Chapter 2
Status Report About Understanding, Monitoring and Controlling Landscape Processes in Siberia

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Abstract Siberia has experienced significant transformations over the past 70 years and particularly since the introduction of the market economy 25 years ago. This has caused implications for landscape processes and for the status of terrestrial and aquatic ecosystems. We review the role of science and technology in monitoring, understanding and developing Siberian landscapes. Data sources were international literature and own expeditions and studies. Russia has great traditions

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in landscape research disciplines such as geography, soil science, hydrology and agronomy. Substantial progress has been achieved in all these fields over the past 25 years. We found particular progress in landscape research based on international projects in the fields of Arctic research, climate change and carbon cycle. Other fields such as agricultural research remained traditional and underdeveloped. In the 1990s there was a great shift of knowledge and technology in the better-interlinked English-speaking European scientific community. In Russia, at the same time, the introduction of the market economy accelerated environmental problems, caused a greater discrepancy between the livelihoods of urban and rural populations, created new knowledge gaps and enlarged the gap between theory and practice in landscape research. The decay of infrastructure in rural landscapes produced an inhospitable environment for science and technology. In view of this, landscape research in Siberia and in the Far East remained very traditional. Other deficits were based on a lack of communication with the international community due to language barriers. Cooperation between leading Russian and European scientists is still poorly developed and funded. The Russian academic scientific system was highly organized until 2013. However, efficiency was low and scientific outputs did not meet the requirements of decision-makers. The ongoing reform of the academic system entails the risk that precisely the opposite to the desired effects of higher efficiency could come true, such as accelerated brain drain and loss of objectivity. We conclude that Trans-Eurasian research cooperation is becoming very important in the current critical transition phase. Modern analytical methods, sophisticated technologies, models and evaluation schemes for landscape research and environmentally friendly soil management technologies are available in the English-speaking community. Substantial progress in monitoring, understanding and controlling landscape processes in the framework of international research projects could be achieved by applying new research methods in Siberia. We present some of them in the following chapters of this book.

Keywords Landscape research · Soil · Water · Russia · Siberia · Academic system · Cooperation

1 Recent Progress in Landscape Research

1.1 Overview

There are several reasons to identify the processes that affect land and water resources. Human activity, land management and changing climate may degrade or upgrade their functions for nature and society. Underlying processes need to be quantified in order to forecast significant effects and to take measures of prevention, control, mitigation or adaption. Scientists have achieved substantial progress in researching into these functions of Siberian landscapes over the past 25 years. Inputs have come from different scientific disciplines such as geography, soil science, hydrology, climatology, agriculture and others. They have come from scientists working in Siberia, from scientists at leading research institutes in Moscow, European Russia, and from cooperating scientists abroad.

There has been a major focus on Arctic and boreal ecosystems in view of climate change, in monitoring vegetation, water and soil quality. Agricultural scientists have developed technologies for optimizing agricultural systems in different climatic zones and regions. Some interesting and important areas of research and examples are mentioned below.

1.2 Arctic Research, Permafrost Processes

Early analyses of Arctic processes and orientation data on Arctic warming were reported by Pavlov (1994), Pavlov and Moskalenko (2002) and Anisimov and Reneva (2006) from polar desert and tundra regions. Romanovsky et al. (2007) also provided a complex analysis of past and more recent changes in air and permafrost temperatures. Ananicheva et al. (2011) measured recent and forecasted changes to Siberian glaciers as indicators of the ongoing climate change. Climate models of thermal and hydrological soil regimes of the Arctic region were developed to make forecasts more reliable (Arzhanov et al. 2008), and the impact of climate warming on vegetation cover and permafrost in the northern Taiga was quantified using deep ground measurements (Moskalenko 2013). These measured a deepening of the active layer by 10 cm between 1970 and 2010 and an increase in the temperature at a depth of 10 cm by about 1 K (°C) in 40 years.

Polar research has been an object of active international cooperation for many years. The Circumpolar Active Layer Monitoring (CALM) programme was implemented (Shiklomanov et al. 2008), and new permafrost observatories were developed and installed (Boike et al. 2012). The evolution of thermokarst in ice-rich permafrost was explained by Morgenstern et al. (2013), and Yedoma complexes were defined and characterized (Schirrmeister et al. 2013). The Yedoma coastline with the Arctic Ocean in the vicinity of the Lena River Delta retreated at a mean rate of 0.59 m/year between 1951 and 2006 (Lantuit et al. 2011).

