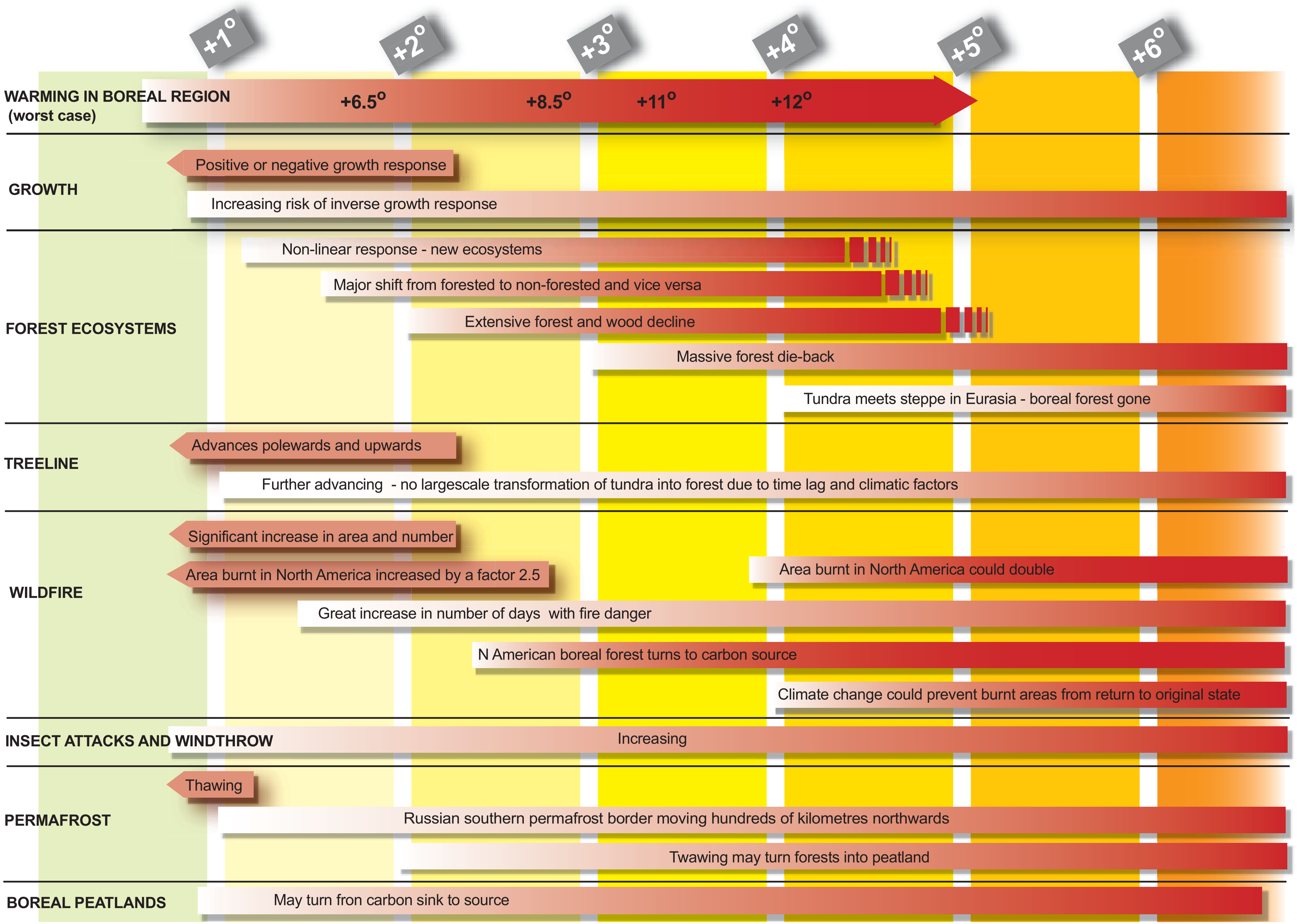
The boreal peatlands have served as carbon sink since the most recent deglaciation, and store between 15 and 30 per cent of global soil carbon stock. Disturbances, most importantly wildfire, may compromise this important carbon sink, eventually turning it into a source.

If global warming exceeds 2°C direct climate effects on forest growth and distribution, combined with climate-induced changes in disturbance regimes, may transform vast areas of boreal forest into open woodland or grassland. The critical limit for large-scale boreal forest dieback may be a rise of 3-5°C. This has been identified as one of the critical tipping points of global change, where positive feedback effects on the climate may cause runaway warming – in this case by the release of enormous amounts of carbon into the atmosphere.

Figure 1 (opposite page). Schematic overview of projected climate induced changes in the boreal forest within this century, related to average global warming. Further explanations for each change listed is given in the text.

Actual climate-induced effect seen at present warming (0.8°C)

The bar illustrates the risk for the change happening, related to temperature increase. More intense red indicates a higher risk. The shift from white to red indicates at which temperature the change may occur. Thus, a slow gradual change of color indicates a greater degree of uncertainty than a sudden change.



+1°
+2°
+3°
+4°
+5°
+6°
WARMING IN BOREAL REGION (worst case)
+6.5°
+8.5°
+11°
+12°
GROWTH
Positive or negative growth response
Increasing risk of inverse growth response
FOREST ECOSYSTEMS
Non-linear response - new ecosystems
Major shift from forested to non-forested and vice versa
Extensive forest and wood decline
Massive forest die-back
Tundra meets steppe in Eurasia - boreal forest gone
TREELINE
Advances polewards and upwards
Further advancing - no largescale transformation of tundra into forest due to time lag and climatic factors
WILDFIRE
Significant increase in area and number
Area burnt in North America increased by a factor 2.5
Great increase in number of days with fire danger
N American boreal forest turns to carbon source
Area burnt in North America could double
Climate change could prevent burnt areas from return to original state
INSECT ATTACKS AND WINDTHROW
Increasing
PERMAFROST
Thawing
Russian southern permafrost border moving hundreds of kilometres northwards
Twawing may turn forests into peatland
BOREAL PEATLANDS
May turn fron carbon sink to source

Scope and method

Figures of warming given in this report are global mean temperature, unless otherwise stated. Thus "2°C warming" means an increase of the global mean air temperature (at earth´s surface) by two degrees above pre-industrial level by the end of this century.

This report summarises and analyses present knowledge on how the boreal forest will be affected by climate change, and how this transformation may feedback on the global climate. The principal questions it tries to answer are:

- What will happen to the boreal forest with a global warming of 2°C by the end of this century?
- What will be the consequences if global warming exceeds 2°C.

The reason for focusing on the +2 degrees scenario is explained below.

The report mainly deals with the unmanaged old-growth forests in the northern part of the boreal zone. This is because we think more attention needs to be paid to the fate of the largest remaining intact forest ecosystem on earth. Furthermore, climate-induced changes in the boreal forests may have severe feedback effects on the global climate.

The data and conclusions presented are based on a literature study. An important starting point for the analysis was the Arctic Climate Impact Assessment, published by the Arctic Council in 2005. In updating the conclusions in this report, relevant scientific papers published in peer-reviewed journals from 2004 until June 2009 have been reviewed. As concerns Russia, additional data and perspectives have been obtained from a number of sources published in Russian, particularly the "Assessment Report on Climate Change and its Consequences for the Russian Federation", published by the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydormet) by the end of 2008. The fact that this source is a government report – even if compiled by leading Russian scientists – has been considered in the analysis. A separate report reviewing the Russian sources will be published at *www.airclim.org*.

