Boreal Forest and Climate Change - regional perspectives

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Boreal Forest and Climate Change - Regional Perspectives

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Introduction

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 varying width on the northern hemisphere stretching through Russia, Alaska, Canada and Scandinavia, roughly between latitude 45 and 70º 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.

Among the land ecosystems of the earth, 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. The effects of global warming on boreal forests on a global scale is discussed in the report ”Boreal Forest and Climate Change” (AirClim report #23, 2010).

This report covers some aspects of the interaction between climate change and boreal forest from a regional perspective, dealing separately with Scandinavia, Russia and North America (Canada). The state of the forest, species composition and forest management are dissimilar in these three parts of the boreal forest, which has to be considered when analysing the impact of global warming. Furthermore, the projected temperature increase by the end of this century differs considerably within the boreal region, especially in high emission scenarios.

Some basic facts and figures are taken from the report mentioned above, in which cases no sources are given here. The section on Russia is an edited extensive summary of a report compiled by Alexei Grigoriev for the Air Pollution & Climate Secretariat. For the large part it is a critical review of “Assessment Report of Climate Change in the Russian Federation”, published (in Russian) by Roshydromet (Federal Service for Hydrometeorology and Environmental Monitoring) at the end of 2008. The report is the most recent and authoritative assessment of present and projected consequences of climate change in Russia. The assessment has involved leading Russian scientists in the field (including a number of well-known climate skeptics). One should keep in mind that Roshydromet is a government agency, which means that the report represents the official Russian view of this issue.

The section on North America is mainly based on two reports:

- Carlson, M, Wells J, Roberts J 2009: The carbon the world forgot. Boreal Songbird Initiative and Canadian Boreal Initiative.
- Ferguson, Nelson E A, Sherman G 2008: Turning up the Heat. Global warming and the degradation of Canada´s Boreal Forest. Greenpeace Canada.

The sources for the part on Scandinavia are listed at the end of that section. Some basic facts and figures were taken from the AirClim report mentioned above. A full list of references can be found in that report.

The Scandinavian perspective

The boreal forest in Scandinavia

Finland has 20 million hectares of forested land, Sweden 24 million and Norway 8 million, in all three countries almost entirely consisting of boreal or boreal/nemoral forest. Together the Scandinavian countries contain about 4 per cent of the global boreal forest.

The forest type is similar to that of western Russia. Two coniferous tree species, Norway spruce end Scots pine, are dominant. In the southern parts mixed forests, with birch and aspen as the most common deciduous tree species, form a transition zone to the nemoral forest.

In Scandinavia, virtually all forests have been affected by forest management and to a very large extent also by industrial logging during the later part of the 20th century. Less than 5 per cent of the forest area remains in tracts of relatively undisturbed forest, primarily in nature reserves *(see note)*. Thus, the present boreal forest of Scandinavia is not to any extent formed by natural disturbances such as fire, but rather by forest policy, management regimes and forestry practices. This is a profound difference compared to the boreal forest of northern Canada and large parts of Russia, particularly in Siberia and the northeastern part of Europe. In other parts of European Russia forest management has transformed the forest as much as in Scandinavia, but remaining fragments of undisturbed forest are more common and generally larger.

The World Resources Institute uses the term "frontier forests" for the remaining large tracts of relatively undisturbed forests, big enough to support viable populations of all indigenous species associated with that forest type. For the purpose of this report this definiton is useful, as it defines the forest areas where natural dynamics is still working, and where the response of this dynamics to global warming is critical. Boreal forest that cannot be defined as frontier forest are in this report defined as managed, meaning that the major disturbance factor is forest management. Figures on remaining unmanaged forests in this report are from *"The last frontier Forests"* (Bryant et al 1997 / WRI).

Climate change in Scandinavia

All climate projections show that warming in Scandinavia will be less dramatic than in other parts of the boreal region. With global mean warming by the end of this century of +2°C the warming in Scandinavia is typically projected to stay at +2-4°C . With global mean warming of +4 °C, warming in the western and southern part of Scandinavia may be up to +5 °C, while it may exceed +6°C in the eastern part. In both cases other parts of the boreal region may experience temperature rises that are twice as high.

As a result of the temperature increase, the vegetation period is projected to become 1-2 months longer. Precipitation is projected to increase by 10 - 20 per cent, mostly in the winter. Extreme climate events, like spring temperature backlashes, are likely to increase in frequency and duration.There will be an increased risk of drought in parts of southern Scandinavia during the vegetation period.

