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KEYNOTE SPEECHES

CHANGING WORLD, BOREAL FORESTS AND IBFRA

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Boreal forests play substantial role in sustainable functioning of the Earth system, protect water and soil, are a home for many indigenous nations, and serve as a unique source of valuable industrial wood and other forest products. Ongoing and future climate change is expected to be the most dramatic in high latitudes that put dangerous challenges for the boreal world. Increasing anthropogenic pressure may accelerate the negative impacts of climatic change on boreal ecosystems. There is an urgent need for development and implementation of anticipatory strategies of adaptation of boreal forest to, and mitigation of, the negative consequences of global change. IBFRA have to play an outstanding role in this process.

Introduction

Boreal forests constitute the circumpolar belt covering about 1,570 million hectare (ha) in 15 countries, of which 3 countries host ~96% of all boreal forest – Russia (61%), Canada (30%) and USA (5%)[20]. The boreal zone is a home of about 500 million people; comprises ~1/3 of the global forest area [4] and the biggest over the globe bogs and bog-forest landscapes; is a source of about 90% of coniferous industrial wood supply; and contains one-third of the global accumulated organic matter in ecosystems (~80 Pg C in live biomass, ~15 Pg C in dead wood, above 250 Pg C in soil). More than two-third of this territory is on permafrost [9]. Thawing the permafrost may substantially accelerate greenhouse effect because frozen grounds contain from 500 to 900 Pg C, basically in form of methane and hydrates. High latitude regions represented by boreal and polar domains play a substantial role in the global climate machine through complex interactions among atmospheric circulation patterns, temperature regimes, permafrost behavior, river discharge, and sea ice formation. The boreal zone is associated with northern cold coniferous and deciduous forests which cover ~33% of the land area. Forest ecosystems are represented by tremendous diversity of climates, land forms and growth conditions.

On-going climatic change is evident in the boreal zone. The trend of increasing annual temperature during recent decades in Russia was three times higher than the global trend: 0.51 and 0.17°C per decade over 1976-2008, respectively. This trend remains rather stable: 2007 was the warmest year in Russia for the entire period of documented temperature records (the temperature anomaly to the average for 1961-1990 was +2.06°C), the second – 1995 (+2.04 °C) and the third 2008 (+1.88 °C) [18]. Annual average precipitation over the country is also increasing (+7.22 mm per decade over 1976-2006 comparatively to the reference period of 1961-1990). However, the observed precipitation trends for large regions of the country, e.g. in the south of European Russia and continental Asian Russia were close to zero, and climate aridity (measured, for instance, by Palmers Drought Severity Index) substantially increases over the entire boreal zone, continuing the tendencies of the previous 50 years [13]. In its major features, similar tendencies are observed in high latitudes of Northern America [8]. Instability of weather is clearly increasing during recent decades and its impacts on forest ecosystems are more dangerous than the trends. Periods with heavy rain alternate with prolonged warm and dry periods. Often it is accompanied by anomalous heat waves, as in the summer of 2010 in European Russia.

Increasing anthropogenic pressure also generates dangerous challenges for fragile ecosystems of the north. Vast areas of high latitudes host unique deposits of oil, gas, metals etc. Forest management and forest protection in these territories require special anticipatory policies. Some boreal countries, like Finland, Sweden, Canada, demonstrate patterns of successful co-evolution of human and nature in a changing world. However, industrial development over vast areas of Northern Eurasia's high latitudes is often provided in wasting way that is accompanied by physical destruction of landscapes, air pollution, water and soil contamination.