Various original approaches were developed; for example, it was possible to reconstruct the 500,000-year history of Siberian permafrost by analysing speleothem growth in caves (Vaks et al. 2013). Areawide digital maps of permafrost temperature and active layer thickness data were developed for modelling climate change over key regions such as Yakutia (Beer et al. 2013). Zakharova et al. (2014) identified the variability in hydrological conditions in Siberian wetlands in terms of water level fluctuations and water storage capacities by satellite radar altimetry. Seasonal amplitudes were 0.7–1.5 m for lakes and 0.2–0.5 m for bogs.

1.3 Carbon Inventory and Cycle, GHG Emissions

In order to identify carbon pools in the soils of the Arctic region, the Northern Circumpolar Soil Carbon Database was developed in international cooperation (Tarnocai et al. 2009). From these data the northern permafrost region contains approximately 1672 Pg (billion tonnes) of organic carbon, accounting for approximately 50 % of the estimated global below-ground organic carbon pool.

Permafrost degradation leads to carbon decomposition and greenhouse gas (GHG) emissions. They were measured in a thermokarst depression (alas) using closed-chamber methods (Takakai et al. 2008). The results showed that the vegetation zone around the pond was an important source of methane (CH_4) and nitrous oxide (N_2O) but a sink of carbon dioxide (CO_2) during the summer time. Khvorostyanov et al. (2008) constructed a new model to study the sensitivity of permafrost carbon stocks to future climate warming. The one-dimensional model solved an equation for diffusion of heat penetrating from the overlying atmosphere and took into account additional in situ heat production by active soil microorganisms. The stability, storage, decomposition and mobility of different soil carbon fractions of permafrost soils (Gleyic Cryosols) is of great importance during permafrost thawing (Rusalimova and Barsukov 2006; Guggenberger et al. 2008). The mobility of black carbon (BC) in its dissolved and colloidal phase is an important export pathway from catchments. Guggenberger et al. (2008) concluded that this transport mechanism may explain the high BC concentrations found in sediments of the Arctic Ocean. This fact was reinforced and made more precise by flux analyses of carbon in rivers (Prokushkin et al. 2011). Zech et al. (2011) analysed the deuterium/hydrogen isotopic ratios (δD) of alkanes in a permafrost loess–paleosol sequence in north-east Siberia and found that maintaining permafrost conditions is most important for the formation and preservation of soil organic matter. Quegan et al. (2011) estimated the carbon balance of central Siberia using different methods, amongst them a landscape–ecosystem approach, atmospheric inversion and dynamic global vegetation models.

Semiletov et al. (2012) determined CO_2 and CH_4 fluxes from the East Siberian Arctic Shelf (ESAS) to the atmosphere. Carbon from degrading terrestrial and subsea permafrost and from coastal erosion contributes to the carbon pool of the ESAS. This affects hydrological and biogeochemical parameters of the Arctic region. Mi et al. (2014) improved the wetland CH_4 emission model Peatland-VU by including an improved hydrological module, incorporating a gross primary productivity (GPP) module, and employing a more realistic soil-freezing scheme.

Shirokova et al. (2013) analysed the biogeochemistry of organic carbon, CO_2, CH_4 and trace elements in shallow and small water bodies in the discontinuous permafrost zones. Upon future permafrost thawing, dissolved organic carbon (DOC) and colloidal metal stocks in the surface will increase in aquatic systems, but CO_2 and CH_4 fluxes from the water surface to the atmosphere will also rise, leading to much higher overall fluxes than previously assumed.

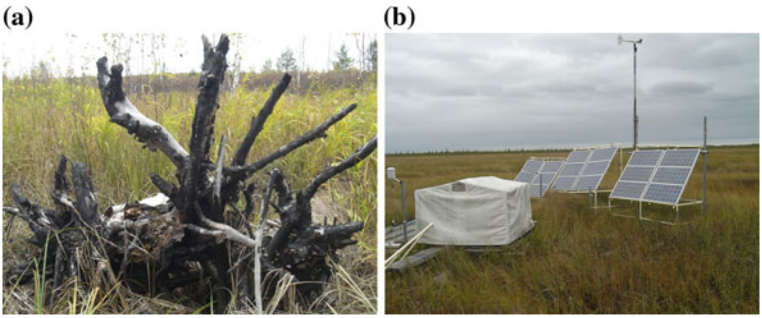

Fig. 1 **a** Fires in peatland and Taiga ecosystems initiate vegetational shifts and altered fluxes of greenhouse gasses. **b** Part of the measuring station in the south of the Vasyugan bog, West Siberia. Tomoko Nakano and colleagues measured the soil/atmosphere methane exchange there after a fire (Nakano et al. 2006)