Climate change and the Scandinavian boreal forest

The fact that almost all Scandinavian forest are under management and the comparatively moderate temperature increases projected must be kept in mind when analyzing the potential effects of global warming in this region. The potential for mitigating unwanted climate effects by management measures may be far greater than in northern Canada or Siberia. On the other hand the fate of this small fraction of the boreal forest belt is not of great significance in the carbon cycle and other global systems affecting the climate. This is mainly due to the limited area, but also to the fact that managed forests store far less carbon (in biomass and soils) than old-growth forest per area unit.

Shift of vegetation zones

A number of vegetation model studies project a northward shift of vegetation zones in response to global warming, typically in the range of 500 km by the end of this century under moderate climate scenarios. In Sweden, changes in species distribution and community composition of seven major tree species have been projected. The boreal tree line will shift upwards and northwards. In the boreal and boreo-nemoral zone, the dominance of Norway spruce and Scots pine will be reduced in favor of deciduous tree species.

Projected decreases in summer precipitation will likely affect spruce and birch on dry soils negatively, while the conditions for pine and oak will improve. By the end of this century drought may cause problems for spruce even on today´s mesic soils in parts of southern Sweden.

Vegetation model studies typically map the potential distribution of species or forest types, and do not take into account limitations in migration rates and other natural factors that may prohibit species from colonizing new suitable environments. Neither do the models include climate-induced changes in disturbance regimes. This makes vegetation model studies of limited value when it comes to projecting changes in unmanaged boreal forests. In the managed forests of Scandinavia, however, tree species composition is not primarily a consequence of natural processes but rather of forest management decisions. Predictions of future climate conditions may of course be useful in guiding such decisions. In fact, scientists, forest authorities and forest owners in Scandinavia are presently engaged in discussions on how to form a forest generation suitable for the future climate. A main focus is on the choice of tree species in reforestation.

Tree and forest growth

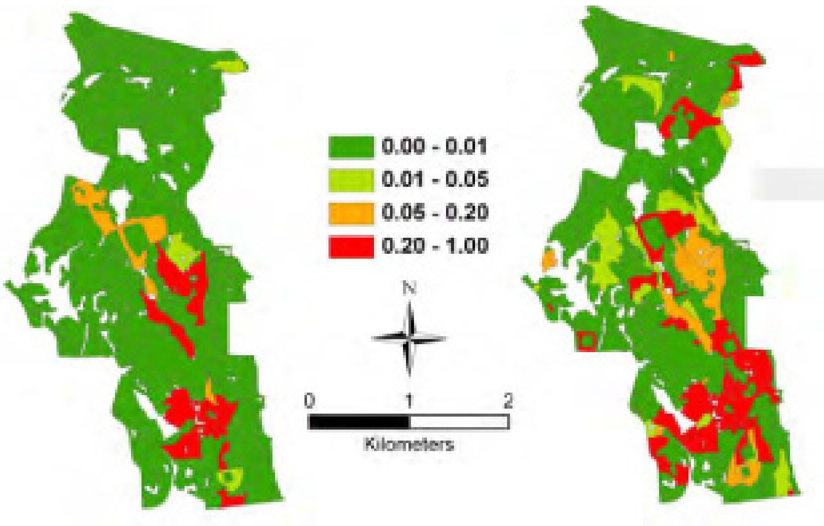
The prolonged vegetation period is generally believed to facilitate increased production in managed forests. The Swedish National Board of Forestry has estimated the possible increase at 24-31 per cent by the end of this century (under the IPCC B2 and A2 scenarios respectively). Since almost all of Scandinavia's forest is under the impact of anthropogenic nitrogen deposition, nitrogen is not likely to be a limiting factor to forest growth in the short run. It should be kept in mind, however, that the present forest generation is not well adapted to a warmer climate and will thus not be able to fully utilize a longer vegetation period. Management measures such as shorter rotation periods and changes in tree species(including introduction of alien species) are presently being investigated by the Swedish forestry sector.

Disturbances

In Scandinavia, logging and forest management is far more important to forest dynamics than natural disturbances. Using the EFISCEN model, the development of forest resources in 15 European countries over the 21st century was studied under a broad range of climate scenarios and under different assumptions of wood demand. Despite noticeable differences in the growth response between climate scenarios, changes in wood demand proved to be the crucial driving force in forest resource development.

EFISCEN - the European Forest Information Scenario Model. For further information on the model, see *www.efi.int/portal/completed_projects/efiscen/*

This is not to say that the effect of changing disturbance regimes can be neglected. According to a model study of climate effects on Norway spruce in Scandinavia, extreme climate events (spring temperature backlashes, summer drought) in combination with raised mean temperature will increase the susceptibility of trees to pests and pathogens.



