3. MAJOR SCIENTIFIC TOPICS

3.1. Terrestrial Ecosystem Dynamics

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3.1.1, Introduction

Information on the status and dynamics of terrestrial ecosystems, the understanding of main driving forces, and prediction of future consequences is essential for global change science, implementation of environmental treaties, development programs, natural resource management, and environmental protection. Terrestrial ecosystems are primary components within the Earth system and strongly interact with other fundamental components of the planet such as the atmosphere, ocean, and human society (Figure 3.1). The mechanism of their interactions is based on the matter and energy exchange processes. In spite of complexity of these interactions, they can be quantified through the appropriate measurement and modeling of water/energy exchanges and biogeochemical cycles.

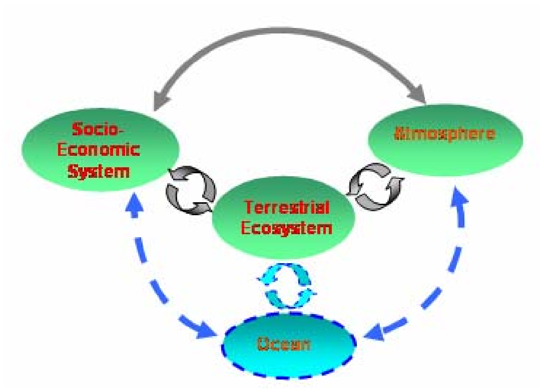

Figure 3.1. Primary interacting components within Earth system.

Terrestrial ecosystems are a source of goods of vital importance for the human society (agricultural production, timber, fuel, and etc). The production of these goods produces significant changes in the landscape pattern and dynamics. Nonetheless, climate is the dominant factor controlling the geographic distribution of the biomes. Climate also drives the phenological dynamics of land cover through seasonal changes in temperature, light, and moisture availability. The vegetation of the northern territories is sensitive to climate change due to the importance of temperature as the main limiting factor for plant growth and succession. Such change in vegetation and land cover characteristics will be a particular focus of the NEESPI terrestrial ecosystem dynamics component. Plans for study of the interactions between terrestrial ecosystems and climate are laid out in Chapter 3.5.

Northern Eurasia is the world's largest terrestrial reservoir of carbon and a region over which climatic variations already appeared, but it is also a region of abrupt, recent changes in the Socio-Economic System that drives anthropogenic land cover change. The collapse of the USSR in the beginning of the 1990's and the subsequent formation of several new independent states have produced profound changes to land-use over much of Northern Eurasia. A focus on these human-induced changes is also a topic of this chapter. Plans to study the feedback changes in human society and corresponding societal-ecosystem linkages are laid out in Chapter 3.4. Changes in Northern Eurasia that affect terrestrial ecosystems and the global climate system are addressed in a set of Chapters (3.3, 3.5, and 3.6).

3.1.2. Ecosystem pattern and key features.

Most of the section has been moved to the Scientific Background Appendix

Northern Eurasia embraces conditions ranging from the arctic deserts and tundra of the north down to some of our planet's oldest forests at the borders of the southern dry steppes, to the arid deserts that span the southern region (Figure 3.2). Northern Eurasia's land cover map for the year 2000 (Figure 1.1) derived from SPOT-Vegetation satellite data gives the most up-to-date and accurate geographical description of the terrestrial ecosystems of the sub-continent. The ecosystems overlap and grade one into another over extensive transition zones, such as forest-tundra, forest-steppe, or semiarid ecosystems. While the role of the climatic factors is important, the distribution of ecosystems also strongly depends on soil forming rocks, relief, and on land-use history and disturbance regimes. The actual composition and geographic distribution of ecosystem types are a result of complex interactions of biota with climate, as well as with other natural and human induced factors (Figure 3.3; Stolbovoi and McCallum, 2002).

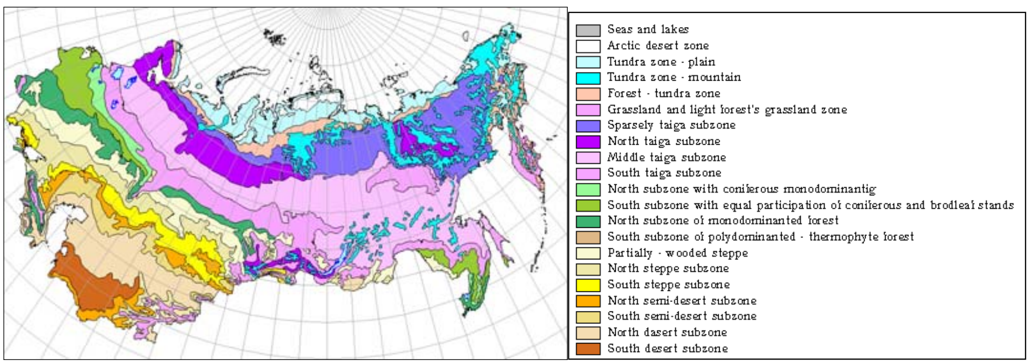

Figure 3.2. Main natural terrestrial biomes of former USSR (Kurnaev, 1973)

