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Side Event: No North without South, no South without North: the urgent need for an integrated view on global forests

Challenges and risks in the boreal domain

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IIASA Thursday 12:45 Hall 4D

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Current state and processes in boreal forests

- Boreal forests (Figure 1) play a substantial role in the global environment and economy providing critical services at local, regional and global scales (Newell, Simeone 2014, Gauthier et al. 2015). The boreal zone (excluding the semi-boreal) is defined as a territory of cold climate, with average daily temperature ≥ 10°C between 30 and 120 days, freezing temperature occurring from 6-8 months, and long snowy winter (Walter 1985). The most northern boreal forests grow at 72°30' in Central Siberia and survive under average annual temperatures of about -15°C and absolute minima around -50°C. Tree species diversity is low: about 90% of the boreal forests are dominated by trees of 4 coniferous (pine, spruce, fir, larch) and 3 deciduous (birch, poplar, alder) genera.

Boreal forests contain more surface water (Burton et al. 2010) and organic carbon than any other biome and have provided 40% of the net carbon sink of established global forests in the last two decades (Pan et al. 2011); the boreal zone delivers more than 50% of industrial coniferous wood and 25% of paper (FAO 2013) in export markets; and it serves to maintain the stability of northern landscapes by protecting soil and water (Shvidenko et al. 2013).

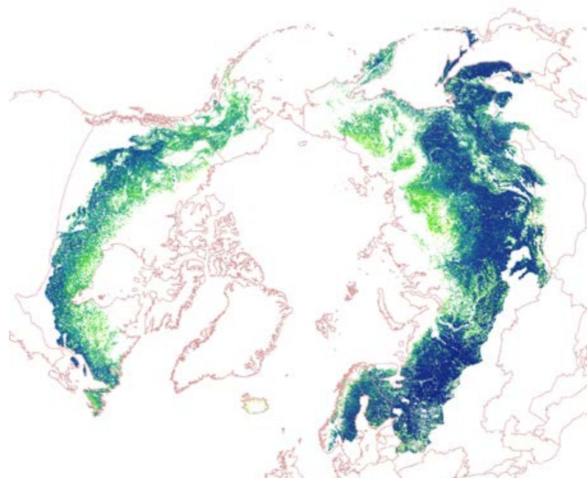

Figure 1. World's boreal forests (modified from Schepaschenko et al., 2015). The total area is estimated from 1.14 – 1.44 billion ha depending on definitions and data sources. Seven countries comprise 99.7% of boreal forests area: Russia (60.7%), Canada (29.5%), USA (5.1%), Finland (1.8%), Sweden (0.8%), Norway (0.7%), China (1.1%) (Burton et al. 2003, Shvidenko, Apps 2006)

- Prevalence of different natural disturbances (fire, insects, wind, pathogens) is an inherent feature of boreal forests. Disturbances have shaped landscape mosaics and a diversity of forest ecosystems displaying different species composition, age, biometric characteristics of stands, succession dynamics, and productivity (Gauthier et `al. 2015).

• More than one-third of boreal forests grows on continuous and discontinuous permafrost. Precipitation over vast boreal continental territories is low (from 200 to 400 mm), and some species (e.g. Larch in Northern Eurasia) have developed ecosystems that depend on permafrost to survive during dry vegetation periods (Osawa et al. 2010). Only two species (*Larix gmelini* and *L. cajanderi* cover vast areas (~200 M ha) on continuous permafrost. The warming during recent decades has already caused degradation of permafrost, changes in hydrology and enhanced tree mortality in the zone of discontinuous permafrost (with 30-80% permafrost), particularly in forest–boreal peatland landscapes (Baltzer et al. 2014).