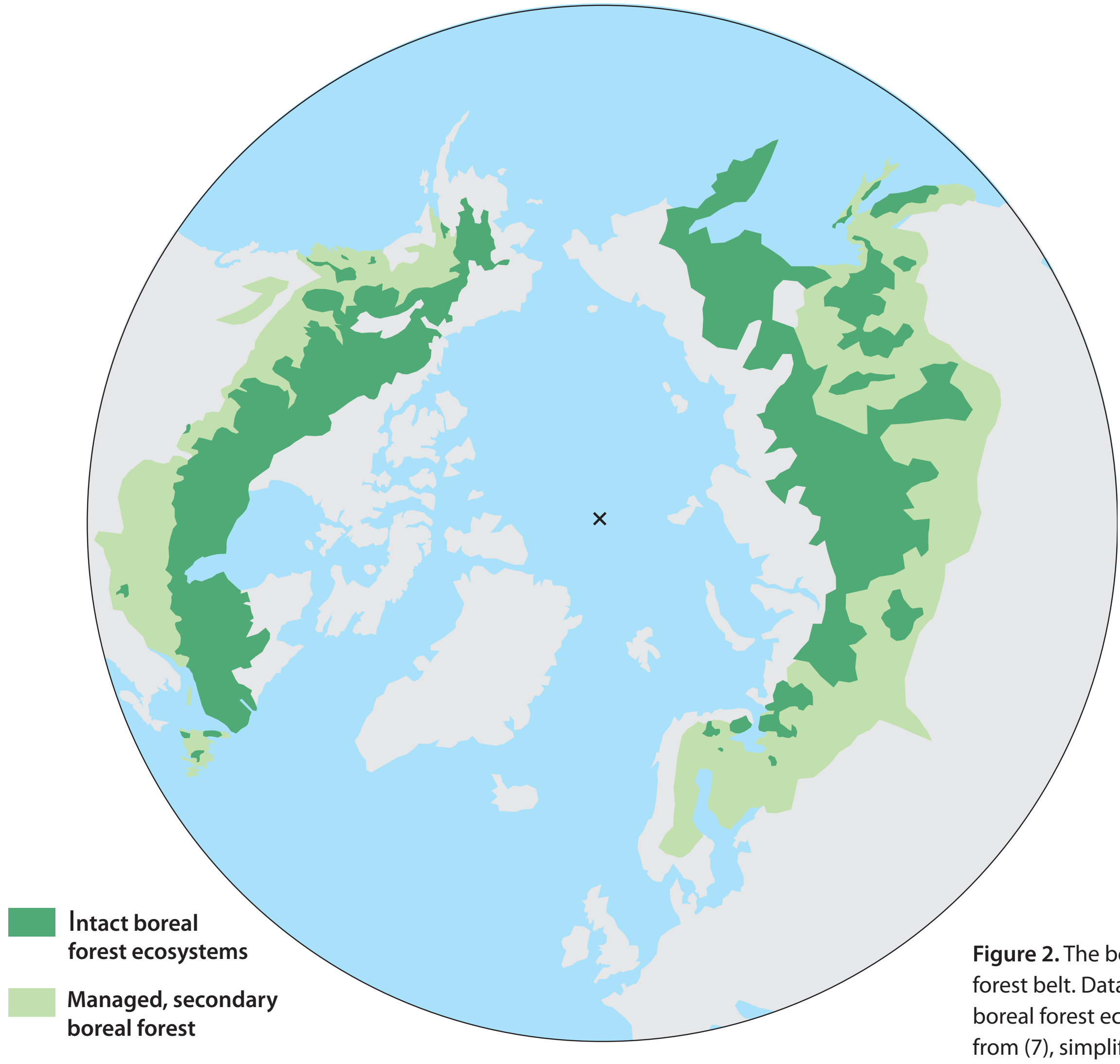


Figure 2. The boreal forest belt. Data on intact boreal forest ecosystems from (7), simplified.

The boreal forest

The boreal forest is the largest continuous land ecosystem in the world, covering about 14 per cent of the earth´s vegetated surface. It forms a "green belt" of various width on the northern hemisphere stretching through Russia, Alaska, Canada and Scandinavia, roughly between latitude 45 and 70° N. The total area of the boreal forest is about 1.4 billion hectares or about 38 per cent of global forest area. The largest part by far of the boreal forest is in Russia.[46]

To the north the boreal forest is succeeded by treeless tundra. In the south the border is less pronounced, forming a transition zone to broadleaved temperate forests.

The continuous winter snow-cover is one of the most important factors in boreal ecology, as it provides an insulating blanket protecting the ground surface from the full impact of low winter air temperatures, thereby creating a micro-environment of vital importance for the survival of many plants and animals. Nevertheless, vast areas of boreal forest experience periods of permafrost and some parts, mostly in Siberia, grow in areas with continuous permafrost.[50]

About half of the boreal forest is still primary, with very limited impact from forestry and other human activities. In general, the largest areas of intact forest are in the remote and very sparsely populated north, with a gradient of increasing human impact to the south.[7] In fact, more than half of the world´s remaining large tracts of relatively undisturbed forest are boreal forests in Canada and Russia.[1]

The most intensely managed part of the boreal forest is in Scandinavia and western Russia, where only patches of old-growth forest remain in reserves.

The boreal forest provides not only timber but also a number of crucial ecosystem services, such as clean water. Furthermore, it has a regulating effect on the global climate, primarily through its effect on the radiation balance and its important role in the global carbon cycle.

Global warming and the +2°C limit

Global warming scenarios

The measurable global warming up to date is 0.8°C (above the preindustrial level by the end of the 19th century).[12] The UN Intergovernmental Panel on Climate Change (IPCC) predicts that warming will continue and reach 1.1 - 2.9°C (best estimate 1.8°C) by the year 2100, if greenhouse gas concentrations in the atmosphere can be stabilised at about twice the pre-industrial level. This scenario presumes a rapid decrease in emissions. If the use of fossil fuels continues to grow to such an extent that greenhouse gas concentrations stabilise at about three times pre-industrial levels, the temperature will raise by 2.4 - 6.4°C (best estimate 4.0°C).[17]

The +2°C limit

A warming of 2°C is considered to be a threshold for catastrophic climate change, beyond which positive feedback loops may be triggered in the Earth system, causing runaway global warming. The International scientific conference on Climate Change in Copenhagen, March 2009, concluded that temperature rises above 2°C will be very difficult for society to cope with.* Other authoritative bodies have reached similar conclusions, which in turn has made an increasing number of states commit themselves to the political target of limiting global warming to below 2°C. At present (summer 2009), 133 states, together accounting for 75per cent of global energy and industry-related carbon dioxide (CO_2) emissions, have made such committments.[11]

*) Key messages from the Congress, 12 March 2009. *http://climatecongress.ku.dk/newsroom/congress_key_messages*

In order to stay below the +2°C limit, emissions of greenhouse gases would have to peak no later than 2015 and must be reduced 50-85 per cent by 2050. However, with current climate change mitigation policies, greenhouse gas emissions will continue to grow over the next few decades.[18] In fact, global CO_2 emissions are presently increasing at a rate exceeding those in IPCC's highest emission scenarios.[41] If this trend persists, greenhouse gas concentrations will reach levels causing global warming of more than 4°C.

Climate change in the boreal region

Virtually all projections show that warming in the Arctic region (north of latitude 60 °N) will be far above the global average, which is also consistent with observed trends.[42]

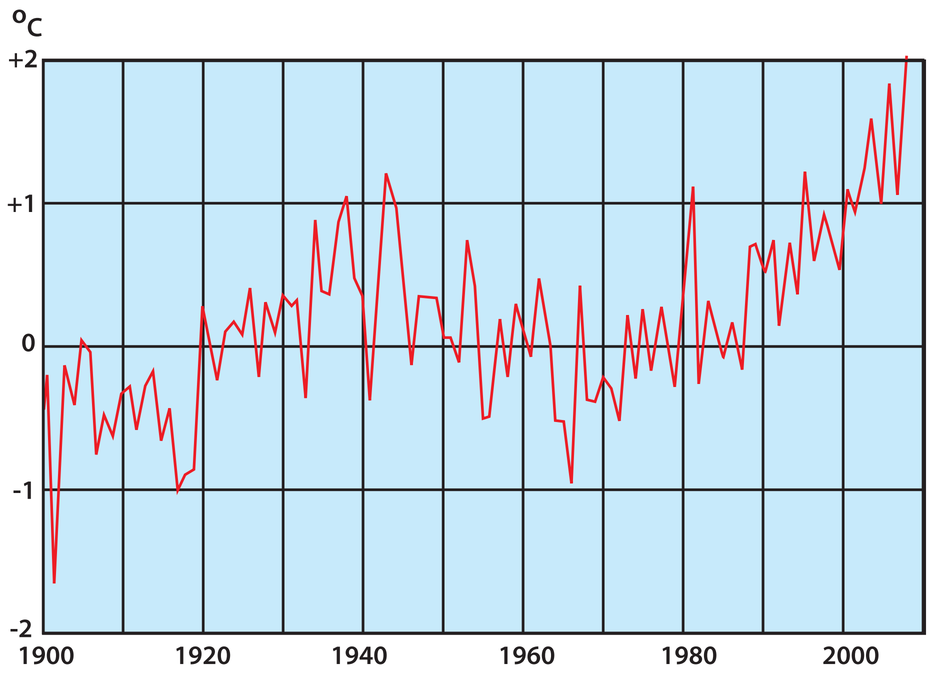


Figure 3. Actual annual mean surface temperature change in the Arctic 1900-2005, shown as deviation from the 1961 -1990 mean. [42]

Average Arctic temperatures have increased almost twice the global rate in the past 100 years.[17]

If global mean temperature in the 21st century increases by 2.8°C, most of the boreal forest belt will experience 4-5°C warming, and some northern parts of Canada even more (see figure 4). For high-emission scenarios temperature increases in the boreal region are projected to be even bigger *(see table 1)*. As shown in figure 6 winter temperatures will increase far more than summer temperatures. [18]