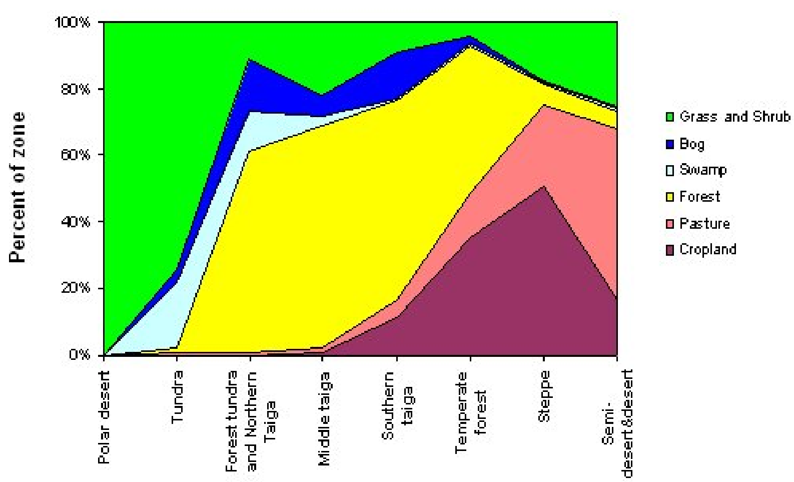

Figure 3.3. Land cover / land use mosaic by natural biomes of Russia

Vegetated lands. In Russia alone, the area of vegetated lands is assessed to be 1630 million ha and the living vegetation biomass of terrestrial ecosystems is estimated as 81.8 Pg of dry matter, including 59.47 Pg accounted for by above-ground phytomass (Morozova, 2002). The aboveground phytomass is highly variable over Northern Eurasia. The lowest aboveground phytomass, about 1 t/ha, is typical for Arctic tundra and desert communities. This amount increases in open woodlands up to 20-40 t/ha, and reaches values of 110-230 t/ha in the forest ecosystems of northern and southern taiga. For some southern broad-leaved forests, aboveground phytomass may reach values of up to 310 t/ha. Although the general pattern of geographical distribution of aboveground phytomass in Northern Eurasia is known and ranges of its variability are quantified, the spatial resolution and accuracy of existing data is far from what is required by global change science and sustainable natural resources management. Biophysical characteristics of Northern Eurasia's vegetation cover, such as Leaf Area Index (LAI) and Fraction of Photosynthetically Absorbed Radiation (fPAR), are imperative for estimation of ecosystem productivity, but still require improvements of their estimations, including geographical distribution and seasonal changes. The status and dynamics of vegetation composition at the level of plants' life forms and/or species and its structure may serve as an important indicator of climate change. They must also be taken into account for biodiversity assessment and as a basis for a wide range of socially important human activities, e.g. forestry and agriculture. The regularly updated data on structural properties of the vegetation cover (vertical and horizontal), such as the presence of vegetation layers and height and density of vegetation cover may serve as important indicators of climate change. They are also needed as input variables into models of energy and water cycles and are essential for land use management. The data on the structural properties of the stands over a significant part of Northern Eurasia is routinely collected by national forest services but, the use of these data at the sub-continental level has come with some difficulties - particularly its lack of accuracy and reliability and, in many cases, its limited accessibility for the research community. For the non-forest natural ecosystems, such as tundra and grasslands, the descriptions of vegetation composition is mainly obtained by dissociated research groups on the test sites with unknown accuracy resulting in non-uniform data sets for the sub-continent. The conclusion can be made that, at *the sub-continental level of Northern Eurasia, there is a lack of uniform data with known accuracy of composition and structural properties of vegetation cover*.