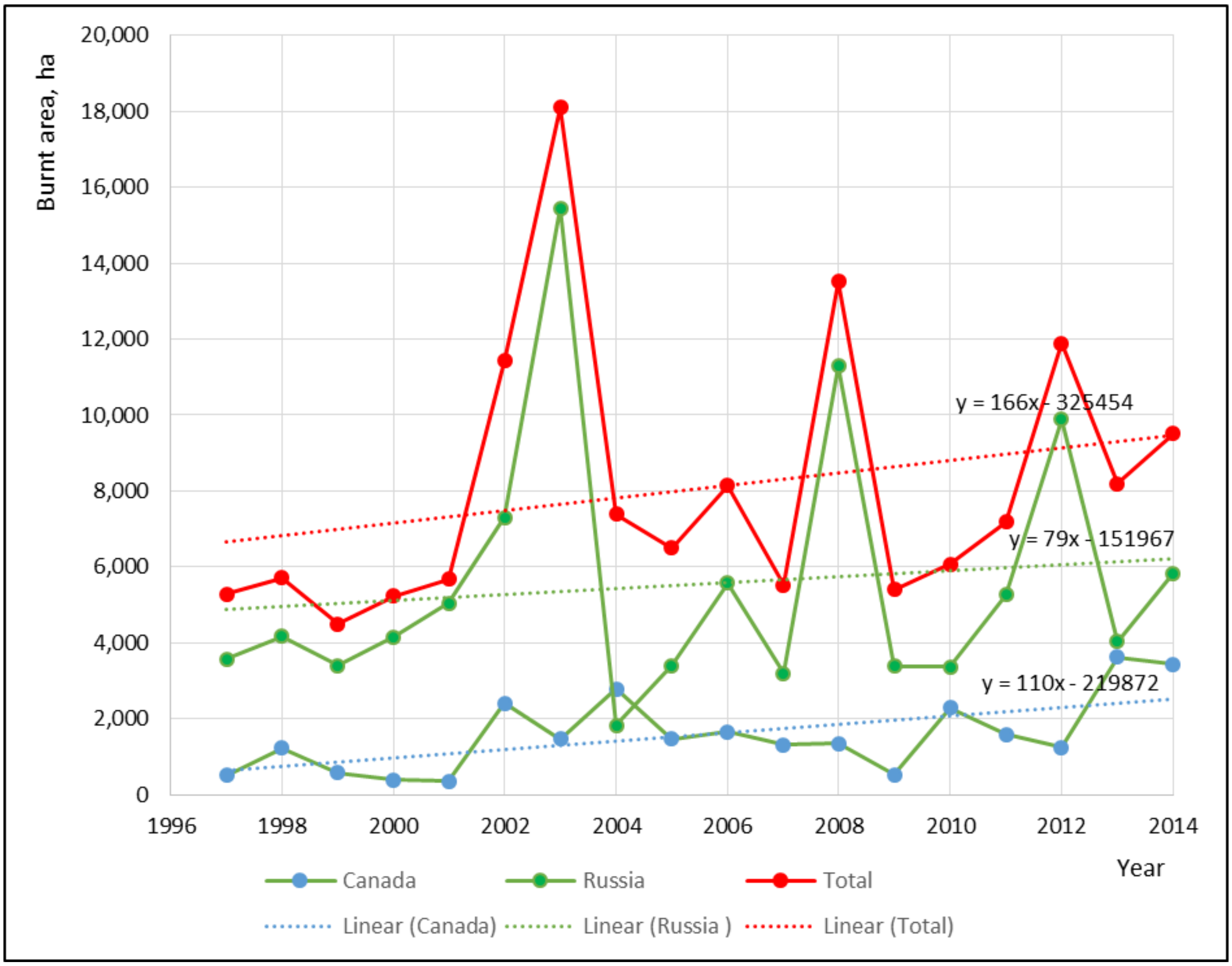

Figure 2 – Areas of boreal forests enveloped by fire during 1997-2014 by GFED4 (Giglio et al. 2013)