Probability of windthrow in a forest area in southern Sweden over the period 2017-2100 under the present climate (left) and projected climate under the IPCC B2 scenario (right). (From SOU 2007:60)

Decreased forest vitality will in turn makes stands more susceptible to windthrow. Increased growth and higher trees will also increase the risk for windthrow, even if the number and severity of storm events remains constant. Marginally increased frequencies and wind speeds of storms may cause disproportionate increases in windthrow. Another factor contributiong to this development may be a decrease in winter frozen ground, especially in southern Scanmdinavia.

Increased windthrow by more frequent storms in the future climate may have considerable effect on the carbon balance. Model calculations indicate that the windthrow of 66 million m^3 of stem wood in the "Gudrun" storm in Sweden 2005 reduced the forest carbon sink by about 3 million tons during the first year, which is about one tenth of the total annual carbon sequestration of Swedish forests. The large "Lothar" storm in 1999 reduced the carbon balance by 16 million tons of carbon, which is about 30 per cent of the biome production in Europe. In the case of "Gudrun", the carbon loss per hectare was two or three times higher from windthrown areas than from clear-cuts in European forests.

Fire frequency is very low in the managed forest and the risk of wildfires is limited by the small amount of litter and dead wood. Even so, the possibility of increased fire frequency under a warmer and drier climate cannot be excluded. In the managed forests of Scandinavia, where fire supression is very efficient, increased fire frequency will primarily result in increased cost for fire supression. According to a government committee report, these costs may increase by a factor of about 30 even within a few decades.

As in other parts of the boreal region an increase in frequency and intensity of insects attacks is predicted in a warmer climate. Increased volumes of wind-thrown timber in combination with a warmer climate is likely to benefit the spruce bark beetle *(Ips typographus)*, which is already today causing considerable losses for the Scandinavian forestry.

A warmer climate will be disadvantageous to some fungal pathogens needing long winters or a lasting snow cover to develop. However, other species will be favored and spread to new areas. Pests that now only occurr in southern Scandinavia are also likely to cause problems further north. Invasion of new pests from the south can also be foreseen.

Root rot, caused by some species of fungi, is one of the most damaging pests to Scandinavian forestry. It is known that the rate of establishment (infection) of the fungi is temperature dependent in the interval +5-25^{o}C (as 24 hour mean temperature), which mean that infections are likely to increase as temperature rises.

Climate change and the lodgepole pine in Sweden

Since the introduction of alien tree species, better adopted to the future climate, is a management option presently discussed in Swedish forestry, the case of the lodgepole pine *(Pinus contorta)* might be worth considering.

Today, the north American lodgepole pine grows on about four per cent of the forest land in central and northern Sweden. The total area of lodgepole pine forests is about 0.5 million hectares. The species was introduced in Sweden in the 1970s, the main reason being that it grows faster than Scots pine. It was also regarded as better suited to survive under certain harsh climate conditions.

Worldwide, forestry has for a long time tested and used exotic tree species to improve production. Nevertheless, the introduction of *Pinups contorta* in Sweden is probably unique, not only because of the massive scale of the introduction. The exotic species is in this case not used in more or less isolated plantations, but integrated in a semi-natural - albeit managed - forest landscape, where one of the dominant native tree species is a close relative to the alien.

Alien invasive species are regarded as one of the biggest threats to biodiversity. It has been shown that the lodgepole pine in Sweden is invasive, i e it is able to regenerate and spread into new areas without the assistance of man. Climate change may escalate this problem.

If winter temperatures rise to levels that prevent Norway spruce from establishing in central and northern Sweden, forests in these areas will develop into mixed pine forests of Scots and lodgepole pine. Warmer climate will increase the possibilities for lodgepole pine to invade Scots pine forests, since higher temperatures are unfavorable for Scots pine. Increased fire frequency may accelerate this process further. There is a risk that lodgepole pine will also invade the remaining old-growth forests in nature reserves and national parks.

The consequences of such a development for biodiversity is unpredictable, but there is every reason for concern. A shift in tree species composition is of course of utmost importance in forest ecosystems, especially in forests formed by only a few tree-species. When such a shift includes the introduction of an alien species the effects are likely to be even more far-reaching.

Carbon balance

On a basic level, the carbon balance of managed forests is fairly simple. If the harvest is equal to the annual growth the balance is zero, i e the forest is neither a carbon source or a sink. If the growth exceeds the harvest the forest serves as a sink, and under the opposite conditions it is a carbon source. If the fate of the harvested wood products is taken into account the picture becomes more complicated, since they in some cases can serve as carbon stocks for centuries (wooden buildings etc), in other cases release their carbon within weeks or months (newsprint, firewood).