Peatlands. The world's largest peatland territories are found in the West Siberian mire massif while The Polistovo–Lovatsky mires are the biggest in Europe. Russian peatlands support globally significant biodiversity and provide a variety of hydrological and biogeochemical functions valuable to people throughout Eurasia. Peatlands are characterized by the unique ability to accumulate and store dead plant material originating from mosses, sedges, reeds, shrubs, and trees as peat, under waterlogged conditions It is difficult to determine whether a mire/peatland ecosystem works as a sink or source of carbon at a given moment. This source/sink function can change from year to year with long- or short-term climatic changes working as a triggering mechanism. Paludified lands and forests having a thin peat layer (<30 cm) are especially sensitive to such functional changes. There is a strong need to improve data on the peat-covered area over Northern Eurasia considering nature diversity of the regions, peatland/mire typology, and peat depth. Remote sensing data could make a valuable contribution to peatland inventory and hard-to-reach northern and eastern regions may have no alternative. Peatlands provide a wide range of wildlife habitats supporting important biological diversity. They play an important role in maintaining freshwater quality and hydrological integrity and carbon stores and sequestration. Peatlands contain one-third of the world's soil carbon and 10 % of the global freshwater volume (Wise …, 2002). Only in Russia can peatlands store from 113.5 (Vompersky et al., 1996) to 210 Gt C (from the data for the USSR obtained by Botch et al., 1995), which makes up 20–50 % of the world's peatland carbon. Peatlands present a high variety of natural conditions and, thus, have quite a different peat accumulation rate, contribution to the other components of the carbon balance, GHG emission, etc. (Vompersky et al., 1998; Vasiliev et al. 1999; etc.). *The accurate data on carbon and water storage, carbon accumulation rate, and GHG emission for Russian peatlands must be developed* using adequate methodological approach to be work properly. From a conservation point of view, it is important that most of the peatlands are relatively intact and offer a rare opportunity for conserving areas large enough to allow natural hydrological and ecological processes to occur.

Fresh water systems. Besides socio-economic functions, fresh water systems (rivers, interior lakes, and reservoirs) play a very important role as a factor of environmental sustainability as well as important link between global and regional cycles of carbon and other biogenic elements (3.2). Because of low water temperatures, the processes of self-purification in the majority of rivers and water bodies of Northern Eurasia go on slowly and that is why the fresh water systems are especially vulnerable. The biotic component of fresh water systems is also very vulnerable to external impacts, including anthropogenic ones. At the same time, it fulfils extremely important functions of the regulation of the fresh water systems state, their self-purification, and self-recovering. Fresh water systems fulfil their regulating optimally when values of their parameters are close to the natural ones.

The important task is to identify optimum balance between economic demands in water and biological resources and their possibilities for themselves preservation. The important index of fresh water ecosystem change is the degree of transformation of structure and metabolism of biocenosis or their ecological modifications (Izrael and Abakumov, 1991). In populated regions of Northern Eurasia, many rivers and water bodies are in a state of anthropogenic ecological tension and ecological and metabolic regress by hydrobiological indices.

Problems. The information on actual the geographical pattern and characteristics of the terrestrial ecosystems need to be improved in order to provide better understanding of land cover distribution over all of Northern Eurasia for better understanding of the main driving forces of the ecosystem dynamics and their links with the fundamental physical, biogeochemical, and socio-economic processes within the Earth system. A particularly advanced land cover database for Northern Eurasia has to be developed with the use of elaborated classification approach for tundra, forest, and peatland ecosystem components. The vegetation cover component of the NEESPI land cover database need to be linked with biophysical (LAI, fPAR, NPP, above- and below-ground biomasses, etc) and structural (plant composition, height and density of the cover, presents of the layers, etc.) properties, which may provide essential input into appropriate global and regional models and serve as indicators of climate change. The complementary database with information on soil and permafrost formations has to be developed in order to compensate the lack of accurate and uniform data related to these important issues. The dramatic scale by which anthropogenic changes happened during the last century, such as conversion of the forests and steppe into agriculture lands and replacement of taiga by secondary broadleaf forest formations as a result of intensive timber harvesting, drying-out of wetlands, and peatland exploitation, are not well documented. Changes also include land cover, vegetation composition and structure induced by fires, insect outbreaks, timber harvest, agricultural establishment and abandonment, overgrazing, air pollution, etc. A multidimensional time series (magnitude and geographical pattern) of the ecosystem changes resulting from these disturbances may provide essential input for the theoretical assessment of the biogeochemical, water, and energy cycles. This can lead to understanding of the climate-ecosystem interactions as well as to the identification of critical regions where the ecosystem changes may lead to environmental degradation or social conflicts. *Reconstruction of the land cover changes over the entire Northern Eurasian territory over the last century in order to estimate their scale and geographical pattern has to be considered among priority scientific tasks of the NEESPI*. This includes the collection of data on responses of the ecosystems, in particular, changes of the phenological rhythms of the vegetation, biophysical properties of the plants, frequency and severity of climate dependent (fires, insects, plant epidemics) disturbances, structure of the vegetation and species composition, as well as changes in the geographical distribution of biomes. *The task performance will require intensive involvement of the historical data records and maps, air photographs, and available satellite images.* The satellite images date back to the early 1960s. Starting from this time, the spatial and temporal resolution of land cover change products may be increasingly improved.