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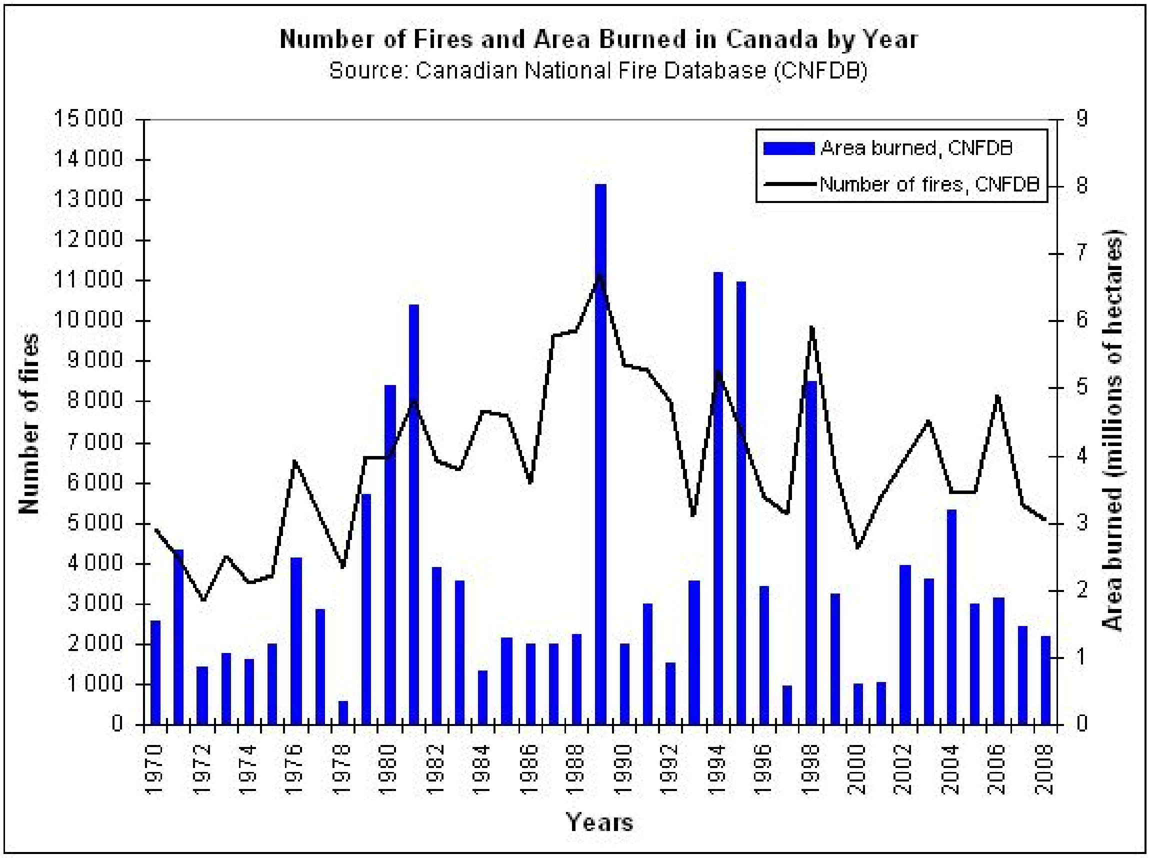

Figure 3 – Numbers of fire and burnt area by national statistics for Canada. Source http://nfdp.ccfm.org/data/graphs/graph_31_b_e.php

- FIRE: On-going climate change of the last decades has increased disturbances in the boreal forest landscapes, where the average burnt area in 2000-2012 is estimated to be between 8 and 10 M ha annually (Figure 2) with a large interannual variation (Giglio et al. 2013, Ponomarev et al. 2013). Note that national fire statistics might substantially differ from those of GFED (e.g., Canadian national statistics in Figure 3). Catastrophic (mega-) fires are a typical feature of current fire regimes, particularly in the vast boreal territories of Northern Eurasia. Mega-fires, sets of near-simultaneous large fires occurring in different parts of vast individual regions and together covering , from hundred thousand to millions of hectares, result in degradation of forest ecosystems, increasing the share of stand-replacing fire in Russia, decreasing biodiversity (particularly in zonal ecotones), destruction of the resource base of forest industry, formation of specific weather conditions over large territories, extremely negative impacts on economics and infrastructure, worsened life condition and health of local populations, and a transformation of part of the burnt area into land unsuitable for forest growth sometimes for centuries. In Russia, megafires have intensified the process of "green desertification" on previously forest land on tens of millions of hectares. Historically, surface fires were considered as a typical feature of fire regimes in boreal Eurasia comprising ~80-85% of the total burnt area; however, under mega-fires the share of stand replacing (crown and peat) fires reaches up to 50% in Russia (Shvidenko, Schepaschenko 2013). In the boreal forests of Canada and Alaska nearly all forest area burned is affected by crown fires.