It should be noted, that these figures originate from the rather moderate scenarios in the IPCC's fourth assessment. As stressed above, the actual emissions are increasing at a rate exceeding those in the IPCC's highest emission scenarios. Furthermore, IPCC's projections do not take into account the possible or probable positive feedback effects on global warming from large-scale, climate-induced changes in the Earth system, such as for example permafrost thawing or forest die-back. A recent study from the UK Met Office, including such feedback loops, indicates that a global warming of 4°C would mean a 10-12°C rise in large parts of the boreal forest region. The regional differences are considerable, with the biggest temperature increases in eastern Canada and central Russia and the smallest (6-8°C) in the Scandinavian boreal region *(see figure 4, bottom)* .[57]

All climate models project that annual mean precipitation will increase over the entire Arctic. For high-emission scenarios 15-20 per cent increase is projected over the 21st century for most of the region. In parts of Siberia and most of Alaska the increase is pro-

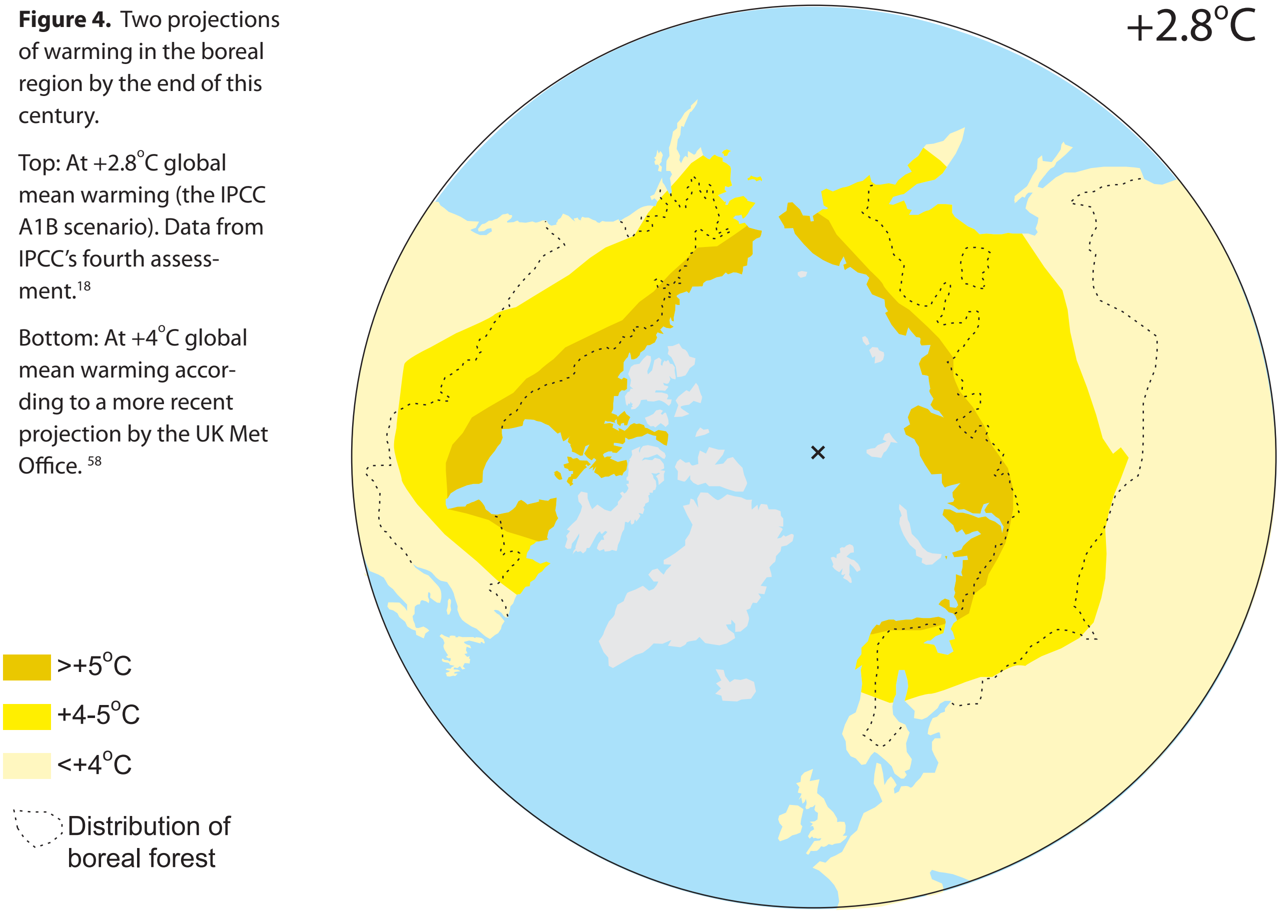
IPCC scenario	B1	A1B	A2
Global mean	1.8 (1.1-2.9)	2.8 (1.7-4.4)	3.4 (2.0-5.4)
Northern Asia	2-5	3.5-6	4-8.5
Western N America	2-6.5	3.5-8.5	4->11
Eastern N America	2-5.5	3-7.5	4-9.5
Northern Europe	1.5-4.5	3-6	3.5-6.5

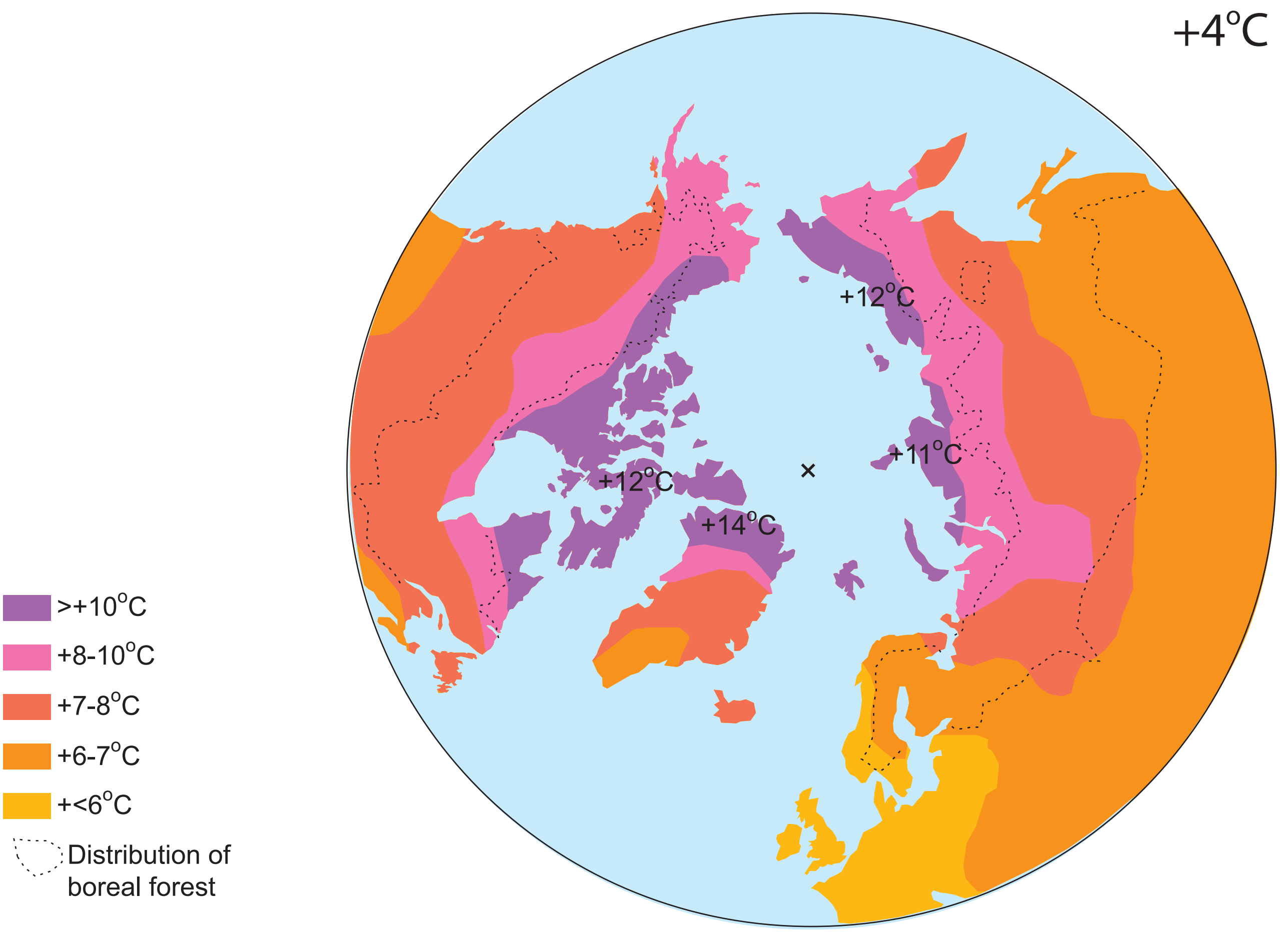
Table 1. Warming in the boreal forest region (°C annual mean, by the end of this century) under three different IPCC scenarios. (From data in 18.)