This simplistic model does not take into account the fact that higher temperatures may cause increasing release of soil carbon due to faster rate of decomposition of organic matter.

In Sweden, a recent government report claims that the forest is a carbon sink in the magnitude of 20 Mton CO_2 per year. Under a business-as-usual scenario, the sink will remain about the same size over the next 20 years. However, annual harvest has been increasing up till now, and growing pressure on the forest as a source for biofuels to replace fossil fuel is likely to accelerate this trend. Still, until 2030 the growing stock is projected to continue to grow, although at a slower rate than the harvest. As a result the annual carbon storage will decrease, but the forest will remain a sink over the period analyzed. It is noteworthy that 70 - 90 per cent of the increase in growing stock will take place in nature reserves and other areas protected from logging. In other words, the land use forming the forest carbon sink is not primarily forestry but nature conservation.

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The Russian perspective

The boreal forest in Russia

In Russia, the boreal forest is a 1,000 - 3,000 kilometer wide belt throughout the entire country, from the Finnish border to the Pacific in the far East. The total area is 760-780 million hectares, which is more than half the global boreal forest area. Five coniferous tree species are widespread, of which larch is the most common. One third of the boreal belt is larch forest.

There is about 340 million hectares of frontier forests in Russia (see note p. 7), the bulk of which is in the northern part of the boreal region. This means that roughly half of Russia' s boreal forest remains in a relatively undisturbed state.

In the European part the dominant tree species in primary boreal forest are pine and spruce. This part of the boreal zone is well populated and developed, and most of Russia' s timber processing capacity is located here. About 2/3 of the national timber harvest takes place in the European part. Consequently, most of the forest has been affected by industrial logging and transformed from primary forest to secondary birch and aspen forests.

In Western Siberia (between the Ural mountains and Yenisei river) the boreal belt mostly consists of pine forests and vast wetlands. In the northern part of this area the boreal forest grows on permafrost. As a result of the development of the oil and gas industry in Western Siberia, forest fire frequency has increased dramatically. Satellite images show that most forests in this region have been affected by fire over the last 40 years.

In Eastern Siberia and the Far East the boreal belt is dominated by larch forests, mostly growing on permafrost. The productivity of these forests are low and they are not subject to industrial logging, except in the vicinity of mining areas and other industrial developments, where existing transport infrastructure facilitates timber harvest. In the southern part of Eastern Siberia, outside of the permafrost region, there are quite productive old growth forests of pine, spruce, fir, larch and Siberian pine. Where transport infrastructure is present, these forests are subject to industrial logging.

The transition zone between boreal forest and northern tundra is usually a few hundred kilometers wide. The main tree species are larch and spruce, mostly growing on permafrost. Population is sparse and to a large extent represented by indigenous peoples. Over the last few decades the activities of the oil and gas industry have expanded rapidly in this zone. As a result of this, the forest-tundra belt has suffered from increasing extensive wildfires. In the absence of infrastructure and efficient forest management and protection systems such fires can burn for months without any attempts at suppression.

In the western and eastern parts of Russia, there is a transition zone of mixed forest south of the boreal forest belt. It is typically 500 km wide in the west, and 100-200 km in the Ural mountains. Forestry and forest management is normally rather active in the western part of this zone. The eastern part of the coniferous-deciduous transition zone is the so called Ussury taiga in the Far East. Because of its location (rather far south), complex natural history and low impact of forestry and other human activities, the Ussury taiga is unique as concerns biodiversity. It is, among other things, home to the Siberian tiger.

The Ussury taiga is one of three globally important biodiversity hot-spots in the Russian forest. (The other two are Altay-Sayany in Siberia and Caucasus in the south-eastern part of European Russia, outside of the boreal region.)

Climate change in Russia

In general, Russian meteorological data is consistent with the overall global picture of a gradually warming climate over the 20th century. Warming has accelerated since 1976. Over the last 30 years, mean surface air temperature has increased by 0.4 °C per decade.

Russian projections, based on the IPCC business-as usual scenario (A2), show increases in mean winter temperatures in the boreal zone of more than +4°C by 2060, while summer temperatures are projected to increase about half as much. Warming is expected to be much higher in the northern parts of the country than in the south, which is consistent with virtually all global climate model projections. A recent study by the UK Met Office projects temperature increase of up to 10°C in northern Eurasia with global mean warming of +4°C. [1]

Overall, precipitation is projected to increase moderately in Russia. Most of the increase is expected to take place during the winter. Summer precipitation is projected to decrease in southern parts of European Russia and Western Siberia.