Boreal forests and ongoing global change

Boreal forest ecosystems may benefit from the warming trend because the expected increase of temperature is below optimal temperature ranges for most boreal tree species. CO₂ fertilization impact and nitrogen deposition are also considered as factors of increasing productivity of boreal forests [21]. On average, productivity of boreal forests grew during the last decades. For instance, productivity of Russia's forests (expressed in terms of NPP, gross and net growth) increased during the last 50 years at level of the 0.2-0.5% per year [1, 22]. However, climate specifics of recent decades pose a large threat to ecosystems which evolutionary developed under stable cold climate. Ecological thresholds and buffering capacity of boreal forests under fast and unexampled warming are not known, and prolonged temperature and drought extremes may negatively impact vitality of ecosystems. From other side, increasing climate variability provokes substantial acceleration of regimes of natural disturbances, primarily fire and insect outbreaks. A distinct feature of recent decades is the

increase of frequency and severity of mega- or catastrophic fires [2]. Catastrophic fires result in substantial ecosystem degradation and impoverishment of biodiversity, create a specific condition of the atmosphere affecting seasonal weather over huge territories, provide large economic and infrastructure damage, substantially impact living conditions of the local population and the health of people. For Russia, this situation is aggravated by substantial decline of forest governance in the country, degradation of civil self-consciousness and destruction of professional nature-protected systems (particularly, by practical elimination of the state forest guard).

During the last twenty years, catastrophic fire situations have occurred in different regions of Russia, generally in the Asian part, with a frequency of about 10 years. Ecological consequences of catastrophic fires are substantial. By estimates, catastrophic forest fires increased the total area deprived of forest in the Far Eastern region by 8 million ha during the last two decades. About one-third of area enveloped by catastrophic fires is transformed into unproductive territories where natural reforestation did not occur during 2-3 life cycles of major forest-forming species (e.g. 300-600 years) [2].

For the last decade, the total area of vegetation fire over the boreal zone varied in the range 10-25 Mha yr⁻¹ of which ~70% are in Russia (GFED3, available at <http://www.falw.vu/~gwerf/GFED/GFED3/tables/countries/>). A recent consistent estimate of the extent of fire in Russian territories between 1998-2010 is at 106.9 Mha, or on average 8.23 Mha year⁻¹, varying from 4.2 (1999) to 17.3 Mha year⁻¹ (2003). More than 90% of burnt areas are situated in Asian Russia, mostly in its southern part (excluding year of 2010 when unprecedented temperature anomalies and drought initiated a catastrophic fire situation in central regions of the European part of Russia). About two thirds (65.1%) burnt areas in Russia are on forest land [23]. Fire in Nordic countries covers small areas.

By the impacts on forest ecosystems, biogenic and environmental disturbances are the second natural disturbance [12,23,24]. Warm and dry years during two recent decades provoked several pandemic insects' outbreaks in different boreal continents. In Canada, the area of moderate to severe defoliation and beetle-killed trees by major insects has been estimated at 15.2 Mha in 2009 including 9.0 Mha killed by mountain pine beetle (<http://nfdp.ccfm.org/insects/>). The area of outbreak of Siberian silk worm in East Siberia in 2000-2001 exceeded 11 Mha, mostly in regions where this pest did not practically occur before. During last years, large areas of forests damaged by bark beetles are observed in the Russian European North.

Biospheric and ecological role of boreal forests

Current assessments of carbon cycling [17, 22, 23, 24] report that boreal forests continue to serve a net carbon sink. Based on forest inventory data, Pan et al. [17] showed that boreal forests (estimated at the area of 1135 Mha, without Alaska and not productive forests in Canada; the FAO definition of forest was used) during the last two decades provided rather stable sink at 0.5±08 Pg C yr⁻¹ [17]. However, 82.5% of this sink in 1990-1999 and 93.6% in 2000-2007 were provided by Russian forests. Relatively small carbon stock in Canadian forests is explained mostly by loss of living biomass from intensified wildfires and insect outbreaks [12]. The sink in boreal European countries was at 65±16 Tg C yr⁻¹ in 1990-1999, and 27±7 Tg C yr⁻¹ over 2000-2007.