- INSECTS: The warmer and drier climate of recent decades has provoked several large-scale outbreaks of forest pests in Canada (Kurz et al. 2008) and Russia (Shvidenko et al. 2013), which have caused substantial natural resource losses for the forest industry and affected communities. Increasing frequency and severity of drought events may have substantially impacted the productivity and vitality of boreal forests, halving the seasonal Net Primary Production and enhancing mortality of trees (e.g., Allen et al. 2010, Bastos et al. 2014)

In Russia, large negative impacts on boreal forests are inflicted by the industrial development of northern territories resulting in widespread air pollution, water and soil contamination (Baklanov et al. 2013), and mechanical destruction of the landscape surface (e.g., about 30% of tundra and northern taiga territories in West Siberia are destroyed by the industrial impact of extraction and transport of natural resources and unregulated movement of vehicles) that is accompanied by undesirable changes in hydrological regimes. Several waves of large-scale drought-induced mortality of dark coniferous forests took place during the last three decades in Russia - in Siberia, the European North and Far East.

- LAND-USE CHANGE Deforestation (i.e. the conversion of forest to non-forest land uses) occurs at very low rates in most boreal forests, e.g. about 0.02% year $^{-1}$ in Canada (Kurz et al. 2014) and Russia (Pan et al. 2011).

- LAND-COVER CHANGE: A recent remote sensing estimate of land cover dynamics of boreal forest area (Hansen et al. 2013) reported that in 1998-2010 the cumulative loss of boreal forest cover was 60.7 M ha, while post-disturbance recovery was detected on 20.7 M ha. The causes of cover loss detected by remote sensing include both human and natural disturbances. Post-disturbance recovery is slow in most boreal forests, and detection of forest reestablishment through remote sensing is therefore difficult. Probably the most accurate estimate of forest cover change in Russia is based on aggregation of 12 remote sensing products and validation and control by Geo-Wiki platform (Schepaschenko et al. 2015) reported that Russia has lost ~27 M ha of forest cover over the period of 2000-2010. However, the forest areas managed by the Russian Federal Service have decreased by ~45 M ha and 18 M ha have been restored by afforestation on abandoned agricultural land. The major part of forest cover loss in Russia is situated in high latitudes, basically on permafrost, as a consequence of intensified fire regimes during the last decade. Forest cover loss from boreal fires is not deforestation and care must be taken not to confuse cover loss and subsequent regrowth with land-use changes (Kurz 2010).

- HARVEST: About two-thirds of the global boreal forest is considered to be managed (Gauthier et al. 2015). All boreal countries declare a transition to sustainable forest management (SFM), and participate in one or two international processes on criteria and indicators of SFM (the Ministerial Conference on Protection of Forest in Europe and Montreal processes).However, there are substantial national and regional differences in intensity and purposes of forest management, from highly intensive timber-oriented forest management within the paradigm of SFM in Finland and Sweden to more extensive forestry in productive forest regions in Canada, to extensive forest management in Russia. In most boreal regions clear-cut logging is the dominant harvesting method but with significant regional variants depending on management intensity. The total area of certified boreal forests is 185 M ha (basically in Canada and Scandinavia) but only 37 M ha (less than 5%) is certified in Russia (https://ic.ifc.org/preview.facts-and-figures-june-2014.a-3311). A decline of forest management and exhaustion of the resource base in regions with developed infrastructure have been observed in Russia during the last decades. This leads to impoverishment of forests across large territories and illegal logging (an estimated up to 20-30% of officially reported amount of harvested wood in Russia originates from illegal logging).

- WOOD PRODUCTS: In spite of economic crises and recessions, the global demand for industrial coniferous wood has been slowly increasing (FAO 2015). Large distances between harvested areas and wood processing facilities, particularly in territories of large northern forest countries, relatively low productivity of forests and concentration of growing stock, often with unsatisfactory developed infrastructure, lead to increasing cost of logging and transport. Wood supply shortages can be addressed through changes in principles of traditional management strategies in some regions of the boreal forests, e.g., the intensification of plantation development with a reduced period of cultivation. For instance, 60-70 years for European spruce (*Picea abies*) in Scandinavia and European Russia (net growth of 4-5 $m^3 ha^{-1}$).