Forestry and forest management

Forestry

Industrial logging during the Soviet era has transformed most of the boreal forest in European Russia into secondary forest, even though some primary forest remains in the northeastern part. Furthermore, logging has also seriously affected forests in the southern part of the Siberian boreal zone, particularly along the Transsiberian railway

The annual timber harvest in Russia declined dramatically in the early 1990´s, from 350 - 400 million cubic meters to 100-120 million cubic meters. During the last decade, annual logging has stabilized around 150 - 170 million cubic meters.

It should be noted, that these figures are based on official statistics, and that illegal logging is a big problem in Russia. According to official statements from high-rank ingFederal Forest Agency officials, illegal logging can amount to 20 per cent of the official, legal logging, which would mean that that total annual logging is 180 - 200 million cubic meters, corresponding to about 900,000 hectares of clearcuts.

According to official statistics 230,000 - 250,000 hectares are artificially reforested every year, mostly with pine and spruce. This means that over 500,000 hectares is left to natural regeneration. Due to the often harsh conditions on large clearcuts, and competition with naturally appearing secondary tree species and lack of precommercial thinning, logged forest commonly regenerates as secondary mixed deciduous forests with a proportion of conifers. This may well have advantages from a sustainability point of view, given the better resilience to climate change of deciduous tree species. Still, forest authorities strongly support large scale artificial regeneration with conifers.

The forest management system

When considering the possible consequences of global warming in the Russian forests it is important to be aware of the present state of Russian forest management.

There has been a quite powerful centralized state forest management system in Russia since the beginning of the 19th century. During the Soviet era forest management and most forestry related activities were governed by the Ministry of Forestry. The manage-

1) Boreal Forest and Climate Change. AirClim report.

Serg Sastavkin/Fotolia

ment organization had 100,000 - 150,000 employees and the nationwide organization carried out forest inventories, issued logging permits, suppressed forest fires and pest outbreaks and was responsible for thinning, sanitary logging, reforestation and in some cases even timber harvesting.

Roughly half of Russia's boreal forest remains in a relatively undisturbed state. Most is in Siberia, where larch is the dominating tree species.

Obviously, the concentration of all these functions to one government body had shortcomings. On the other hand this structure had a long tradition, experience, highly professional staff and a strong corporate identity.

During the last few years the forest management system has been subject to so called market reforms, which have caused serious deterioration. It has lost its independence and been incorporated in the Ministry of Natural Resources and later (2008) in the Ministry of Agriculture. Ministers and top level officials have frequently and unpredictably been replaced, in some cases after corruption scandals.

As a result of the implementation of a new Forestry legislation most forest management functions were moved from the federal to the regional level in 2008. It has become obvious that many regions were not ready to take on this responsibility, which means that vast forest areas simply have been left without any forest management and control of forestry activities. For example, the federal State Forest Guard system was liquidated, and only some regions have created something similar. All in all, the number of professional forest management officers fell dramatically to about 30,000, working in an environment of unpredictable and incomprehensible changes, failing social security network and low wages. The ability of this system to handle forest fire, large pest outbreaks and forest losses due to drought is very limited. Furthermore, it has great difficulty in tackling illegal logging efficiently.

One of the ideas underlying the forest management reform was that responsibility for forest management should be taken over by timber companies leasing forest areas (which they have to do to get logging permits). However, so far no more than 200 million hectares have been leased for industrial logging, which means that 550 million hectares remains under the severely deteriorated state forest management system, working through regional authorities.

Climate change and the Russian boreal forest

Tree and forest growth

Existing data shows that warming already has caused changes in forest phenology in Russia. In northern part of European Russia, for example, birch leaves are appearing on average 6-8 days earlier than they did 30 years ago. However, autumn leaf fall also comes earlier, which means that the vegetation period has not been extended. There is no clear understanding of the mechanisms behind this.

As in other parts of the boreal zone, tree ring analyses show that there has been no general positive growth response to a warmer climate so far.

Northward shift of forest ecosystems

The official assessment report confirms that boreal forest is moving polewards and upwards (towards higher altitudes in mountain areas) as a result of global warming. However, the establishment of new forests is a slow process. In other parts of the boreal region, century-long time lags are expected.

The official assessment does not take into account how increasing temperature will affect the fire disturbance regime at the forest-tundra ecotone. Increased fire frequency might even cause the forest border to move southwards.

Forest fires

According to official figures, forest fire affects on average about one million hectares of forest in Russia annually, with great variation between years. The mean annual forest loss due to fire is 180,000 hectares.

There are reasons to question the official statistics on disturbances and forest losses. As concerns forest fires, remote sensing gives a very different picture of the impact of forest fires in Russia, and has done so for a long period of time. Data from satellite images in general gives 3-5 times higher figures on area burned compared to the official statistics.