Contribution of Russian forests is crucial for current understanding the total role of boreal forests in the global carbon cycle. Recent studies [22, 23] were based on a full carbon account methodology showed that during the last decade Russian forests (based on the national definition of forests) served as a net sink of 0.55-0.75 Pg C-CO₂ yr⁻¹. It constituted about 90-95% of the total carbon uptake in vegetation ecosystems of the country. This estimate is very close to the results received by inverse modeling and upscaling of eddy covariance measurements. Nevertheless, large areas, mostly in disturbed forests and on permafrost are estimated as the carbon source. Interannual variability of the sink substantially depends on the variability of seasonal weather and connected to this regimes of natural disturbances. Forest is also estimated as a methane source of 1.26 Tg C-CH₄, mostly supplied by forests on peatland and as part of fire emissions. The application of DGVMs TEM [14] showed that from 1997 to 2006 the terrestrial areas of tundra and northern part of boreal Asia annually gained 42.7 Tg C as CO₂ from the atmosphere, lost 31.6 Tg C as DOC to the ocean, lost 24.8 Tg C as CH₄ (cf. with an empirical estimate for all Russian land at 16.2 Tg C yr⁻¹ [23], and lost 51.8 Tg C as CO to the atmosphere That caused a total negative carbon balance of this territory at 65.4 Tg C yr⁻¹. Uncertainty of these numbers is not known. However, very likely, these results reflect an on-going process of switching large northern territories on permafrost from sink to source due to warming and intensifying of wildfire.

Disturbances impact the carbon budget significantly. Overall, vegetation fires over the boreal zone of the last decade emitted on average ~200 TgC yr⁻¹ with the high interannual variability. For Russia, direct carbon fire emissions during 1998-2010 are estimated at 1.57 x 10⁹ t of carbon, or on average at 121.0 x 10⁶ t C yr⁻¹, or 2.4% of NPP. Post-fire dieback generates the flux of about the same magnitude. The interannual variability of fire carbon emissions is high – from 50 x 10⁶ t C year⁻¹ (2000) to 231 x 10⁶ t C year⁻¹ (2003). Forest lands deliver a major part of carbon emissions – 76.0% of the total. Estimates for Alaska, Canada, Mongolia and Kazakhstan were 12, 42, 7 and 21 Tg C yr⁻¹, respectively. Outbreaks of insects and deceases are the second substantial source, e.g. ~50 t C yr⁻¹ in the Russian territory on average.

Future climates and boreal forests

All climatic models predict a substantial acceleration of the recent climatic tendencies by end of the 21st century across the boreal zone. For different regions of Russia, the likely increase of annual average temperature is expected in the range of 4-12°C [5, 8, 15]. Although the diversity of forecasts by individual models is high, some trends are consistent and clearly recognized: (1) the maximal increase of temperature is predicted for the most cold months (December-February); (2) the minimal warming is expected for spring and summer (March to August) – on average from 4 to 4.5°C by 2100; (3) the increase of precipitation is expected mostly during wintertime; (4) summer increase of precipitation will not compensate the increase of temperature; increasing climate aridity is very likely, particularly in the southern continental regions; (5) the maximum increase of the annual average temperature – for about 10-12°C – is predicted by end of the century towards the north-east of the Asian continent; and (6) substantial acceleration of weather variability is very likely. In its major features, similar climatic change is expected in boreal and polar domains of Northern America.