- CLIMATE CHANGE: The current rate of warming in the boreal zone is more than twice as high as the global average. The most dramatic climatic change globally is expected in continental boreal regions of Northern Eurasia and in the high latitudes of the boreal forests of Canada. If the IPCC RCP8.5 scenario is realized (that on average corresponds to global warming of 4°C until the end of the century), the regional temperature increase in the boreal zone is expected to range from 6 to 11°C with a relatively smaller increase of precipitation (IPCC AR5, Chapter 12). This will generate a substantial threat for health, productivity and vitality of boreal forests directly (impact of extreme temperature, water stress and drought) and indirectly (increase of fire and biogenic disturbances), which may lead to the transformation of boreal forests into a tipping element (Lenton et al. 2008). Practically all models indicate substantial (but regionally diverse) increases in fire danger over the boreal zone (Flaningan et al. 2009, Mokhov et al. 2006, Malevsky-Malevich et al. 2008) and risks of pandemic outbreaks of insects over large territories. However, the question of whether boreal forests will reach a tipping point is not clearly answered yet. Still, the probability of this is high for large continental regions, e.g., in Northern Asia. Tipping points in major boreal regions (Canada, Russia) include increased tree mortality due to drought and fire regimes leading to a transition from boreal forest to grasslands (in the south) or open lichen woodlands (in the north) (Price et al. 2014, Shvidenko et al. 2013).

Management Implications

- Continental and regional diversity of boreal forests, social and economic specifics of boreal countries, and different national mentalities and historical development paths have led to different national circumstances and possibilities to transition to sustainable forest management.

- The future contribution of boreal forests to the stability of the Earth system and to human well-being depends upon their vitality, productivity and adaptive capacity to global change (Gauthier et al. 2015). Sustainability of boreal forest ecosystem services during the 21th century will depend upon the rate of climate change, its impact on forest growth, mortality and disturbance rates and the success of the ongoing transition to ecosystem-based Sustainable Forest Management (SFM). SFM in boreal forests, particularly in territories with high expected climate change impacts should be ***adaptive*** forest management (AFM) which aims to preserve the intrinsic functionality of forests as a prerequisite for fulfilling the future need for forest ecosystem services (Wagner 2004). More operationally, AFM is "a dynamic approach to forest management in which the effect of treatments and decisions are continually monitored and used, along with research results, to modify management on a continuous basis to ensure that objectives are being meet" (Canadian Forest Service 2009). AFM should be addressed to all components and ramification of forest management activities: establishment of new forests; regulation of species composition, age and spatial structure of both individual forest stands and forest cover of landscapes; regulation of age of harvest (e.g., implementation of short-rotation plantations), spatial organization of forest cover over large boreal regions; development of a new paradigm of forest fire protection; introduction of systems of specially protected territories oriented towards problems of climate change; etc. The transition to AFM in the boreal zone is region- and forest-type specific. In this sense, AFM may generate different cognitive problems and contradictions with some traditional tendencies of current forestry (e.g., "management closed to nature").

- Over many thousand years boreal forests have experienced relatively stable cold climates and both the thresholds of their resilience and the capacity to buffer expected unprecedented warming and drying are not well known. However, there is a high risk that the rate and magnitude of climate change will exceed the resilience of boreal forests over vast territories. Thus, future adaptive forest management should seek to *integrate adaptation and mitigation objectives.* It is important to note that climate warming is an ongoing process that will require adaptation responses for several centuries, even if uncertainties of the climate change forecasts remain high. Past experiences cannot serve as a satisfactory knowledge base for future conditions. Adaptive environmental management outlined an approach suitable for decision making under uncertainties, that incorporated an iterative process of impact hypotheses (from management and natural disturbances), modelling of expected outcomes of alternative actions and ongoing monitoring of the system's responses to the actions. This approach enables ongoing learning as the ecological system evolves over time.

Modern computer modelling tools can support adaptive forest management and the ongoing planning process. Such decision support tools, should use open, iterative, distributed-modular modeling systems based on operational data sets derived from integrated observing systems, tools libraries and process-based models at different spatial and temporal scales aggregated on a "data-models-policy fusion" platform (Schnellnhuber 2003). Forest management aimed at sustaining ecological services needs to take changes in natural disturbances into consideration. Some developed countries (Scandinavia, Canada) demonstrate substantial progress along this way, while others (e.g. Russia) are clearly less advanced with the implementation of management systems that take climate change into consideration.