Figure 4. Two projections of warming in the boreal region by the end of this century.

Top: At +2.8°C global mean warming (the IPCC A1B scenario). Data from IPCC's fourth assessment.[18]

Bottom: At +4°C global mean warming according to a more recent projection by the UK Met Office.[58]





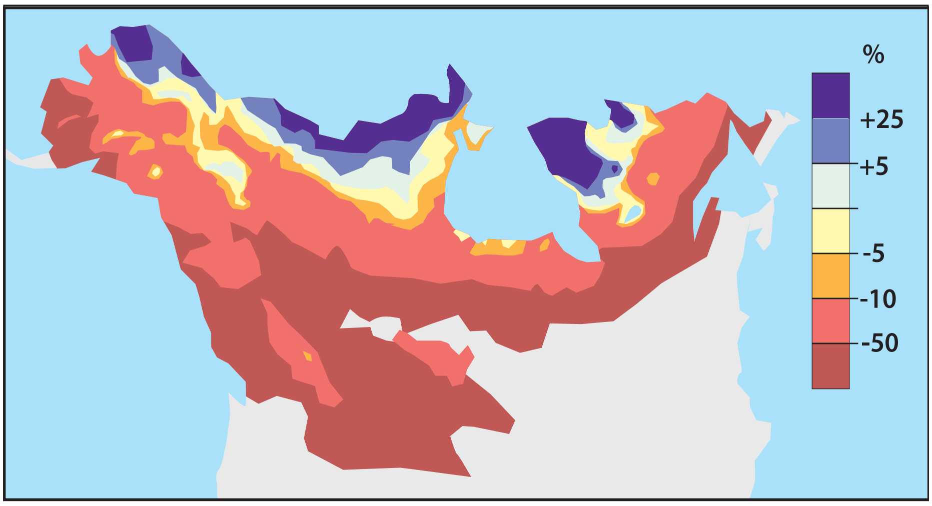


Figure 5. Projected snow depth changes in March in North America at +3.4°C warming (A2 scenario), compared to 1961-1990.[18]

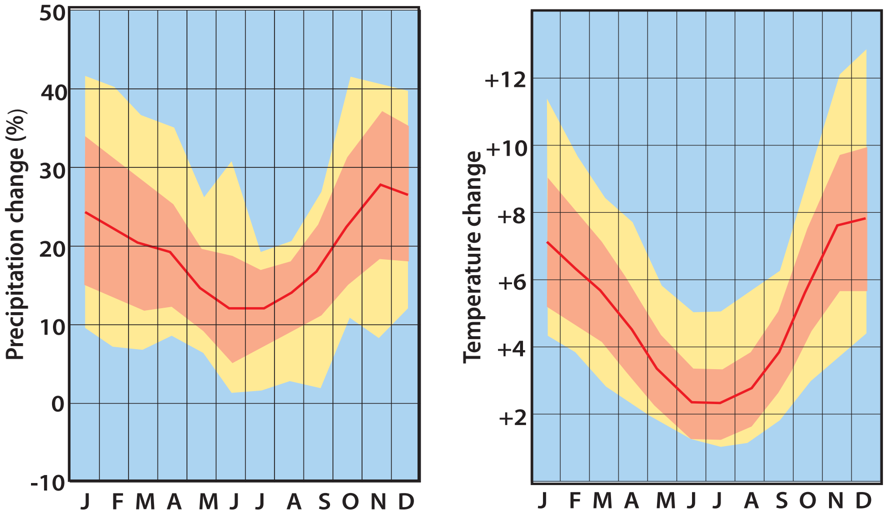


Figure 6. Projected annual change, month by month, in precipitation (left) and mean temperature (right) in the Arctic region at 4°C warming. Expressed as changes from 1980-1999 mean values. The read line represents the total median of 21 climate models, while the yellow area shows the total range of all models.[18]

jected to exceed 20 per cent. In southern Canada and Russia, precipitation is projected to increase in winter and spring, but decrease in summer.[15 18]

Snow cover area is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. It is very likely that extreme climate events, such as heat waves, heavy precipitation, spring temperature backlashes and summer drought will increase in frequency and duration.[17 44]

How global warming affects the boreal forest

Global warming is already strongly affecting terrestrial biological systems, including such changes as earlier timing of spring events and poleward and upward shifts in ranges in plant and animal species.[17] In northern latitudes an extension of the growing season by up to two weeks has been observed.[19]

For increases in global average temperature exceeding 1.5-2.5°C, forests globally face the risk of major transformation of forested land into non-forested and vice versa, and this risk will be further pronounced if warming exceeds 3°C.[20] Boreal forest is likely to be especially affected by climate change, because of its sensitivity to warming and the high rates of projected warming in the Arctic region.[17]

Like other ecosystems, boreal forests are likely to respond to increasing external forcing in a non-linear manner. Most initial ecosystem responses appear to dampen change, but amplify it if thresholds in magnitude or rate of change are surpassed.[20]

Tree and forest growth

It may seem reasonable to assume that moderate levels of warming would be beneficial for tree and forest growth, especially where the growing season is short and temperature a limiting factor. Furthermore, increasing atmospheric CO_2-content (CO_2 fertilization) could in itself facilitate faster growth of green plants, since carbon dioxide and water are the raw naterials of the fundamental process of photosynthesis, through which green plants "feed" on solar energy.

However, the actual growth response of boreal forests to global warming so far is not unequivocal. Warmer temperatures over the last few decades have either improved or decreased tree growth, depending on tree species, site type and region. Some tree-growth declines are large and have been seen at different points across a wide area. Temperature-induced drought stress has been identified as the cause in some areas.[1]

Studies of tree-rings from all parts of he boreal forest zone have shown that inverse growth responses to temperature during the 20th century are widespread, occurring in all investigated conifer species and in nearly all geographic areas. Growth decline occurred more frequently in the warmer part of the distribution area of each species, suggesting that direct temperature stress might be a factor. At many sites the response of trees to temperature changed after 1950 (approximately), as correlations with temperature weakened or, in some cases, shifted from positive to negative. Several causes has been suggested for this, including temperature stress and drought stress.[33 15]

For Canadian boreal forest it has been shown that the potential effect of climate change related warming on growth is exacerbated or offset depending on whether these changes are accompanied by decreases or increases in precipitation, respectively.[22]

As global warming increases, negative effects on tree and forest growth may be even more widespread, because ecosystems and species will be unable to adapt to increasingly extreme environmental conditions.[20] It should be kept in mind, for example, that atmospheric CO_2 content has been relatively stable below 300 ppm for at least the last 600,000 years, which means that the ability of trees to cope with higher levels has not been tested during evolution.[16]

At 2°C warming models predict a radical growth decline for jack pine, aspen and black spruce in managed forest in Manitoba, Canada. The positive effect of extended growing season length could be counteracted by increasing summer temperatures causing drought stress.[13] In this part of the boreal region, precipitation is likely to decrease in summer.

The growth of boreal forests is strongly limited by the availability of nitrogen in the soil, which may be one explanation why warmer climate and increased CO_2 availability do not result in increased growth. It is indicative that positive growth responses have generally been detected where moisture and nutrients are not limiting, such as in Europe and eastern North America.[1] These parts of the boreal forest belt, close to populated and industrialised regions, are affected by anthropogenic nitrogen deposition. In some areas, deposition is more than ten times the natural background level. Even so, anthropogenic nitrogen deposition is assumed to affect no more than 30 per cent of the total boreal forest area, while lack of available soil nitrogen will remain a limiting factor for tree and forest growth in the remaining 70 per cent.[16]

Effects on forest ecosystems

Northward shift or new ecosystems?

A straightforward response of the boreal forest to a warmer climate would be for the vegetation in any present zone to migrate northward and eventually reconstitute the zone further north. A number of model studies have projected such a wholesale redistribution of trees in the 21st century (typically in the range of 500 km or more northward migration[26]), where large parts of the present tundra is transformed into boreal forest. How-ever, the output of these vegetation models is generally based on the assumption that trees will occupy all climatically suitable areas. This is not likely to happen. One obvious reason for this is that the migratory responses necessary to track climate zones far exceed what has been recorded for the period since the last ice-age.[2] Even with just 2°C warming a northward shift of boreal climate zones by 500 km by the end of this century is projected by several models.[25] This climate zone shift rate of 5 km per year could be compared to estimates for migration rates of trees, averaging at 200-300 metres per year.[20]

It is also noteworthy that nothing comparable to the present boreal forest biome existed in earlier warm periods in the history of our planet. During the global "greenhouse" interval of the Late Mesozoic and Paleogene era (245-23 million years ago) evergreen taxa do not appear to have been competitive in the lowlands of the high arctic. Instead the vegetation consisted of a unique circumpolar forest dominated by deciduous conifers and broadleaved trees. Probable sources for the tree species of today's boreal forest were the evergreen forests of the mountain range in western North America. If evergreen taxa are unable to survive at low elevations at high polar latitudes, global warming might once again make such conifers restricted to montane refugia, while the lowlands of the high arctic would be populated by a larch-dominated deciduous conifer forest of low diversity and limited geographic extent.[49]

Biomes are the large ecosystems of the earth. Savanna, steppe and tropical rainforest are examples of biomes.