The official assessment report concludes that climate change will increase the fire danger conditions in Russian forests, both in terms of area and number of days with severe fire risk. In addition, recent developments in the Russian forestry sector clearly show an increase of other factors increasing the risk of wildfire (such as the presence of humans and human activities). However, no projections of the actual fire frequency or areas affected are made in the official assessment. It is reasonable to believe that fire frequency and areas affected will increase dramatically as a result of climatic and other factors combined.

As a consequence of the deterioration of the national forest management system, the capacity for forest fire suppression has declined dramatically in Russia. The national airborne forces for fire suppression *(Avialesookhrana)* had around 10,000 employees, including paratroopers, and direct access to 100 airplanes and helicopters. As a result of the regionalization of the forest management system over the last few years, this force has in fact ceased to exist. The federal responsibility for forest fire suppression has been transferred to the Department of Emergency Situations and is limited to situations where people or buildings are threatened.

Droughts

About 125,000 hectares of forest is lost annually due to “unfavorable weather conditions”, which in most cases means drought. Drought events are most common in the southern part of the forest belt.

As a result of more frequent and severe drought events these losses can be expected to increase. Dry pine forest on sand may be especially vulnerable. However, the official assessment does not consider this scenario.

Pest outbreaks

According to official statistics, pest outbreaks is the third most important cause of forest losses in Russia, killing about 70,000 hectares of forest annually.

In the mid-1990s, nearly one million hectares of fir-spruce forest in the Krasnoyarsk region of Siberia was affected by a massive outbreak of the Siberian moth. Nearly 300,000 hectares of forest was killed, and the timber loss was estimated at the equivalent of seven years of logging in the entire region. Studies from other part of the boreal region indicate that global warming is already a driving force behind increasing pest outbreaks in boreal forests, and that this trend will be enhanced by future higher temperatures. In Russia, the official assessment of climate change is concerned about this when analyzing the agricultural sector, but surprisingly not when it comes to forestry

Permafrost thawing

According to the official assessment, warming has already caused extensive changes in the permafrost regime, and will continue to do so as temperature increases. Due to the huge inertia, vast areas of permafrost will remain in most parts of Siberia for a long time, but the southern permafrost border is expected to move north considerably - in some cases hundreds of kilometers - during the course of this century. The most dramatic changes are expected in the lowlands of Western Siberia.

Permafrost thawing may lead to total destruction of the land surface. However, this is likely to be the case only in limited areas. A more common and widespread consequence may be changing water regimes, causing forest death through rising ground water table.

The official assessment does not analyze how permafrost thawing may affect forests and forest growth,

Carbon balance

As shown above, statistics on logging, fire and other disturbances are not reliable. In addition, official analyses of the future carbon balance of Russian forests so far have not included a number of possible or probable consequences of changing disturbance regimes. This must be considered when judging any official assessments of Russian forests as a carbon sink.

In this context it should be mentioned, that over the last two decades, secondary birch or aspen forests have colonized about 20 million hectares of abandoned farmland in Russia. This development is only partly reflected in the official land use statistics, where much of this land is still represented as agricultural land. This inaccuracy in the statistics will affect any official assessments of the carbon balance of Russian forests, just as the underestimation of area burned (but in the opposite direction).

According to official figures, the inter-annual variation in the carbon balance of Russia´s forests is big. Over the last 15 years it has shifted from being a source of almost 500 million tons of CO_2 to a sink of 1,400 million tons in 2007, the latest year for which official figures are available. If this extreme year is excluded, since 1990 Russia´s forests have been a carbon sink with a mean annual storing capacity of 325 million tons of CO_2. The total anthropogenic CO_2 emissions in Russia were 1,400 - 1,500 million tons (mean for 1995 - 2006), which means that forests are an important factor in the overall carbon budget of Russia.

The sudden huge increase of forest carbon storage for 2007 presented in the official assessment has been questioned and debated in Russia. So far, no official explanation has be given as to why carbon storage this year was almost twice as big as in any of the previous 15 years and four times bigger than the annual average.

The North American perspective

The boreal forest in North America

As in Eurasia, the boreal forest forms a green belt across the North American continent, from New Foundland in the west to Alaska in the east. Its maximum extension in the north-south direction is somewhat smaller than in Asia.

The boreal forest of Canada cover 545 million hectares. Canada has about 340 million hectares of frontier forest (see note p. ##), the bulk of which is in the boreal region. This means that over 60 per cent of Canada´s boreal forest remains in a relatively undisturbed state.