- The transition to AFM in the boreal domain supports the current societal demands for ecosystem services. For “optimistic” scenarios of future environmental changes (RCP 2.6 and 4.5), AFM could be realized without substantial deviations from the traditional forest management paradigms, although the uncertainty of the predicted forest responses to climate change is very large. For “critical” future scenarios (particularly RCP 8.5) completely new environmental conditions will require significant efforts to develop adaptation strategies which will require considerable investments whose benefits may only become evident with a lag of 30-50 years and uncertain benefits.

- Thawing of permafrost (particularly under extreme scenarios of global warming) will lead to dramatic, often irreversible changes of the hydrological regime on vast territories, particularly in high latitudes of Northern Eurasia. Very likely, it will generate critical water stress over large areas that would lead to a high level of mortality and will very likely transform these forests into a tipping element. Moreover, the 20 m upper layer of permafrost in North-East territories of Russia (*yedoma* deposits) contains more than 500 PgC-equiv., in the form of methane and hydrates (Zimov et al. 2006). If large proportions of this carbon are released, the emissions would substantially exceed those due to tropical deforestation.

- Development and maintenance of permafrost-protective ecosystem services for forested landscapes on permafrost is a major service of AFM in high latitudes, particularly in Asia, aiming at two major goals: 1) providing resilience of forests and open woodlands over vast territories, and 2) reducing the risk of increased greenhouse gas emissions to the atmosphere. It would require major changes in management. For instance, undisturbed larch forests on permafrost in high latitudes of Northern Eurasia promote protection of lichen-moss forest floor, prevent thawing of the active layer, and do not substantially decrease the albedo, particularly in winter (Osawa et al. 2010). This supposes the theoretical total suppression of fire in permafrost remote territories which may not be possible and which may have other undesirable ecological consequences. Exclusion of fire contradicts the life history of boreal forests which – to a substantial extent – is adapted to and dependent on periodic fire. In addition, any activities assisting the rate of forest migration to the north due to climate change requires delivery of seeds to mineral substrate of remote territories that inevitably leads to a need of forest floor destruction, e.g., by fire. Under all theoretical and economic difficulties which accompany any effective solution of such a problem in evident ways, a new paradigm of permafrost forestry is a real challenge, at least for Northern Asia

- Particular risks are also expected for the ecotone “forest-steppe”, which stretches across around 6,000 km of the Eurasian continent and across ~1000 km of Northern America. For this transition zone (1) uncertainty of climate forecasts is higher than in in other regions of the planet; (2) vulnerability of forests is extremely high; (3) ecologically dangerous processes (degradation of forest ecosystems, oxidation of soil organic, agricultural pressure) are very likely; and (4) a substantial part of the ecotone, basically in East Europe and Asia, has an unsatisfactory structure of land cover and soil quality of agricultural land. This transition zone requires a specific system of adaptation and mitigation.

- Theoretical mitigation potential of boreal forests is high but differs greatly by regions within the boreal zone. In spite of the low rate of deforestation, large areas of treeless forest land (e.g., unregenerated clear cuts; burnt areas, particularly along the northern tree line;

grassy glades) exist in some regions where substantial forest areas have inadequate stocking and species composition with low growing stock. However, economic and social incentives for climate change mitigation activities are currently very low. For example, the theoretical mitigation potential in the Russian forest sector was estimated at 500-800 Tg yr^{-1} (Shvidenko et al. 2003), while the economically reasonable system of actions was estimated at 5-10% of that value (Isaev et al. 2006). Current international and national forest policies are not able to appreciably change this situation in Russia.

- High global meaning of boreal forests with respect of their current and possible future impacts on the Earth climate system seems underestimated on the international environmental agenda. Taking into account current knowledge and believes, expected climate change and their impacts on global forests, tundra and boreal domains deserve more global attention from both the scientific point of view as an inseparable part of the Earth system and a need of development of anticipatory systems of adaptation and mitigation over the entire Arctic belt.

- The most important knowledge gaps concerning future boreal forest management are uncertainties and inconsistences in our understanding of boreal forest dynamics, resilience, and thresholds (tipping points) in responding to projected environmental changes, particularly on permafrost (Kurz et al. 2014, Price et al. 2014).