The changing climate rearranges land cover and impacts ecosystems biophysical and biochemical processes directly and indirectly. This dramatically impacts succession dynamics, morphological structure and species composition, carbon cycling and zonal distribution of vegetation, although different models present an extensive diversity of the results [e.g., 6, 7, 25, 26, 27]. A number of studies have already indicated a strong response of coniferous forests to the warming in both alpine and geographical forest tundra ecotones of Northern Eurasia by an increasing increment, stand densification and regeneration density, upward tree line shift, and transformation of *krummholz* to aboreal forms [10, 11, 19]. The application of the Siberian bioclimatic model (SibClim) in two contrasting IPCC scenarios A2 and B1 and Hadley Centre HadCM3 climatic model showed that Siberian ecosystems will be substantially altered by end of this century. In the above scenarios, the areas of tundra, forest-tundra, and taiga would decrease from the current 81.5% to 30 (50)% by 2080, and forest-steppe, steppe, and semidesert zones will expand from 18% to 67 (50)%, respectively [25, 27]. Taking into account that rates of the natural migration of boreal vegetation are at least of two orders slower than shifting the climatic conditions, this forecast supposes a catastrophic impoverishment of boreal forest and decline of its area. However, the substantially different result has been obtained by a process-based spatially explicit dynamic model of forest succession and disturbance LANDIS-II. The model has been applied to a forest region of the Irkutsk oblast' at the boundary of southern and middle taiga [6, 7]. The most interesting result of this study was that major response variables (e.g., species composition, live biomass) were more strongly impacted by forest management regimes and insect outbreaks than the direct effects of climate change.

Future regimes of disturbances are driven by climate change. Current model predictions of future fire regimes in the boreal zone suppose doubling of number of fire by end of this century; substantial increasing of number of catastrophic and escaped fires; dramatic increase of the intensity of fires and fire emissions; and change of composition of products of burning due to a wider distribution of deep soil burning [3, 25]. Very likely, thawing of permafrost and following aridization of landscapes on permafrost will lead to explosive acceleration of wildfire, degradation and death of coniferous forests and to wide distribution of “green desertification”. There is a high probability of positive feedback between warming and escalation of fire regimes: the increase of concentration of CO₂ in the atmosphere will lead to increase of frequency of long and dry periods which would promote the growth of area and intensity of fires, and, consequently, to substantial increase of emissions of greenhouse gases. In turn, growth of the emissions leads to destabilization of the Earth climatic system and following increasing threat of fire.

Already today, forest fire protection services of developed boreal countries balance in the narrow range between successful forest fire protection and large economic, ecological and social losses, particularly over catastrophic fire years. The situation in Russia is much more dramatic. Very likely, escalation of future fire regime will be disproportionate large comparatively to increase of fire danger. The boreal countries, and Russia particularly, need urgent development of a new system of forest fire protection which would be satisfactory in a rapidly changing world. Introduction of such a strategy in Russia still remains a problem of the future.

Transition to sustainable forest management is a mainstream of current and future interaction of human and boreal forests. Some boreal countries have already made substantial steps along this way. Complexity of this quasi-manageable, ill-defined and uncertain problem is evident. In essence, forests and entire northern landscapes represent very complicated stochastic open dynamic fuzzy systems with diverse interconnections including numerous impacts, responses and feedbacks that are accelerated by on-going global climate change. Multifunctional forest services generate sophisticated interplay – from synergetic to tolerant to conflicting to exclusive. Future societal cost of different services is not completely known. Searching for optimal decisions and identifying relevant tradeoffs are an incredibly difficult task due to the extreme complexity of the systems; diversity of interests of major stakeholders which are usually incompatible or contradictory or even exclusive; and the dynamic character, non-linear tendencies and uncertain forecast of the situation that requires decisions.

Adaptation and mitigation strategies should be an inherent part of transition to sustainable forest management. However, background philosophy of classical forestry of the perception of forest-forming processes; assessment of forest conditions; studying productivity and dynamics; etc. were to determine the future

based on knowledge of the past. Such an approach becomes less and less reliable in a continuously changing world. Currently, forest professionals are not able to encompass all the complexities of future developments of forest and needs in its services. Integrated modeling becomes a working tool for practical forest management.