3.1.3. Soils. Most of this section has been moved to the Scientific Background Appendix

Soils act as a reservoir for carbon in the form of soil humus. In this case, any type of soil degradation, as a rule, leads to disengagement of soil carbon to the atmosphere and the lack of such data provides mistakes in the modeling of the global carbon cycle and global climate. The second point is that soils are home to more than 80% of terrestrial animals and act, in this case, as the necessary element for biodiversity conservation issues. Lastly, soils act as a "shield" for litho- and hydro- spheres preventing their destruction and pollution and providing the sustainability of their chemical composition (Dobrovolskiy and Kust, 2003). Unfortunately, the understanding of the role of soils in the biosphere is a very new scientific concept and there are almost no data on soils on this issue. Most soil data have been collected only for agricultural and (much less) for forestry purposes; they were presented in the forms of land inventories and not renewed for the past 20 years. Moreover, most of these data were not published and are stored in "hard copies" in the archives of different organizations (Kust and Kutuzova, 2003). The conclusion can be made that *there is a lack of present uniform soil data available to use for the adequate assessment of the real role of soil cover in the environmental changes of Northern Eurasia*

3.1.4. Driving forces of the large-scale ecosystem dynamics

Terrestrial ecosystems are highly dynamic due to both natural forces and anthropogenic actions. An important objective of NEESPI is to improve our knowledge on large-scale dynamics of terrestrial ecosystems over all of Northern Eurasia (including past and immediate changes), to gain a comprehensive understanding of the main driving forces of these dynamics and scientific explanation of their links with the fundamental physical, biogeochemical, and socio-economic processes in the Earth system. This knowledge may also serve for better prediction of possible future changes in the geographical pattern of the land cover, structure, and productivity of the terrestrial ecosystem (the magnitude and spatial variability of the main dynamic factors under various scenarios of climate change and social development). There are evidences of dramatic changes of Northern Eurasia's land cover during last few centuries resulting from land-use change and natural disturbances.

Anthoropogenic factor. Considering the most recent history among the most profound human induced changes of 20th century are the conversion of steppe ecosystems in to agricultural lands in Southwestern Siberia and Kazakhstan through extensive logging of taiga forests in the European North of Russia, drying-out of wetlands mainly for peat extraction and agriculture, development of oil and gas production industry in Siberia. Only in Kazakhstan, during the period of years 1954-1960, 25.5 million ha of virgin steppe was newly ploughed and converted to croplands (http://kazakhstan.awd.kz). Broadleaf trees now occupy the vast area of former dark coniferous forests in the taiga belt of European Russia. This conversion happened mainly during the last century and resulted from extensive forest logging in USSR and which had two peaks of activity: at the industrialization time in the 1920s and after the second Word War. As reported by The State Committee on Land Resources of Russia, the annual area of wetlands dried-out during 1991-98 was about 5 millions ha (http://www.aris.ru/MSHP/DEMELIO/hist.html). Certainly, many other examples of land cover change of less impressive scale, but spread almost everywhere over Northern Eurasia, can be given to illustrate the statement. The environmental changes during last century are not well documented and quantified, although such data are needed in order to estimate environmental consequences and mitigate them if they are of negative character. They are also necessary for better understanding of actual ecosystem evolution and prediction of future status and feedbacks. The immediate changes of the terrestrial ecosystems, to a great extent, resulted from natural and human caused disturbances. Post-disturbance dynamics, such as natural regeneration and consequent successions of the vegetation cover within disturbed landscape, is an important component of the terrestrial ecosystem sustainability. Both, the disturbance and post-disturbance dynamics strongly depend on the functioning of the Socio-Economic System, which includes industry, forestry, agriculture, grazing, water management, and other human activities which influence both the terrestrial ecosystem and climate. The well being of the Socio-Economic System, including human health, also strongly depends on the ecosystem status.

***Tundra ecosystem*.** The dynamics of the tundra ecosystem caused by the past climate change considerably vary between different Arctic regions (Serrese et al., 2000) and result in both positive and negative feedbacks in "permafrost – active-layer – vegetation – atmosphere – climate" interactions (Chapin et al, 2000). *The situation stresses the necessity of the development of an adequate methodological base to generalize known effects on permafrost areas of Northern Eurasia.* The system of climate-tundra feedbacks includes more than just the carbon dioxide balance. The lakes and over-humidified tundra soils are important sources of methane fluxes (Zimov et al., 1997). The climate changes can lead to increased unfrozen periods and stimulate methane emissions. On the contrary, a drying climate results in the restriction of tundra wetlands and a corresponding decrease in methane emissions.