Glagolev et al. (2011) measured CH_4 emission from a mire in West Siberia using a static chamber method. Similar methods had been developed and tested by Nakano et al. (2006), Fig. 1. Projecting these data to West Siberia by standard model estimates reveals a CH_4 flux from West Siberian mires of 2.93 ± 0.97 million tonnes CH_4–C/year, accounting for about 2.4 % of the total methane emission from all mires or 0.7 % of the global CH_4 emission from all sources. Vasileva and Moiseenko (2013) focused on methane emissions from wildfires using MODIS satellite data. They found most emissions in the southern part of the boreal forest zone (48°–55°N) contributing 5–20 % of the ecosystem methane emissions of the regions, which come mainly from wetlands. Schepaschenko et al. (2013) have developed an automated information system including the carbon pool of the 1-m-deep soil layer, which makes it possible to estimate spatial distributions of soil organic carbon pools with a resolution of about 1 km^2 for Russia as a whole.

Back in the 1990s, scientists already recognized that organic carbon emissions from cropping soils contribute considerably to GHG emissions. In a continuous fallow in grey forest soils of the Baikal forest steppe, the total carbon release into the atmosphere varied from 558 to 1880 kg/ha per year. This was associated with permanent and irreversible humus losses from soils (Pomazkina et al. 1996). Titlyanova et al. (2001) estimated that within 200 years of soil cultivation in West Siberia the stocks of soil organic matter (0–20 cm) decreased by 30 %. This is very different from the largely undisturbed vegetational succession. Vorobyeva (2012) monitored a dark-grey wood soil and weakly leached Chernozem on slopes with forest steppe of South Siberia and found the contents of total carbon, humic acids and insoluble residues had increased up to threefold, indicating a shift from the forest steppe towards the grassland steppe.

1.4 Soil Hydrological Processes and Runoff Generation

Scientists found and predicted a significant alteration of hydrological processes in all landscape zones. Frozen soil acts more or less as a hydrological barrier depending on thermal and other conditions. This has different effects on runoff pathways and consequences for soil processes. Those interactions were studied by a research team of the Institute of Soil Science and Agrochemistry (ISSA) Novosibirsk (Fig. 2). Snow ablation and spring runoff generation depend on the autumn soil moisture and the maximum snow water equivalent (Suzuki et al. 2006). Blome (2014) analysed the influence of permafrost processes on large-scale energy and water cycles over Siberia by applying the regional climate model REMO (Jacob and Podzun 1997) and found that the freezing-induced reduction of water infiltration is the most sensitive process to alter near-surface climate and fluxes of water, matter and energy. Being largely impermeable for snowmelt water, frozen soil favours the development of shallow runoff and erosion processes. On the other hand, when snowmelt water is prevented from infiltrating beyond the soil profile, this stop Chernozems from forming a percolative water regime, which would lead to the fast leaching of minerals (Ollesch et al. 2008; Tanasienko and Chumbaev 2010). During snowmelt infiltration and runoff generation, in combination with enhanced biological and biochemical processes in the active layer, the overall discharge regime of subarctic rivers is altered in its quantity and quality. Increased river loads of elements have already been monitored (Pokrovsky et al. 2012), and more extreme hydrological events are probable (Korytny et al. 2007).

Fig. 2 Russian–German field expedition team for measuring landscape hydrological processes in West Siberia in the frame of the "Soil quality indicators" project. Participants came from the Institute of Soil Science and Agrochemistry (ISSA) Novosibirsk and from the Leibniz Centre of Agricultural Landscape Research Müncheberg (ZALF) in Germany

Research has been carried out into the processes and regulators of lake and river chemistry, as well as ecology, to create better forecasts. Bazhenova and Kobylkin (2013) analysed the dynamics of soil erosion as a source of water pollution in the Selenga basin. Parham et al. (2013) studied the combined effect of permafrost and fires on the chemistry of watercourses, focussing on specific concentrations of DOC and cations. Those empirical data are important for modelling biogeochemical cycles in this region.