Pollen and fossil data from northeast Siberia, Alaska, and northwest Canada indicates that during the early Holocene (13,000-10,000 years ago), shrub tundra ecosystems responded to climate warming through a shift to deciduous forest or woodland. The shift could have happened rapidly, and the new vegetation was structurally and functionally different from today's dominant vegetation types. Thus, the development of deciduous boreal forest is a possible feedback response of vegetation to global warming.[8]

Furthermore, projected increase in temperature is very likely to result in thawing of permafrost in considerable parts of the boreal forest region. This would transform forest soils and create site conditions that have few or no current analogues.[1]

Even if global warming is limited to 2°C a more likely scenario than northward shift of present boreal forest ecosystems is a nonlinear forest response, including effects not seen within the range of temperature variability experienced during the last millennium.[1] Species with limited capacity to adapt to new environments will likely face extinction.[2]

Tree line movement

The concept or model of a northward shift of vegetation zones in response to global warming includes boreal vegetation spreading into tundra at higher latitudes and higher elevations as the climate becomes warmer.

In fact, shrubs and the tree line already have advanced polewards in response to recent warming,[20 15] but satellite data show no expansion of boreal forest into tundra, indicating century-long time-lags for the forest limit. This indicates considerable uncertainties in how fast forests will shift northwards. The time-lags may weell be century-long.[20]

In Alaska the mean lag between initiation of recruitment and forest development above the present treeline was estimated at approximately 200 years, similar to the findings of modelling studies. Although the continued advance of white spruce forests is the most likely scenario of future change, nonlinear forest response to warming may be likely due to limitation of spruce establishment in permafrost-affected sites, changes in seed dispersal and early establishment, and recent changes in the growth responses of individual trees to temperature.[34]

Over the past century, tree lines of Norway spruce, Scots pine and aspen rose at 95 per cent of studied localities in the mountain region of Scandinavia, with means of 70-90 metres and maximum upshifts by about 200 metres, which manifests a near-perfect equilibrium with recorded air temperature change. However, this magnitude of response was realised only in particular topographic situations, foremost wind-sheltered and steep concave slopes. Other sites, with more wind-exposed conditions, experienced lesser magnitudes of upshifts. Thus, even in the case of substantial climate warming, tree lines are unlikely to advance on a broad front and a large proportion of the alpine tundra will remain treeless.[26] A study from Quebec confirms that local topographic factors influence the rise in tree lines and recent establishment by seed. Reforestation of the southernmost tundra sites might be slowed down by the harsh wind-exposure conditions.[12]

Changing disturbance regimes

The previous two sections have dealt with the direct response of trees and forests to climate change. However, in order to understand the full effect of global warming on the boreal forest, one also has to consider the fundamental importance of disturbance regimes. Disturbance is the driving force behind vegetation dynamics in the boreal biome. Wildfires, tree-fall events caused by wind and tree-killing insect outbreaks all play major roles that can affect large portions of the landscape. Fire is particularly significant, not only because of the large areas affected and the heavy impact on forest and soils. Furthermore, fire has direct feedback effects on permafrost dynamics, regional climate, and the storage and release of carbon.[1]

Climatic factors, especially prolonged periods of warm weather, often create the conditions that result in fire and insect disturbances in boreal forests. The boreal forest is already subject to rapid changes causing long-term consequences as a result of such climate-related effects. Landscape-scale interactions between vegetation and disturbance are particularly important in the forest–tundra ecotone, where vegetation change is very likely to have large feedback effects on climate.[1]

Climate, disturbance, and vegetation interact and affect each other, and together they influence the rate and pattern of changes in vegetation, the rate of future disturbance, and the pattern of new forest development. Knowledge of these interactions and feedback effects is critical in order to understand how scenarios of climate change will affect future disturbance regimes and the consequences these ecological changes will have for boreal forests. Nevertheless, current projections of vegetation response to climate change either assume that the disturbance regime does not change or use globally averaged disturbance rates. [1]

Forest fires

Apart from regions where forest management measures decrease the risk of ignition and where fire suppression is present and efficient, forest fires have become more frequent and the area burned has grown all over the boreal forest region during the last few decades.

Across the entire North American boreal region the total burned area increased by a factor of 2.5 between the 1960s and the 1990s, while the area burned as a result of manmade fires remained constant.[23] The annual area burned in western North America doubled in the last 20 years of the 20th century.[1]

In Canada, five of the eight largest fire years since 1920 transpired in the last 17 years. Over the 56 years of forest fire record in Alaska, seven of the eleven largest fire years have occurred since 1988, which is consistent with the increased number of large fire years in Canada and Russia.[46]

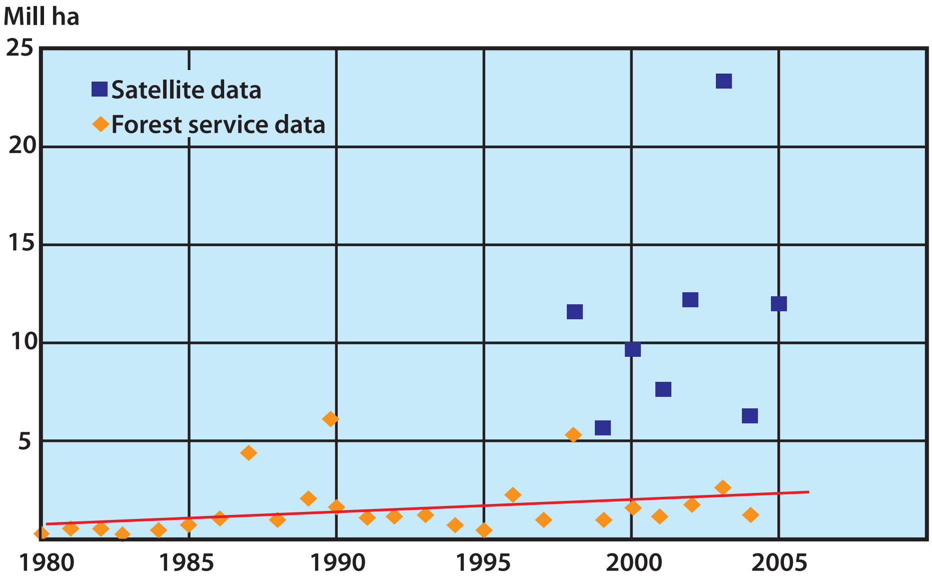
According to official Russian data, on average about one million hectares of forest was affected by fire annually during the years 2003-2007. The area burned in the warm decade of the 1990s was 29 per cent greater than the area burned during the 1980s. It should be noted that there is a big difference between official fire statistics and satellite data: the burnt area is on average 55 per cent larger according to satellite data. However, both data sets show an increase in area burned since 1998. During normal fire years, about 22 per cent of the area burned in Russia is by high-severity crown fires. In extreme fire years this figure increases to about 50 per cent. High-severity crown fires dominated four of the five years from 1998 to 2002. Furthermore, 2003, 2005 and 2006 were also extreme fire years. Consequently, seven of the nine years 1998-2006 have been extreme fire years in Siberia.[46]

The reform of the Russian forest management administration over the last few years has greatly affected the efficiency of wildfire suppression in Russia. The airborne fire suppression forces *(Avialesookhrana)*, which previously had about 10,000 employees (including paratroopers) and access to several hundred aircraft, has been deprived of much of its former capacity.[15]

Outputs from four climate models have been used to project forest fire danger in Canada and Russia in a warmer climate. All four models projected large increases in the area extent of extreme fire danger in both countries with a warming of around 2°C. Scenarios are still of limited use, however, in projecting changes in ignitions.[1,15]

Modelling suggests further increases in wildfire impact during this century under a wide range of scenarios.[20] If global warming reaches 4°C the area burned in the North American boreal forest could increase by 74-118 per cent by the end of the 21st century.[10]

Figure 7. Area burned in Russia 1980-2005 according to official statistics and satellite data. [46]