Additional problems in the prediction of tundra biome dynamics are created by changes in the feedback hierarchy under long-term climate influence with stimulation of negative feedbacks (Camill and Clark, 2000; Oechel et al., 2000b). *To improve conclusions of climate change effects on tundra ecosystems, it is necessary to have more observations on the system functioning in different regimes over long-term scales.* The specific question is the current destruction of shores of Arctic seas (3.6.2). During this process, the terrestrial substances enter the seawater, affecting the biogeochemical cycles in marine ecosystems. *The scales of coast destruction and ecosystem effects need to be investigated.* The frequency of tundra fires was expected to increase during global warming (Oechel, 1993). The recent catastrophic fire events in the Far-East region of the Eurasian tundra confirm that prediction. Tundra fires often lead to complete destruction of aboveground vegetation cover and up to 15 cm of top organic soil horizons. The direct CO_2 emissions from tundra fires constitute up to 50 tC ha^{-1}. The majority of tundra territories in Russia are not fire protected, which is leading to the absence of data on fire events and burned areas. The period of post fire regeneration of the carbon pool in vegetation is nearly 10 years and, in soil, nearly 100 years (Zamolodchikov et al., 1998). *The up-to-date and accurate data on tundra fires, including burned areas and fire severity, have to be collected on a regular basics.* The important part of the tundra ecosystem is the reindeer populations, as they are a major consumer of the net primary production. The reindeer husbandry presents the basis of life for many native people such as the Nenets, Evenks, Chukchi, and others. *The system approach to the study of tundra biome demands the consideration of reindeer population dynamics as a possible object for optimization* (3.4). The industrial influence on the tundra biome is expressed mainly in resource exploration and pollution (3.4). Any types of building and transportation activity in tundra lead to disturbances of vegetation cover and hydrological regimes, changing the soil heat conductivity and permafrost degradation. The similar processes are observed in polluted zones in The Cola Peninsula and the southern part of The Taymyr Peninsula. *The remote sensing technique is considered as most appropriate to estimate the impact of human caused disturbances on the regional scale* (Virtanen et al., 2002).

The following specific scientific questions may form a basis for tundra ecosystem research activity of the NEESPI science plan:

- *What are regional and zonal trends in permafrost dynamics and related changes in biogeochemical cycles?*
- *What is the climate influence on long-term dynamics of tundra ecosystems?*
- *What are inputs of tundra wetlands and lakes in regional biogeochemical cycling?*
- *What are the scales and biogeochemical impacts of the destruction of sea costs?*
- *What are the scales and ecosystem effects of tundra fires?*
- *What is the role of reindeer populations in biogeochemical cycling of tundra ecosystems?*
- *What is the environmental impact of resource exploration in the Arctic on the regional and zonal scale?*

Forest ecosystem. The current pattern of forest vegetation reflects the combined effects of anthropogenic and natural disturbances over a range of time scales. Nowadays, the growth of forest trees and the functioning of the forest ecosystems are affected by multiple stresses as a combination of climate change and disturbances. Forest ecosystems of Northern Eurasia are subjected to climate changes that may result in changes in length of the growing period and snow cover period, production and vegetation carbon storage enhancement, replacement of tundra with boreal forest, warming permafrost, and fire frequency increase. But some observations in the northern regions were already said to contradict the general predictions on global warming (Normile, 1995; Polyakov et al. 2003)

Thus, there still exist major uncertainties in prediction of the length of the growing season changes. The accuracy of predictions can be increased by the coordinated investigations of past changes in both biotic and abiotic environments (Houghton et al, 1996), taking into account regional variations.

Analyses based on satellite data suggest that both production and vegetation carbon storage have generally been enhanced across the boreal forests in recent decades (Myneni et al, 1997; 2001; Randerson et al, 1999; Zhou et al, 2001), an observation that is consistent with climate warming. One hypothesis for the mechanism of increased production is that warming increases decomposition of soil organic matter to release nitrogen in forms that can be taken up by plants. Since production is often limited by plant nitrogen supply in boreal forests (Van Cleve and Zasada, 1976; Van Cleve et al., 1981; Chapin et al., 1986; Vitousek and Howarth, 1991), an increase in nitrogen availability to plants should increase production. Several boreal warming experiments and modeling studies have provided support for this mechanism (Van Cleve et al., 1990; Bonan and Van Cleve, 1992; Bergh et al., 1998; Stromgrem and Linder, 2002; Clein et al., 2002). Increased N deposition, management changes, and increased CO_2 are also possible explanations for these records (Erisman and de Vries, 2000). Increased accumulation of soil organic matter in European forests has also been observed. One of hypothesis is that increased N deposition causes an increased rate of soil organic matter accumulation due to an increased biomass of assimilative organs, litter production, and a reduced decomposition of organic matter (Berg and Matzner, 1997).

The hypotheses explaining production and carbon storage enhancement across the boreal forests in recent decades have not been critically evaluated for ecosystems in northern Eurasia.