The chemistry of surface water is largely associated with salinization processes, mainly in the steppes, but also in semiarid Taiga regions. Zolnikov et al. (2011) monitored the humidification dynamics in the south of West Siberia by means of ground-based field observations and space-acquired images of moderate spatial resolution (Landsat, SPOT). The areas of lakes and solonchaks are aridization indicators. Romanov et al. (2014) used the SMOS satellite with a MIRAS radiometer for monitoring waterlogging, soil salinization and salt lake dynamics. In ground studies, Lebedeva and Lopukhina (2006) analysed the chemical and mineralogical composition of salts, classified salt lakes and surrounding solonchak soils in the Kulunda steppe. Seasonal changes of salt and soil moisture distribution in the active layer of undisturbed larch forest and a thermokarst depression (alas) were studied by Lopez et al. (2007) to explain how forest growth is hindered by surface salinization. The technogenic salinization of soils is also widespread in forest–tundra and northern Taiga ecosystems of areas that are polluted by oil and gas mining (Solntseva and Sadov 2000).

1.5 Analysing the Ecosystem's Response to Climate Change

Research has provided some new findings on the Arctic's response to climate change. Zimov et al. (1995) analysed the impact of grazing herbivores on the kind of vegetation. Results are based on observations that large mammals trampling and grazing tundra regions cause a vegetational shift in dominance from mosses to grasses. Either grass-dominated steppe or moss-dominated Tundra can exist under Pleistocene, current and future climates. Water and nutrient cycles are important under those conditions. Nitrogen (N) in soils can be lost by denitrification and leaching from the system in thawing permafrost, or it can be acquired by plants and boost the N-cycle (Mack et al. 2010). Those processes and ecosystem alterations will probably cause a decline in the populations of Arctic animal species and the expansion of the ranges of some southern species into the Arctic (Callaghan et al. 2011). Overall plant species richness will probably increase at high latitudes (Venevskaia et al. 2013). Many alien species could invade new territories, but this issue has not received much attention (Olonova and Zhang 2013). Models and assessment frameworks have been developed for individual aspects of climate–vegetation interactions. Khomutova et al. (2007) computed the climate-driven limitation of biomass at high latitudes using the Lund-Potsdam-Jena Dynamic Global Vegetation Model (LPJ-DGVM), which is a process-based biogeochemistry/biogeography model. Vasil'evskaya et al. (2012) developed a procedure for calculating and assessing the degradation status of Tundra soil and vegetation based on the properties of natural and disturbed soil cover. Potential alterations to forest, forest steppe and steppe ecosystems have also been the subject of intensive empirical disciplinary studies conducted by international teams over recent years. Interesting examples of these research topics in Siberia are the ongoing German–Russian interdisciplinary projects "Sustainable land management and adaptation strategies to climate change for the Western Siberian corn-belt" (abbreviation "SASCHA") and "How to prevent the next "Global Dust Bowl"?—Ecological and economic strategies for sustainable land management in the Russian steppes" (KULUNDA project 2014; Illiger et al. 2014).

1.6 Development of Landscape Information Systems and Databases

To understand the complexity of landscape processes, research and monitoring programmes of higher complexity and interdisciplinarity are required and in progress (Moskalenko 2013). The creation of Russian soil geography databases (Shoba et al. 2008; Rozhkov et al. 2010) and their correlation with international standards were important steps towards monitoring, modelling and understanding landscape processes. Stolbovoi and Fischer (1997) developed a digital geo-referenced database of soil degradation in Russia, and Stolbovoi (2000) correlated Russian soil types with the legend of the FAO Soil Map of the World and World Reference Base for Soil Resources (WRB). Schepaschenko et al. (2011) developed a new hybrid land cover dataset for Russia which is very important for modelling landscape processes. Datasets of local or regional importance and validity, such as soil survey databases (Mikheeva 2013), vegetation databases (Chepinoga 2012) and others, have been created based on and for the purpose of further local and regional studies. Koneva and Batuev (2014) developed a biogeographical map series for Asian Russia. Most of those databases also have the potential to become integrated into databases and information systems of higher complexity. An information system of this kind has been developed by Gordov et al. (2013). It shall serve as a basis for environmental research in Siberia and is a crucial component of the Northern Eurasia Earth Science Partnership Initiative (NEESPI).

1.7 Development of Research Equipment and Methodology

The focus of research methodologies has changed crucially over the past decades. Whilst most textbook knowledge about landscape structures and processes is based on very detailed ground studies at individual locations, a lot of current knowledge has been generated by studies over large areas utilizing and elaborating on remote sensing methods. Examples are the application of remote sensing methods for vegetation and land cover mapping (Golubeva et al. 2010; Urban et al. 2010), thermokarst monitoring (Fedorov and Konstantinov 2003), glacier observation (Ananicheva et al. 2011), monitoring soil and surface hydrological processes such as salinization (Zolnikov et al. 2011), or environmental pollution and their consequences (Bergen et al. 2013; Gutman et al. 2013). BC emissions from agricultural burning in Russia have been quantified using methodologies based on remote sensing data (Romanenkov et al. 2014).