The number of days with fire danger conditions is projected to increase by maximum 12 –30 per cent in the Russian boreal forest zone during the 21st century as a response to a global warming of 2.4°C. The maximum increase is expected for the southern forest zone boundary both in European Russia and in Siberia, while no significant increase is projected for other areas.[36] Fire management agencies' ability to cope with this increase is limited for a number of reasons, including the remoteness and inaccessibility of large parts of the boreal forest. As a result a large number of fires may escape initial attack under a warmer climate, resulting in an area burned that will be much greater than the corresponding increase in fire weather severity. Studies suggest a doubling of the area burned along with a 50 per cent increase in fire occurrence in parts of the boreal region.[10]

Changing fire regimes are likely to impact boreal forests at least as much as climate change itself. Already, intensified wildfire regimes appear to be changing vegetation structure and composition, with shifts from spruce- to pine-dominated communities and 75 to 95 per cent reduction in tree densities in Eastern Canada.[20]

One long-term potential consequence of intensified fire regimes arising from increasing temperatures is that fire-induced changes in vegetation are likely to lead to a more homogenous landscape dominated by early-successional deciduous forest.[1]

The changed climate and the altered surface conditions may in turn prevent the veg-e-tation from returning to its original state. The effect of fire on local climate and its implications for forest regeneration were studied in the Tuntsa area of Finnish Lapland, affected by a widespread forest fire in 1960. Among other effects, fire-induced deforestation increased the wind velocity by 60 per cent and changed the soil thermal regime due to a 20-30 cm reduction in snow cover. The resulting severe local climate is probably one of the precluding factors in the recovery of the forest in this sensitive region.[54]

Insect outbreaks

The impact of insect damage in boreal forests is significant. In terms of area affected, it exceeds that of fire. Spruce budworm, for example, defoliated over 20 times the area burned in eastern Ontario between 1941 and 1996.[55] British Columbia is presently experiencing an unprecedented outbreak of the mountain pine beetle, affecting 37 million hectares of boreal forest.[29] The multi-year outbreak of spruce beetle on the Kenai peninsula in Alaska resulted in about one million hectares of tree mortality from 1992 to 2000, or 90 per cent of the region's spruce.[55]

The timber loss due to a massive outbreak of Siberian moth in the Krasnoyarsk region, Russia, in the 1990's was assessed at 50 million m^3, equal to seven years of timber harvest in the region.[15] (It should be noted, however, that forest damage of the same or even bigger magnitude has previously been recorded over the last 100 years.[46])

The spruce beetle outbreak in Alaska was facilitated by the extreme impact of several years in a row of warm, dry summers. The increase from 2003 to 2004 was attributed to the record warm temperatures in the summer of 2004. The outbreak appeared to be triggered in part when temperatures became warm enough for beetles to complete their life cycle in one year rather than two.[55]

The spruce budworm is the most destructive insect defoliator of forests in North America. Climatic influences on this species' life history are considered a major factor in restricting the extent and intensity of outbreaks. It has been found that among spruce budworm populations, those from locations with extreme winters tend to have heavier eggs than those from more benign environments. This genetically based adaptation allows populations to increase their potential recruitment substantially when winters are mild, as each female can produce a larger number of eggs.[55]

Insect outbreaks are expected to increase in frequency and intensity with projected changes in global climate through direct effects of climate change on insect populations and through disruption of community interactions. In addition, climatic variability can enforce this effect through its impact on parasitoid-host interactions. A decrease in levels of parasitism as climatic variability increases has been shown, suggesting that climatic variability impairs the ability of parasitoids to track host populations. Given the important role of parasitoids in regulating insect herbivore populations in natural and managed systems, an increase in the frequency and intensity of herbivore outbreaks through a disruption of enemy-herbivore dynamics can be expected as climates become more variable. [48]

Windthrow

The number of extreme weather events, including storms, is projected to increase in the boreal region as an effect of global warming.[17] This is likely to increase the impact of windthrow and other forest damage due to strong winds in boreal forests.

Massive forest die-back - a boreal tipping element

If global warming exceeds 2°C the change of ecosystems in the boreal forest region may be even more far-reaching than outlined in previous sections. Direct effects of warming on forest growth and distribution, combined with indirect effects of climate-induced changes in disturbance regimes may transform vast areas of boreal forest into open woodland or grassland.

In regions where the boreal forest presently is succeeded by continental grasslands in he south, a contraction of forest is projected due to increased impacts of droughts, insects and fires. With a global warming of more than 2-3°C extensive forest and woodline decline in mid- to high latitudes is predicted. [20]

At the end of this century annual temperatures in the southern boreal forest of central Eurasia are projected to be in the range typical of present-day temperate forest, but water deficit and limitations in species migration could hinder development of temperate forest in this region. In Siberia, the current territory of southern taiga is projected to be replaced by forest steppe. At the upper range of temperature increases (+7°C or more in the arctic region) it is possible that warming and drying effects will bring tundra into contact with semi-arid steppe in Eurasia, meaning that the present boreal forest belt will be wiped out.[1]

A group of leading international experts has identified boreal forest die-back as one of nine possible global “tipping elements” of concern. A tipping element is a sudden and dramatic response as global warming exceeds a certain threshold value. One selection criteria for the expert group was that the non-linear response to global warming can be estimated to happen during this century and within the range of 6°C warming.[31]

The mechanisms behind boreal forest die-back would be increased water stress and higher peak summer heat causing increased mortality, also indirectly through higher vulnerability to disease. Increased fire frequency will be another important factor. In interior boreal regions, temperate tree species will not be able to establish further north due to frost damage in winters that can still be very cold. Once the critical threshold is passed, the process may be rather fast; the transition of the boreal forest ecosystem is estimated to take place over a period of about 50 years.[31]

The critical limit for large-scale boreal forest dieback may be +3-5°C (globally), but this figure is highly uncertain.[31]

Permafrost thawing

Permanently frozen ground, permafrost, covers vast areas in high latitudes of the northern hemisphere, where it is created and maintained by low winter temperatures. South of the permanent permafrost belt there are regions with discontinuous permafrost. In this zone, regional temperatures are not low enough to sustain permafrost everywhere, so patterns of permafrost distribution are determined to a large extent by local factors such as topography, hydrology, vegetation and snow cover.[45]

A large part of the boreal forest is growing on permafrost and will thus be affected by changes in soil structure and hydrology as global warming causes permafrost thawing. In Russia, the tundra-forest ecotone, dominated by spruce and larch, is several hundred kilometres wide. In the northern part of western Siberia vast expanses of boreal pine forest grow on permafrost.[15]

An **ecotone** is a transition area between two adjacent plant communities, such as forest and grassland.

One observed effect of permafrost thawing is an increase in windthrow. Another possible outcome is forest death from flooding when permafrost at the surface is thawing while underlying frozen soil prohibits draining.[15]

Simulations show that climate change has induced degradation of permafrost in most of Canada. From the 1850’s to the 1990’s, the area underlain by permafrost was reduced by 5.4 per cent. For those areas where permafrost existed in all the years throughout 1850-2002, the mean depth to the base of permafrost decreased (became shallower) by three metres and the mean active layer thickness increased by 34 per cent. Results also show that supra-permafrost taliks were formed and became larger and more frequent with climate warming in the southern permafrost region, which greatly enhanced permafrost thaw from the top and could have severe impacts on the landscape, hydrology and ecosystems.[56]

The active layer is the upper part of the permafrost that thaws during summer and freezes in winter.

Taliks are patches of unfrozen ground in permafrost areas.

Fires can remove the surface organic layer or decrease surface reflectivity, both of which increase ground heat flux and permafrost thawing. Natural fires are known to have resulted in repeated permafrost collapse in boreal peatlands since the last deglaciation, leading to significant changes in vegetation and surface hydrology.[45]

In Russia, global warming is expected to push the southern border of permafrost several hundred kilometres northwards. The most dramatic changes will occur in the lowlands of western Siberia.[15]

Investigation of peat cores within and adjacent to a permafrost collapse feature in Alaska shows a transition from a terrestrial forest to a sedge-dominated wetland over 100 years ago, and to a peat moss-dominated peatland in approximately 1970. The shift from

Figure 9. Distribution of permafrost in the Northern Hemisphere.[45]

sedge to peat moss coincided with an increase in the growing season temperature record. This concurrent wetland succession indicates a step-wise ecosystem-level response to a change in regional climate. Future warming and/or increased fire disturbance could promote permafrost degradation and peatland expansion across this landscape. However, the development of drought conditions could reduce the success of both black spruce and peat moss.[37]

How boreal forests affect the global climate

The boreal forest is not only affected by the climate. In fact, the boreal ecozone is a keystone region where both its sensitivity to change and its size make it likely to affect the global climate. It has the potential to impact the climate:

- by altering the radiation budget through albedo change (land use change, burned landscapes and species composition change)
- by modifying the global carbon budget by altering the sequestration and release of carbon
- by modifying the moisture balance.[46]