The replacement of tundra with boreal forest occurred in earlier warm periods of the Holocene in Northern Eurasia (MacDonald et al., 2000). Over the last half-century, treeline advances into tundra have been documented in Alaska. There are also some evidences of this phenomenon in Russia (Gorchakovsky and Shiyatov, 1978). Because a significant part of Russian forests (41 %) is categorized as mountain forests, investigation of tree line variations in mountains is of great importance. Permafrost maintains a perched water table that keeps moisture in the root zone and maintains forest cover. Loss of permafrost is expected to increase soil drainage and may result in aridization in these areas and loss of forest cover (3.6.1).

While treeline advance and warming permafrost may affect climate change, investigations of temporal and spatial variations of these phenomena are challenging.

Vegetation type and distribution have large impacts on regional and global climate through effects on terrestrial carbon storage (Smith and Shugart, 1993) and on water and energy exchange (Charney et al., 1977; Shukla et al., 1990; Bonan et al., 1992). Forest ecosystems, through water/energy and radioactively active gases, have an exchange with the atmosphere and may respond to climate change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (3.2, 3.5). *The present and future role of Northern Eurasia cannot be adequately understood without better knowledge of response of forest ecosystems to climate change. Of particular concern is the likelihood of amplifying a feedback loop that can cause a further warming (3.5).*

Disturbances. Human influences on the disturbance regime include both direct effects, such as harvesting or inducing and/or suppressing natural disturbances (fires, insects, flooding, etc.), and indirect effects from altering the forest environment. Indirect influences include both climate change and atmospheric pollution and their effects on tree health and survival.

Because of natural and human- induced disturbances, forest area in Northern Eurasia is a gigantic mosaic of successions (Smirnova, 2004). The most important disturbance factor in the forests of Northern Eurasia is ***fire***. In northern Eurasia, most of the fires occur east of the Ural Mountains. It is estimated that large fires account for 90% of the area burned in central Siberia (Ivanova et al., 2002). Official fire statistics available from Russia suggest that area burned in Russia is much less, with only approximately 1 million ha burning annually, and that the maximum annual area burned is less than 3 million ha (Kasischke et al., 2003). However, analyses based on satellite data estimate that 11.7 million ha burned in 1987 and that 13.3 million ha burned in 1998 (Conard et al., 2002; Kasischke et al., 2003). More careful analyses of fire frequency in Russia suggests that fire frequency in Siberia is higher than in Alaska and Canada (Shvidenko and Nilsson, 2000; Shvidenko and Goldhammer, 2001; McGuire et al., 2002). Thus, for boreal forests outside of Europe and European Russia, official statistics of fire in Russia represent a significant underestimation of burned area and available data suggest that between 0.5 and 1% of boreal forest burns annually with the highest rates in Siberia along the Yenisey River (McGuire et al., 2002). The degree to which increased fire frequency has the potential to release carbon in the boreal forest depends, in part, on fire severity. Fires in central Russia, which is dominated by Scots pine, tend to be surface fires in which trees survive because of thick bark. In contrast, fires in far eastern Russia tend to be stand-replacing fires. Analyses of the effects of climate change projections on fire weather suggest that climate change has the potential to increase fire frequency in northern Eurasia (Csiszar et al., 2003). *A major challenge is to understand how the extent, timing, and severity of fires in northern Eurasia change in response to climate and other factors.* Periodically Northern Eurasian forests are subject to massive ***insect infestations*** that occur on millions of hectares, causing forest dieback or damage. These outbreaks are induced by a combination of favorable weather conditions (optimal temperature, low levels of precipitation and humidity) and occur with a periodicity of 15 to 25 years. Harsh climatic conditions have, thus far, limited the outbreaks to areas below 60^o north latitude. However, with increased warming, outbreaks may occur in the forests north of this line since desirable food species are available. *Adequate detection and mapping of insect outbreaks is essential for understanding of their impacts and the assessment of potential for northward expansion*. The forests of northern Eurasia represent a wood resource of global significance. Forests are heavily managed for wood production and harvest resulting in losses of the organic matter and nutrients. In general, ***forest harvest and management*** results in lower vegetation and soil carbon stocks than equivalent unmanaged forests. Wood harvest could reduce carbon storage in Siberia's boreal forest (Rosencranz and Scott, 1992) and may have already done so. Agricultural activities in Northern Eurasia have also been changing rapidly over the last decade. According to official statistics, 29 million ha of arable lands were lost in Russia from 1990 to 1999 (Russian Statistical Yearbook, M., Goscomstat RF, 642 pp). Ongoing analyses of satellite data indicate that most of the abandoned agricultural land is converted to young forest regrowth (Bergen and Zhao, 2003; Utkin and Zukert, 2003). While the ***abandonment of agricultural lands*** is likely increasing carbon storage in Northern Eurasia, the increase has not been well quantified. *Because of the changing dynamics of logging and agriculture in northern Eurasia, it is important to understand how these disturbance regimes are changing throughout Northern Eurasia to better understand net changes in carbon storage associated with these activities.* Nowadays, ***air pollution*** is an important driving factor of forest dynamics. According to modern hypotheses, the growth of forest trees and the functioning of the forest ecosystems are affected by a combination of direct air pollution, indirect soil-mediated acidifying impacts of S, N deposition and eutrophication, and changes in weather conditions, either acting directly via drought or indirectly via pest infestation or fungi attack (Erisman and de Vries, 2000). In Russia, monitoring and investigations of pollutant effects on forests are rather scarce and a critical load of these pollutant maps are based on a limited amount of data (see Downing et al, 1993; Posch et al., 1995, 1997; Koptsik and Koptsik, 1995; Koptsik et al., 1996; Semenov et al., 2001). Application of dynamic models is much more limited (Koptsik and Koptsik, 2001). In recent years, concerns about the large-scale dispersion of heavy metals that may regulate the C cycle through impacts on microorganisms have arisen. That is why quantitative analyses and predictions are important for non-acidifying atmospheric pollutants, as well. Results showed that the uncertainties in the calculated critical load values are considerable. Important sources of possible error include variations in soil properties over Russia, the restrictions of the methods used, and the application of the effect-based threshold levels. Thus, *at present, there are no systematic assessments concerning critical loads of S, N, and heavy metals on Northern Eurasia's forests. Critical load maps should be revised as new experimental input data become available and as assessment methods will be improved. To gain insight into damage delay or recovery time, application of dynamic models is needed.* Obviously, due to a lack of data and other resources, it would be impossible to run dynamic models on all sites in Russia for which critical loads can be calculated. However, the assessment of short and long-term environmental risk of excess sulfur, nitrogen, and heavy metal inputs on forests with a dynamic biogeochemical model seems to be reasonable for a few (key) intensively monitored sites in Russia.