Summary in three sentences

- Boreal forests are an important contributor to the stability of the Earth climate system and to the well-being of the global and local human populations, but their ability to fulfill this function in the future depends on the rate of global climate change.

- Climate change generates increasing challenges and risks for boreal forest ecosystems, which evolved in and adapted to cold climatic conditions. Over one third of boreal forests grow on permafrost lands that are particularly vulnerable to warming which could lead to large increases of emissions of GHG to the atmosphere.

- Future adaptive management of boreal forests should consider the impacts of climate change, both positive and negative, and develop sustainable strategies aimed at meeting both climate change mitigation and adaptation objectives while continuously monitoring forest responses to climate change.

References/ Further reading

Allen C.D., Makalady A.K., Chesjuini H. et al. (2010) A global overview of drought and heat-induced tree mortality revels emerging climate change risk for forests. *Forest Ecology and Management* 259, 660-684.

Baklanov A., Penenko V.V., Mahura A.G. et al. (2013) Aspects of Atmospheric Pollution in Siberia. In *Regional Environmental Changes in Siberia and Their Global Consequences*, P.Y. Griosman, G. Gutman (eds). Springer, New York, pp. 171-249.

Baltzer J.L., Veness T., Chasmer L.E., Shiderhan L.E., Quinton W.L. (2014) Forests on thawing permafrost : fragmentation, edge effects, and net forest loss. Global Change Biology, 20, 824-834.

Bastos A., Gouvenia C.V., Trigo R.M., Running S.W. (2014) Analysing the spatio-temporal impacts of the 2003 and 2010 extreme heatwaves on plant productivity in Europe. *Biogeosciences*, 11, 3241-3435.

Brandt J.P., Flannigan M.D., Maynard D.G., Thompson I.D. (2013) An introduction to Canada's boreal zone: ecosystem processes, health, sustainability, and environmental issues. *Environ. Rev.* **21**, 207–226.

Burton P.J. (2013) Exploring complexity in boreal forests. In: *Managing Forests as Complex Adaptive Systems - Building Resilience to the Challenge of Global Change,* C. Messier, K. J. Puettmaan, K. D. Coates (eds.) Routledge, New York, 79-108.

Burton P.J., Messier C., Smith D.W., W.L. Adamowicz (eds.) Towards management of the boreal forests. NRC Research Press, Ottawa, Ontario, Canada, 1059 pp. (2003).

Burton P.J., Bergeron Y., Bogdanski B.E.C., Juday G.P., Kuuluvainen T. *et al.*, (2010) in *Forests and society – responding to global drivers of change,* G. Mery, P. Katila, G. Galloway, R.I. Alfaro, M. Kanninen et al., (eds.). IUFRO, Vienna, pp. 249–282. (http://www.iufro.org/science/special/wfse/forests-society-global-drivers/).

Canadian Forest Service, Glossary of terms. Available at http://cfs.nrcan.gc/glossary/6/a (2009).

FAO 2012. The Russian Federation Forest Sector. Outlook Study to 2030. (Food and Agricultural Organization of the UN, Rome; http://www.fao.org/docrep/016/i3020e/i3020e00.pdf

FAO 2015. Forest products. FAO yearbook 2009-2013. FAO Forestry Series, No 204. UN FAO, Rome, Italy (2015).

Flanningan M., Stocks B., Turetsky M., Wotton M., Impacts of climate change on fire activity and fire management in the circumpolar forest. *Global Change Biology*, 15(3), 549-560 (2009).

Gauthier S., Bernier P., Kuuluvainen T., Shvidenko A., Schepaschenko D. (2015) Boreal forest health and global change. *Science*, 349, 819-822.

Giglio L., Randerson J.T., van der Werf G.R. (2013) Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4). *J. Geophys. Res. Biogeosciences*. 118, 317–328.

Gustafson E.J., Shvidenko A.Z., Sturtevant B.S., Sheller R.M. (2010) Predicting global change effects on forest biomass and composition in south-east Siberia. *Ecological Applications*, 20(3), 700-715.

Hansen M.C., Potapov P.V., Moore R. et al. (2013) High-resolution global maps of 21st-century forest cover change. *Science*, 342 (6160), 850-853.

Kauppi P. E., Posch M., Pirinen P. (2014) Large impacts of climatic warming on growth of boreal forests since 1960. *PLoS ONE*. 9, e111340. doi:10.1371/journal.pone.0111340.