Climate change in North America

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. If global mean temperature in the 21st century increases by 2°C, most of the boreal zone in North America will experience +3-4°C warming.

A recent study by the UK Met Office projects temperature increases of up to 10°C in boreal North America with global mean warming of +4°C.

Climate change and the North American boreal forest

Tree and forest growth

As in other parts of the boreal zone, tree growth response to warming so far is not equivocal. Inverse growth response is common, occurring more frequently in the warmer part of the distribution area of each species. For Canadian boreal forest it has been shown that the potential effect of warming on tree growth is exacerbated or offset depending on whether these changes are accompanied by decreases or increases in precipitation. With +2°C warming models predict a radical growth decline for jack pine, aspen and black spruce in managed forests in Manitoba.

Northward shift of forest ecosystems

Climate change over the last century has already resulted in species, including plants, insects, fish, birds and mammals, shifting ranges northwards or upslope to higher altitudes. Yet, natural migration of trees and other plant species is unlikely to keep pace with the expected dramatic northward shift of climate zones, suggesting that the persistence of some species may be jeopardized.

In the absence of disturbance, existing forest communities may resist change for decades. Once disturbed, however, colonization will favor weedy species with high dispersal abilities, jeopardizing the existing forest communities.

The effects of changing plant communities on biodiversity at large will be discussed below.

Increased fire frequency may already have caused Canada´s boreal forest to shift from a carbon sink to a source. Climate change is projected to increase future fire frequency dramatically.

Bill Gabbert / Fotolia

Forest fires

Across the entire North American boreal region the total area burned increased by a factor of 2.5 between the 1960s and the 1990s. The annual area burned in western North America doubled in the last 230 years of the 20th century. Modeling suggests further increases in wildfire impact during this century under a wide range of scenarios. If global warming reaches +4°C the area burned could increase by 74-118 per cent by the end of the 21st century.

Pest outbreaks

Insect outbreaks are expected to increase in frequency and intensity with projected changes in global climate through direct effects on insect populations and through disruptions of community interactions.

The North American boreal forest is already experiencing unprecedented insect attacks. 37 million hectares of forest in British Columbia is affected by the mountain pine beetle. A multi-year outbreak of spruce beetle on the Kenai Peninsula of Alaska killed 90 per cent of the region´s spruce from 1992 to 2000.

Permafrost thawing

Simulations show that climate change has induced degradation of permafrost in most of Canada. From the 1850s to the 1990s the area underlain by permafrost was reduced by 5.4 per cent, and in the area of continuous permafrost the mean depth to the base of permafrost decreased by three meters.

Draining of wetlands

Much of North America´s boreal region contains vast areas of lakes and wetlands even though it receives low amounts of precipitation. This is due to low evapotranspiration in the cool climate. Warming will increase evapotranspiration resulting in drying and potentially reducing the area of lakes and wetlands, which in turn will affect biodiversity and the carbon storage of the boreal forest landscape.

Melting of permafrost will contribute to the disappearance of aquatic habitat by causing wetlands and lakes to drain. Permafrost melting has in fact caused a decrease in wetland habitat in boreal regions of Alaska.

Biodiversity and ecosystem services

Drying of wetlands will reduce habitat for the 12 to 15 million ducks that depend on Canadian aquatic habitats for their breeding.

Models suggest that large numbers of wildlife species are at risk of large decreases in population size and that many are extinction prone because plant communities on which they depend are not able to keep up with climate change.

The timing of plant development, animal breeding, migration and other life history events are often triggered by climate variables. Many wildlife species have evolved to match such events to other species upon which they depend. Rapid climate change may threaten to disrupt such interconnections between species. In fact mismatches are already apparent, for example between caribou calving and the earlier leaf emergence, leading to significant increases in calf mortality.

Birds that migrate loing distances generally use seasonal changes in daylight as the cue to begin spring migration. In a rapidly warming climate these birds may not arrive at the breeding grounds soon enough to ensure that hatching of the young coincides with the abundant insect food supply needed to feed them. This effect has been shown to cause lower reproductivity among Pied Flycatchers in Europe.

Climate effects on wildlife are likely to become more severe in a fragmented forest landscape than in large areas of intact forest ecosystems.

North America´s boreal forest contains eight of the ten largest intact forest blocks on Earth, including the largest contiguous forest ecosystem left on the globe - the boreal forest south of Hudson bay in Ontario and Manitoba. Due to its high level of intactness, North America´s boreal forest region is better suited than most to withstand climate change. Large intact ecosystems are critical in maintaining resilience to climate change and minimizing losses in biodiversity and ecosystem services. The diverse biota supported by Canada´s boreal forest region includes billions of migrating songbirds and among the world´s largest populations of northern mammals such as caribou, bear, wolf and moose. The total value of ecosystem services provided by Canada´s boreal forest - including clean water, food, recreation and climate regulation - has been calculated at approximately $700 billion.