The different types of disturbances are often linked. For example, in some forest types the probability and intensity of fire may increase following insect outbreaks because of increases in available fuel. In other cases, salvage logging (recovering the usable timber following a disturbance) can reduce the total area of living forest that is disturbed in a given year by all agents combined. It is common to try to replace natural disturbances (such as wildfires) with commercial harvesting using a combination of protection and scheduled logging. The interactive effects of disturbances and climate change need to be studied. Fire, insect outbreaks, timber harvest, agricultural establishment and abandonment, and air pollution fall within the disturbances resulting in large-scale changes in forest biome that may affect climate. The major challenges are:

- *to critically evaluate the hypotheses explaining production and carbon storage enhancement across the boreal forests of Northern Eurasia in recent decades*
- *to assess temporal and spatial variations in tree line advance and warming permafrost phenomena in Northern Eurasia*
- *to understand how the extent, timing, and severity of fires in Northern Eurasia change in response to climate and other factors*
- *to detect and map insect outbreaks and to assess the potential for northward expansion*
- *to understand how logging and agricultural establishment and abandonment regimes are changing throughout Northern Eurasia*
- *to assess critical loads of S, N, and heavy metals on Russian forests with application of dynamic models to gain insight into damage delay or recovery time.*
- *to assess the balance between positive and negative feedbacks (net effect) that can generate climate change.*

Grasslands and arid ecosystems. Grasslands, and especially semi-desert and desert ecosystems, are very fragile. At the same time, grasslands are the main regions for the primary agricultural activity. Now, despite the big area occupied by grasslands and arid ecosystems in Northern Eurasia, one can find here very few plots of natural grasslands (that are substituted mostly by arable lands) as well as a great areas of degraded ecosystems in arid and semi-arid conditions (usually used for grazing). The natural biomes remain only on the territories of protected areas (natural reserves and parks, military polygons) or in remote, unsettled regions. Desertification is determined by the UNCCD (1992) as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Principal factors of desertification in the region are connected with pasture degradation (overgrazing) and cause unfavorable changes in the species composition of pastures (decrease in grass yield in the hayfields and rangelands). The second main cause is the unjustified tillage of soils that leads to wind and water erosion, causing the development of dust-storms and an increase in the mobile sand area. Improper (especially drainless) irrigation, such as abuse of irrigation technology during drought conditions, usually causes secondary salinization and alkalinization. These causes, as well as felling of trees and shrubs for fuel in economically weak developed regions separately or in synergetic ways, result in the increase of the surface albedo, loss of biological diversity, depletion and pollution of local water resources, increase in climate aridity manifested in the increased occurrence, intensity, and duration of soil and atmospheric draughts. A lot of local causes being replicated are comparable with regional and global effects, and manifested in the following degradation trends: water erosion of soils, formation of sands that are subjected to deflation, salinization and/or alkalinization of soils and ecosystems, soil compaction, and soil dehumidification. The desertification phenomena does not take place everywhere in the area, but the potential risk of various desertification trends occur in 90-95% of the whole grassland territory (Andreeva and Kust, 1999). The following specific scientific questions may form a basis for grassland, arid and semi-arid ecosystems research activity of the NEESPI science plan:

Assessment of the past, present and future dynamics of ecosystems

- *What were the initial pre-industrial conditions in drought affected ecosystems in the past (natural trends, human induced trends)?*
- *What are the observed trends? Have they changed during the last decade?*
- *What changes are predictable?*

Land-use and natural land resources

- *What were the effects of the land uses and land-use changes on the Earth system function (e.g. regional climatology, water resources, carbon and surface energy balance, biogeochemistry, biodiversity)?*
- *What lessons can be learned from system responses of dramatic land-use modifications for sustainable natural resource management?*
- *How do human modifications of land cover affect regional Northern Eurasian and global ecosystem functions and ecosystems feedbacks?*
- *What is the vulnerability of grasslands, semi-arid, and arid ecosystems (incl. agricultural lands) to expected climate and socio-economical trends?*

Peatlands. Human activities continue to be the most important factors affecting peatlands. Vast peatland areas in Russia are being traditionally used in a broad range of activities. Human pressures on peatlands are both direct, through drainage, land conversion, excavation, inundation and visitor pressure, and indirect, as a result of air pollution, water contamination, water removal, and infrastructure development. The key management issues related to peatlands in Russia are peat extraction for different purposes (fuel, cattle breading, horticulture, fertilizers, chemistry, medicine, etc.) and drainage for agriculture and forestry. The main indirect threats to peatlands in Russia are peat fires, road and pipeline construction, contamination in oil and gas mining regions, air pollution, and recreation activities within populated regions. The vast territory, different traditions, and social-economic background lead to geographical and spatial uncertainty of peatland use and threats to them in Northern Eurasia. Many important sites have been destroyed and degraded throughout most of the industrial and agricultural regions. A few data available demonstrated a high variety of peatlands' reactions to paleoclimate change (Klimanov and Sirin, 1997; etc.). Dry/wet and cold/warm periods in the past were marked by changes in vegetation species compositions, in carbon accumulation values, but sometimes no reaction could be found. Mires worked out several specific mechanisms to survive during unfriendly periods and we could not expect an equal response of peatlands, having a different origin and geographical location, to future climatic changes. The following specific scientific questions may form a basis for peatland ecosystem research activity of the NEESPI science plan:

- *What is the present day paludification? What approach and methods should be worked out and used to study it on a local and regional level?*
- *What was the reaction of peatlands and paludified forests of different origins to paleoclimate changes, especially during last Millennium, and what we could expect under various climate change scenarios?*
- *What are inputs of peatlands in regional biogeochemical cycling?*
- *What are the environmental effects today of peatland exploitation under different land use practice, peatland nature origin, and geographical conditions?*
- *What are the scales, ecosystems' and environmental effects of peatland fires?*
- *What changes could be expected under climate change scenarios concerning peatland regulation functions (watershed hydrology, carbon sequestration, GHG emission, etc.), their resources, and biological diversity?*

Fresh Water Systems. Climatic short-term and long-term dynamics is one of the main forces of hydrological changes (Belyaev and Georgiadi, 1992; Klige et al., 1998). From the beginning of 20th century, and especially since 1930s, the increasing role begins to play the anthropogenic factor, which is imposed on natural variability, increasing during the whole 20th century, till the 1980-1990s (Koronkevich, 1990). The fresh water systems of the central and southern parts of the Russian plain, (the southern and western parts of Siberia) were characterized by an extraordinarily high intensity of river runoff resource use (Voronkov, 1970; L'vovich, 1974; Water Resources…, 1987; Shiklomanov, 1989, 2002; Koronkevich, 1990; etc.). The following specific scientific questions may form a basis for water system research activity of the NEESPI science plan:

- *How do fresh water systems, including their biota, respond to changing conditions of climate and economic activity? What is the contribution of each of them to the change of the amount and quality of water resources (state of water ecosystems)? What is the hydrological role of human activity on river watersheds, which affects fresh water systems indirectly through soils, surface biota, and the atmosphere?*
- *Which hydrological changes have taken place in the contemporary period (since the beginning of the 1990s) in fresh water system functioning due to a specific combination of natural and anthropogenic factors of water resources formation?*
- *What are the maximum permissible anthropogenic loads upon fresh water systems, both on quality of water in them and on its volume?*
- *What is the contemporary state of fresh water systems in the main regions and river basins of Northern Eurasia and what is their contribution to sustaining the equilibrium in the biosphere of the Earth?*
- *What will the future state be for the fresh water system as a result of the possible climate change and economic activity?*
- *What should be done in order to optimize the contemporary and expected unfavorable changes of fresh water systems?*