W. A. Kurz *et al.*, Mountain pine beetle and forest carbon feedback to climate change. *Nature*. 452, 987–990 (2008).

Smyth C.E., Stinson G., Neilson E.T., Lemprière T.C., Hafer M., Rampley G.J., Kurz W.A. (2014) Quantifying the biophysical climate change mitigation potential of Canada's forest sector. Pacific Forestry Centre. DOI: 10.5194/bg-11-3515-2014.

Lenton T.M., Held M., Kriegier E. et al., Tipping elements in the Earth climate system. Proceedings of the National Academy of Sciences, 105(6), 1786-1793 (2008)
Kuuluvainen T., Siitonen J. (2013) In *Managing Forests as Complex Adaptive Systems - Building Resilience to the Challenge of Global Change,* C. Messier, K. J. Puettmaan, K. D. Coates (Eds.) Routledge, New York, pp. 244–268.
Lindner M. *et al.* (2010) Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *For. Ecol. Manage.* 259, 698–709.
Lemprière T.C. *et al.* (2013) Canadian boreal forests and climate change mitigation. *Environ. Rev.* 21, 293–321.
Malevsky-Malevich S.P., Molkentin E.K., Nadyozhina E.D., Shklyarevich O.V. (2008) An assessment of potential change in wildfire activity in the Russian boreal zone induced by climate warming during the twenty-first century. Climatic Change, 86, 463-474
Mokhov I.I., Chernokulsky A.V., Shkolnik I.M. (2006) Regional model assessments of fire risks under global climate change. Doklady Earth Sciences, 411 (9), 1485-1488.
Newell J.P., Simeone J. (2014) Russia's forests in a global economy: how consumption drives environmental change. *Eurasian Geogr. Econ.* 55, 37–70.
Osawa A., O. Zyryanova, Y. Matsuura, T. Kajimoto, R.W. Wein (eds). (2010) *Permafrost Ecosystems. Siberian Larch Forests.* Springer, Netherlands.
Pan Y. *et al.* (2011) A large and persistent carbon sink in the world's forests. *Science.* 333, 988–994.
Ponmarev E.I., Shvetsov E.G. Characteristics of vegetation fire categories in Siberia, according to satellite-based and other observations. Investigation of Land from Space, No 5, 45-54 (2013) (in Russian)
Scheffer M., M. Hirota, M. Holmgren, E. H. Van Nes, F. S. Chapin, Thresholds for boreal biome transitions. *Proc. Natl. Acad. Sci. U. S. A*. 109, 21384–21389 (2012).
Schepaschenko D.G., Shvidenko A.Z., Lesiv M. Ju. et al. (2015) Area of Russian forests and ist dynamics based on a synthsis of remote sensing products. *Forest Science*, 3, 163-171.
Shellnhuber H.J. (2003) Integrated assessment of adaptation and mitigation. World Climate Change Conference, Moscow, 94-95.
Shvidenko A., Nilsson S., Vaganov E. (2003) Biospheric role of Russian forests at beginning of the rthird millennium and Protocol Kioto. Siberian Ecological Journal, No 6, 649-658. (in Russian).
Shvidenko A., Apps M. (2006) The International Boreal Forest Research Association: Understanding boreal forest and forestry in a changing world. *Mitigation and Adaptation Strategies for Global Change* 11, 5-32.
Shvidenko A. Z. *et al*. (2013) in *Regional Environmental Changes in Siberia and Their Global Consequences,* P. Y. Groisman, G. Gutman, (eds.) Springer, New York, pp. 171–249.
Shvidenko A., Schepaschenko D. (2013) Climate change and wildfires in Russia. *Contemporary Problems Ecol.*, 6, 683-698.
Wagner S. (2004) Moeglichkeiten um Beschrankungen eines funktionsorientierten Waldbaus. Forst und Holz, 59, 105-111 (in German).
Walter H. (1985) Vegetation of the Earth and ecological system in the Geo-Biosphere. Translated from the 5th revised German edition. Springer-Verlag. Berlin. 318 pp.
Zimov S.A., Schuur E.A.G., Chapin F.S. III (2006) Permafrost and the global carbon budget. *Science* 312, 1612–1613.