The ability of forests to sequester atmospheric carbon in biomass and in the soil is a very significant mechanism in this context. The boreal forest holds about 27 per cent of the world's vegetation carbon and between 25 and 30 per cent of the world's soil carbon.[52] Together, the boreal forest and northern tundra represent the largest reservoir of terrestrial carbon on Earth, primarily held in the organic soils of the forest floor.[46] The boreal forest plains within and immediately south of the discontinuous permafrost region occupy the zone of maximum carbon storage in soil organic matter on the Earth.[1] However, several studies have concluded that boreal forests have an overall warming effect on the climate because the cooling from storage of carbon in vegetation and soils is cancelled out by the warming due to the absorption of the sun's heat by the dark forest canopy.[47]

Effects on the radiation balance

Albedo

The boreal forest cover has a significant effect on the radiative balance of the planet. The rough-textured, dark surface of land covered with boreal forest canopy intercepts and absorbs a large part of solar radiation, converting it to heat. In contrast, the smooth, snow-covered surface of the tundra is highly reflective. In high-latitude regions where snow covers the ground for half the year or more, the albedo effect of tundra versus boreal forest cover is magnified.[1]

Climate model simulations show that the low surface albedo during the snow season warms climate compared to when there is an absence of trees. Consequently, the boreal forest has the greatest biogeophysical effect of all biomes on annual mean global temperature. Loss of boreal forest has a cooling effect,[5] while future expansion of the forest into present-day tundra regions would amplify warming.[1]

Increased future area burned could further alter the radiation balance, since it will create a more homogeneous landscape dominated by early-successional deciduous forest. A shift from coniferous to deciduous forest dominance is very likely to have a negative feedback effect on temperature increases due to changes in albedo.[1 3]

Aerosols and cloud formation

Through emission of organic vapours and the resulting condensational growth of particles in the atmosphere (aerosols), boreal forests double regional cloud condensation nuclei concentrations, thus facilitating cloud formation.[47] A study of European boreal forest indicates that the forest is a major source of climate-relevant aerosol particles, most likely also capable of competing with the anthropogenic loadings of cloud condensation nuclei transported over forested areas.[51]

A global homeostasis

The combination of radiative forcings related to boreal forests may result in an important global homeostasis. In cold climatic conditions, the snow-vegetation albedo effect dominates and boreal forests warm the climate, whereas in warmer climates they may emit sufficiently large amounts of organic vapour, modifying cloud albedo and acting to cool climate.[47] Climate-induced changes in vegetation types and distribution of boreal forests thus have important implications for radiation budget estimates and are of great relevance for the evaluation of feedback loops believed to determine our future climate.[51]

Boreal forests and the global carbon cycle

Boreal forest take up CO_2 through photosynthesis and store carbon in live and dead plant matter, including substantial long-term accumulations in large tree boles and in soil. Forests release CO_2 to the atmosphere through decomposition of dead organic matter, live plant and animal respiration, and combustion that takes place during fires.

Four processes largely control the storage and release of carbon in boreal forests:

- the rate of plant growth;
- the rate of decomposition of dead organic matter;
- the rate of permafrost accretion and degradation;
- the frequency and severity of fires.

All four processes are affected by landscape-scale disturbance. Rate, timing and pattern of disturbance by fire and insects are crucial factors in determining the net uptake or release of carbon by forests.[1]

The most likely mechanism for significant short-term change in boreal carbon cycling resulting from climate change is a change in rates of organic matter decomposition in the forest floor and mineral soil, resulting from major changes in species composition caused by alteration of disturbance regimes.[1]

Plant growth and vegetation changes

The uptake of atmospheric CO_2 by tree and other plant growth may either increase or decrease with increasing temperature, depending on the species, the geographic region, the range of the temperature increase, and other climate factors such as precipitation that are likely to change in a changing climate.[1] Previous model assessments of the response of land ecosystems to climate change concluded that terrestrial carbon sinks globally should peak by about the year 2050 and then diminish towards the end of the twenty-first century.[39]

As shown above, increased growth is far from always the response to climate change in boreal forests. Inverse growth response to warming is widespread and likely to become even more common as temperature increases. Furthermore, longer growing seasons and other projected climatic changes will also increase dead organic matter decomposition rates, and the ultimate outcome for carbon sequestration may not always be positive.[28]

The carbon balance in terrestrial ecosystems is particularly sensitive to climatic chang-

One Pg (Petagram) is 1,000,000,000,000,000 grams. It is also equal to one Gigatonne (Gt).

The global stock of carbon in soils is 1,500 Pg, while growing plants contain 500 Pg. The amount of carbon in the atmosphere is about 30 Pg, and the annual emissions from fossil fuels and industrial processes are 8 Pg. The boreal forest is estimated to be a carbon sink in the magnitude of 1 Pg/year.[17]

es in autumn and spring. It has been found that both photosynthesis and respiration increase during autumn warming, but the increase in respiration is greater. In contrast, warming increases photosynthesis more than respiration in spring. Simulations and observations indicate that northern terrestrial ecosystems may currently lose carbon in response to autumn warming at a rate of about 0.2 Pg carbon/ °C. This would offset 90 per cent of the increased carbon dioxide uptake during spring. Until now, warming has occurred at a faster rate in autumn than in spring. If this trend persists, the ability of northern ecosystems to sequester carbon may be diminished earlier than previously suggested.[39]

Model simulations of a black spruce forest in Alaska support the general conclusion that change in the seasonal weather pattern strongly affects the carbon balance, and that carbon sequestration will not necessarily increase in a warmer climate.[53] Total carbon stock in trees has been shown to increase with increasing soil summer degree-days, while carbon stock in the soil decreases. In other words, carbon stock is shifting from below- to above-ground reserves as temperature increases, which obviously has implications for the vulnerability of carbon lost in boreal forest wildfires.[21]

In the Russian forest as a whole, a pronounced increase in the share of green parts (leaves and needles) has been detected. In northern Siberia, where the climate has become warmer but drier, the fraction of green parts has decreased while the fractions of roots and above-ground wood has increased. These changes are consistent with experiments and mathematical models that predict a shift of carbon allocation to foliage with increasing temperature and lower allocation with increasing soil drought. The increase in the share of green parts may have caused a misinterpretation of the satellite data and a systematic overestimation by remote sensing methods of the carbon sink for living biomass of the Russian forest.[30]

Nitrogen deposition (or fertilisation) has the potential to increase boreal forest production and retard the decomposition of soil organic matter, hence increasing both tree stand and soil carbon storage.[38] However, this is not likely to be of importance in the northern old-growth forests, where nitrogen deposition is close to natural background levels. Not more than one third of the boreal forest area is estimated to be affected by deposition of anthropogenic nitrogen.[16]

It is a long-standing view that forests must be managed and regenerated to serve as carbon sinks, because ageing forests cease to accumulate carbon. However, it has recently been shown that old-growth forests accumulate carbon for centuries. The net carbon balance is usually positive in forests between the age of 15 and 800 years. Half of the primary, unmanaged forests of the world are located in the temperate and boreal forests of the northern hemisphere, the bulk of which is in the boreal. The living biomass and the soil in these forests are estimated to sequester about 1.3 Pg of carbon annually, which is equal to 10 per cent of the global ecosystem sink. Because old-growth forests accumulate carbon for centuries they contain vast quantities of it. Much of this carbon will be lost to the atmosphere if they are disturbed.[35]

Disturbance regimes

Disturbance of ecosystems is a major factor in regional carbon budgets, and it is believed to be partly responsible for the large inter-annual variability of the terrestrial part of the carbon balance. Model results and field experiments show that when ecosystems are disturbed, significant losses of soil carbon and nutrients can occur for a number of years after the disturbance. Forest fires have so far been considered as the most important disturbance, but insect outbreaks or windthrow may also contribute significantly.[1]

Modelling results suggest that forest ecosystems in Canada shifted from a carbon sink to a carbon source around 1980. This has been explained as a result of a change in the disturbance regime, which is consistent with recent fire statistics.[1]

Model projections for a hypothetical North American boreal forest landscape indicate that carbon losses from disturbances cannot be offset by increases in growth, if higher decomposition rates caused by altered disturbance regimes are taken into account. Very high increases in growth, sustained across the entire landscape, would be required to offset the increases in disturbance regimes hat are being projected for the North American boreal forest. However, as shown above , it is not likely that all boreal forest will exhibit enhanced growth as an outcome of global change.[28]

Fire

Fire plays a major role in the carbon dynamics of the circumboreal region, causing the release of carbon not only during but also after fires. Tree mortality after surface fires can be extensive, leading to a pulse of carbon released as fine roots die and above-ground fine plant material (i.e. needles) fall to the ground and decompose rapidly.[1]

The carbon balance of a Canadian boreal forest landscape was found to be driven by changes in fire disturbance from 1948 to 2005.[6]