Development of adaptation and mitigation strategies in boreal forests should provide a solid background of transition to adaptive forestry and forest management and include *inter alia*: (1) nationally adapted concepts of sustainable development and sustainable forest management of regions of high latitudes; (2) integrated land observing systems over the entire circumpolar polar and boreal biomes as an information basis of integrated land use management under global change; these systems should provide early warning of changes in the functioning Earth system; (3) a new system of specially protected territories; (4) new strategy and institutional background of advanced fire management system which would be satisfactory under ongoing and future climate changes; (5) legislative and normative base of adaptation and mitigation as a background of adaptive forest management; (6) system of adaptation of structure of boreal landscapes to climate change as a basis for prevention of distribution of wasting disturbances; and (7) considering management of major biogeochemical cycles, as a crucial issue of future strategies. Large uncertainties of climatic and social projections define a major principles of future adaptation and mitigation strategies: minimizing the overall systems losses if alternative scenarios are realized.

The above and other activities are closely tied with the overall problem of sustainable management of natural resources, economic and social development of the entire boreal territory, and ecological safety of population. In essence, climate change should be one of cornerstones of regional strategies of social and economic developments with inherently implemented global issues and links. Forest in northern regions is a major stabilizing element of natural landscapes, and forest management paradigm requires substantial reconsideration – from a pure resource to multi-service use of forests with a clear emphasis to environmental and protective services. It requires a proper quantification of “global utility” of forests. Overall, the problem of interaction of humanity and nature in northern regions requires new ways of thinking and principally new solutions in many aspects - education; institutions; capacity building; development and introduction of ecologically friendly methods, machinery and technologies of industrial development of northern territories.

International Boreal Forest Association

Global importance of boreal forests, dramatic challenges of the changing world, uncertainty of predictions, and urgent needs of actions define a crucial role of effective international cooperation in boreal forestry and forest management. The International Boreal Forest Research Association (IBFRA) came into being as an international attempt to stimulate a required level of coordination and collaboration within the boreal forest professional science and managerial communities. At its first organizational meeting in Mezghorie (Ukraine) in July 2011 the mission of IBFRA was defined to be: “to promote and co-ordinate research to increase the understanding of the role of the circumpolar boreal forests in the global environment and the effects of environment change on that role”. Two last decades have verified the timeliness and expediency of IBFRA’s development. During 20 years of its history, IBFRA organized 15 international science conferences in 7 countries hosting boreal forests. These conferences resulted in 8 volumes of peer reviewed International Journals and 6 volumes of proceedings. These collections contained more than 500 research papers on the most important scientific and practical issues facing boreal problems and needs. IBFRA field expeditions and Working Groups [21] contributed substantially to obtaining the new knowledge. IBFRA was at the cradle of many projects and initiatives which substantially improved understanding of ecology, environmental role, condition, and functioning of boreal forests, as well as understanding of needs and relevant ways to transition to adaptive forestry and forest management in the boreal world.

The current understanding of the boreal world, observed tendencies of dynamics of boreal forest ecosystems, expected climate and environment changes, and socio-economic developments clearly show that the boreal world has unique challenges and requires urgent actions which would allow the mankind to protect and preserve this unique value of global meaning. Solutions which should be taken today in order to successfully defend boreal forests against strong current and future threats of global change might be laborious and expensive. These solutions require advanced knowledge, political will and comprehension of responsibility to future generations. A strong circumpolar network of scientists and practitioners could serve a powerful tool for facilitating such solutions. In this context, the extraordinary current and future role of IBFRA becomes evident. It seems relevant to concentrate the current and future strategies of IBFRA around the following major activities: (1) to act as a global window for boreal forest ecosystem science, independently and in close collaboration with IUFRO, FAO, IGBP and other major global actors; (2) create forums for communication and information of public about societal efforts needed for preservation and sustainable development of boreal forests; (3) promote developments of integrated information systems including implementation of multi-sensor remote sensing concept, improved national forest inventories and environmental monitoring which would be able to provide early warning on undesirable changes of boreal forest ecosystems; (4) develop and implement a paradigm of sustainable forest managements; and (5) broaden the human dimension of the boreal world with a special emphasis to aboriginal people.

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