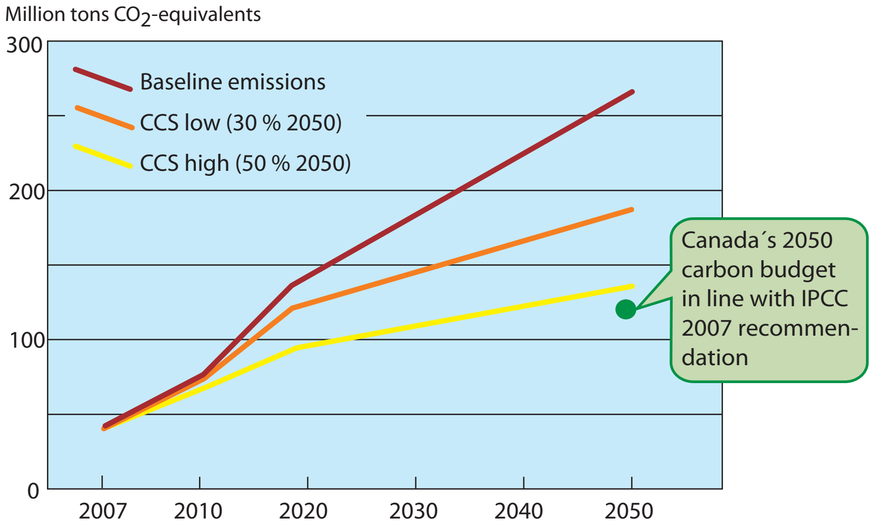
Carbon balance

Canada´s boreal forest stores about 71.4 billion tons of carbon in forest ecosystems, and 136.7 billion tons in peatland ecosystems. The mean annual carbon sequestration between 1920 and 1989 was 205 million tons, which approximates to the total Canadian anthropogenic greenhouse gas emissions. It is important to note, that forests continue to sequester carbon as they age, which means that older forests store more carbon.

Carbon storage of forest is affected by global warming in several ways, including direct effects on forest growth and distribution and - as mentioned above - draining of wetlands.

Furthermore, disturbance regimes are a major factor in boreal carbon budgets, and are believed to be partly responsible for the large inter-annual variability of the terrestrial carbon balance. Modeling results suggest that forest ecosystems in Canada shifted from a carbon sink to a carbon source around 1980, which has been explained by increasing

The carbon emissions from Alberta´s tar sand extraction will exceed Canada´s entire carbon budget if IPCC´s recommendation of an 80 per cent cut by 2050 is met. The graph shows the emissions from well to tank if the industry continues to grow rapidly. In the baseline scenario no effect of carbon storage is included, while the CCS high scenario represents the industy´s own best-case CCS estimates.. (From :Carbon capture and storage in the Alberta Oil sands – a dangerous myth. WWF UK 2008.)



fire frequency. In a warmer climate, carbon emissions from fires will increase. Insect outbreaks also represent an important mechanism by which climate change may undermine the ability of northern forests to store atmospheric carbon. For example, the present mountain pine beetle attack in British Columbia is estimated to have converted 370.000 km^2 of forest from a small carbon sink to a great 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.

In this context, logging may be considered as a disturbance, albeit artificial. It affects carbon storage by removing forest biomass from ecosystems. It also causes the release of soil carbon as decomposition of soil organic matter increases. Although some of the harvested timber is subsequently stored as forest products and in landfills, net emissions can still be substantial. In 2006, almost 10.000 km^2 of harvest activity extracted close to 45 million tons of carbon from Canada´s forests. Because of the large amounts of carbon stored, logging of old-growth forests has particularly negative effects on the carbon balance.

Deforestation increases carbon emissions and diminishes biotic carbon storage. Globally, impacts from land use such as deforestation accounted for nearly 20 per cent of global anthropogenic carbon dioxide emissions. As concerns Canada, this proportion is substantially smaller, but on the regional scale deforestation can still be a factor of importance. In Saskatchewan, 73 per cent of the southern boreal transition zone has been converted to agricultural land, and the deforestation continues at a rate three times the global average.

A specific area of concern regarding land use changes is the tar sands region of northern Alberta. As of 2009, surface mines and associated footprints had disturbed 686 km^2 of land, of which half was carbon-rich peatlands. It has been estimated, that if the tar sand fields are fully developed 238 million tons of biotic carbon would be released into the atmosphere.

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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