There is evidence that fire scars on the landscape are a net carbon source for about 30 years after burning. Experiments in the Alaskan boreal forest showed that about 20 per cent of the carbon in the soil surface layer is lost through decomposition during the first 20 to 30 years after a fire due to increased soil temperature.[1]

In Canada forest fires released an average of 0.027 Pg carbon per year for the 1959-1999 period. In some years the release exceeded 0.1 Pg. In Siberia, an average of 0.2 Pg carbon was released from forest fires in the years from 1998 to 2002.[47] Together, the direct and indirect fire-generated carbon emissions from boreal forests worldwide may exceed 20 per cent of the estimated global emissions from all biomass burning.[1]

Modification of soil thermal regime and permafrost degradation as a result of fire have been documented. Warmer and drier conditions following a forest fire increase decomposition and decrease carbon storage. Simulation results suggest that a 5ºC warming results in a 6 to 20 per cent decrease in the total carbon stored in the soil over a 25-year period.[1]

Modelling studies of scenarios ranging from 2.4-3.4ºC warming suggest that carbon emissions from fire will increase by 2.5-4 times by 2100 (relative to the last decade of the 20^{th} century), depending on the scenario and assumptions about CO_2 fertilisation. Despite the increases in fire emissions, the simulations indicate that boreal North America will be a carbon sink over the 21^{st} century if CO_2 fertilisation is assumed to occur in the future. In contrast, simulations excluding CO_2 fertilisation indicate that the region will change to a carbon source, being 2.1 times greater at 3.4ºC warming than if warming can be limited to 2.4ºC.[4]

The positive feedback of carbon losses from forest fires has the potential to be a major factor in our changing climate, whereby increased carbon emissions results in a warmer and drier climate, which will create conditions conducive to more fire.[46] However, the increased frequency of fires will also feedback negatively by increasing the surface albedo. The net effect is complex because the severity of fire affects the trajectory of both carbon stocks and albedo following fire, and these are likely to differ between high latitude ecosystems in Eurasia and North America.[14] At least one study indicates that, averaged over an 80-year fire cycle, the negative forcing due to surface albedo exceeds the smaller positive forcing due to carbon losses.[5]

Insect outbreaks

So far, the impact of insects on forest carbon dynamics has generally been ignored in large-scale modelling analyses. Insect outbreaks neverrtheless represent an important mechanism by which climate change may undermine the ability of northern forests to store atmospheric carbon. The widespread tree mortality reduces forest carbon uptake and also increases future emissions from the decay of killed trees. The present outbreak of the mountain pine beetle in British Columbia is estimated to have converted 370,000 km^2 of forest from a small carbon sink to a large source, both during and immediately after the outbreak. In the worst year, the impact on the carbon balance of this outbreak was equal to 75 per cent of the average annual direct forest fire emissions from all of Canada.[29]

As a result of two major insect outbreaks the managed forests of Canada have recently shifted from carbon sink to source, and it is estimated that they could be a carbon source of between 0.030 and 0.245 Pg CO_2-equivalents per year during 2008-2012. This indicates, that future efforts to influence the carbon balance through forest management could be overwhelmed by increases in natural disturbances, not only in Canada.[27]

Windthrow

The "Gudrun" storm, which hit Sweden in January 2005, resulted in 66 million m^3 of windthrown stem wood over an area of about 2,720 km. It has been calculated that the net release of carbon from the windthrown area during the first year after the storm was 897-1,259 g carbon per square meter per year. This is a much higher carbon loss than from clear-cuts in European forests, which range between 100 and 420 g. The reduction in the carbon sink scaled up over the whole windthrown area was estimated to 0.003 Pg carbon during the first year. By historical data on windthrow in Europe combined with modelling, it was estimated that the large Lothar storm in 1999 reduced the European carbon balance by 0.016 Pg, which is about 30 per cent of the net biome production in Europe. Thus, the impact of increased forest damage by more frequent storms in future climate change scenarios must be considered.[32]

Permafrost thawing

Thawing permafrost and the resulting decomposition of previously frozen organic carbon is one of the most significant potential feedbacks from terrestrial ecosystems to the atmosphere. In addition, wildfires may contribute significantly to the offset of carbon from previously permafrost soils into the atmosphere.

Climate warming is likely to lead to net permafrost loss on regional and global scales. Despite mechanisms that can partially offset some of the effects of thawing permafrost on climate, the loss of carbon to the atmosphere is likely to represent a substantial source over the next century. For the entire circumpolar region addition of up to 50 to 100 Pg C (depending on emission scenario) to the atmosphere by the end of the century is predicted. One study estimates that 48 Pg carbon can be released from Canadian permafrost over this century if the mean annual air temperature increases by 4°C.

Model predictions incorporate changes in vegetation and other disturbances, as well as carbon release from permafrost, to determine the net effect of climate warming. However, they typically do not include the complex interactions that may cause rapid permafrost thaw. In combination with dry conditions or increased water infiltration, thawing and fires could, given the right set of circumstances, act together to expose and transfer permafrost carbon to the atmosphere very rapidly.

A recent projection of the consequenses of 4°C warming indicates almast complete disappearance of near-surface permafrost from northern Siberia.[58]

Increased carbon uptake by plant growth and an extended growing season are likely to be relatively small, while cooling albedo effects from fires will mostly offset only carbon emissions from those fires or from other warming albedo effects. None of these ecosystem mechanisms appears likely to offset carbon loss from permafrost thaw.

Above-ground tundra vegetation contains roughly 0.4 kg carbon per m^2, whereas boreal forest can average approximately 5 kg per m^2, suggesting that a gain on the order of 4.5 kg carbon per m^2 is possible if present tundra is colonised by forest. In contrast, a typical tundra permafrost soil can contain up to ten times that amount, compared with approximately 9 kg carbon per m^2 in the top metre of non-permafrost boreal forest soil. Thus, the potential carbon loss in transformation from permafrost tundra to boreal forest would be approximately 35 kg carbon per m^2. This potential loss can become greater (on the order of 100 kg carbon per m^2) if soil to the depth of three metres is considered.[45]

Boreal peatlands

Boreal peatland ecosystems occupy about 3.5 million km^2 of the Earth's land surface and store between 250 and 455 Pg of carbon as peat. While northern hemisphere peatlands have functioned as net sinks for atmospheric carbon since the most recent deglaciation, natural and anthropogenic disturbances, most importantly wildfire, may compromise peatland carbon sinks. Studies of a region in Alberta where peatland cover 2,280 km^2 indicate that an increase in non-winter temperature of 2°C and a doubling of the frequency of fires are likely to turn these *Sphagnum*-dominated bogs from carbon sinks into carbon sources.[24]

Sphagnum = peat mosses.

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Air Pollution & Climate Secretariat

(former Swedish NGO Secretariat on Acid Rain)

The essential aim of the Secretariat is to promote awareness of the problems associated with air pollution and climate change, and thus, in part as a result of public pressure, to bring about the needed reductions in the emissions of air pollutants and greenhouse gases. The aim is to have those emissions eventually brought down to levels that the environment can tolerate without suffering damage.

In furtherance of these aims, the Secretariat:

- Keeps up observation of political trends and scientific developments.
- Acts as an information centre, primarily for European environmentalist organizations, but also for the media, authorities, and researchers.
- Produces information material.
- Supports environmentalist bodies in other countries in their work towards common ends.
- Participates in the lobbying and campaigning activities of European environmentalist organizations concerning European policy relating to air quality and climate change, as well as in meetings of the Convention on Long-range Transboundary Air Pollution and the UN Framework Convention on Climate Change.

Taiga Rescue Network

Taiga Rescue Network (TRN) is a network of organisations and groups working to support local struggles and strengthen the cooperation between individuals, NGOs and indigenous peoples and nations concerned with the protection, restoration and sustainable use of the world's boreal forests by means that ensure the integrity of natural processes and dynamics.

The Network's working methods include

- Education and Advocacy: The network works to disseminate information among governments, industry, and the general public about boreal forest issues.
- Campaign Coordination: We promote cooperation through joint projects among NGOs and indigenous peoples.
- Research and Policy Analysis: We coordinate NGO input into various national and international processes and facilitate joint position papers outlining the NGO vision for sustainable forestry in the boreal region.

www.taigarescue.org

The northern part of the boreal forest belt is the largest remaining intact land ecosystem on earth. If this vast forest can be maintained it will continue to store enormous amounts of carbon for centuries to come.

However, the boreal forest is sensitive to temperature and grows in regions where warming is projected to be far above the global average. The effects of climate change are already evident in all parts of the boreal forest, and change will be far more dramatic as temperature continues to increase.

It has been a common perception that the boreal forest will respond to global warming by migrating northwards, eventually turning northern tundra into forest. This is not likely to happen. A rise of just two degrees may trigger the creation of new, hitherto unseen ecosystems. Three to five degrees warming may be the critical limit for massive forest die-back in the boreal region.

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