Particular progress in remote sensing methods was possible because of the change in the political situation in Europe at the beginning of the 1990s, when satellite data and other geo-referenced airborne data became available for civil purposes. At the same time new generations of information technologies have emerged and boomed. Those geo-referenced spatiotemporal data enable more sophisticated simulations of the land and water surface and atmospheric processes (Arzhanov et al. 2008). Data handling by interdisciplinary teams is becoming more reliable and convenient thanks to soft- and middleware tools developed by Eberle et al. (2013).

If the focus is not on the spatial scale of observations alone but on the timescale in high resolution, advanced technologies are also required. Examples of those ground-based process studies and monitoring are GHG flux measurement systems, advanced lysimeters and automatic stations for measuring hydrological and aerial matter fluxes, and sophisticated ecosystem models. In this field of research and monitoring the progress needed for the landscapes of Siberia can be only provided by better international cooperation.

1.8 Advances in Research on Forest and Agro-Ecosystems

Forest ecosystems: The research on forest ecosystems has focused on climate change issues. Outstanding work has been carried out quantifying carbon budgets over the whole area of Russia. The current soil carbon could be estimated from soil maps (Stolbovoi 2006) but possible alterations to this pool remain the largest uncertainty in carbon budgeting (Shvidenko et al. 2011). Aspects of forest acclimation (Lapenis et al. 2005; Tchebakova et al. 2006) and of adaption to stressors such as fire (Ivanova et al. 2011; Kharuk et al. 2011; Krasnoshchekov et al. 2013) or pollution (Sorokin 2009) have become better understood over recent years.

Agro-ecosystems, agronomy: Based on an extended system of education and research in soil science, agronomy, agrochemistry and related disciplines, agro-ecosystems have been well studied over recent years. The greatest focus was on the optimization of local and regional crop production systems. Much progress has been achieved, and numerous dissertations and other publications reflect this best. Enhancing and stabilizing cereal yields by breeding, soil tillage and fertilization and plant management have been of main importance (Gamzikov and Nozov 2010; Trubacheva et al. 2011). Multifactorial trials containing factors of fertilization and other agrochemistry, soil tillage and rotations have been very typical for dissertations. Crop yields and yield quality have been the most frequently tested parameters of success, tested using classical statistical methods. Some examples of the latest work are studies about the effects of organo-mineral fertilization (Sorokin 2011), about the crop yield of a cereal–fallow rotation at different primary tillage (Rzaeva and Fedotkin 2013), about the influence of cultivars and seeding time on yield and grain quality of barley (Puzyreva 2013), about improving the agrotechnology for barley (Shtro 2013) and about optimizing spring wheat yielding capacity in the forest steppe (Skomoroshchenko et al. 2013). Experiments have revealed the site-specific optimum selection of cultivars, fertilization, tillage and plant management. They showed that systems which are more biological have an advantage over those on cropping sites in Europe: local cultivars, extended rotations and low to moderate fertilization levels. A few Siberian experimental sites are part of the Russian agro-ecological monitoring network (Fig. 3). Remote sensing methods for controlling the state of agricultural crops are emerging (Pugacheva et al. 2010).

Modelling agro-ecosystems and agroclimatic potentials: Some progress has been achieved in this emerging topic. Concepts and initial results of modelling agroclimatic potentials were developed by Kirsta (2006) and Tchebakova et al. (2011). Dronin and Kirilenko (2011) developed climate change and food stress scenarios by including socio-economic criteria in models.

Fig. 3 Monitoring stations coordinated by the Geo-Network Department of the Pryanishnikov All-Russian Institute of Agrochemistry (VNIIA) in Moscow. Only a few stations are located in Asian Russia

Soil science related to agronomy: Besides the classical work of soil mapping and studies of pedogenetic processes under different land use, the valuation of soil fertility and productivity, and testing interactions of cropping systems with soil fertility have been an important topic of experimental research work in soil science. Examples of such work include studies about the fertility, rational use and preservation of Chernozems (Abramov and Salova 1998; Eremina 2009; Khmelev and Tanasienko 2009), about acid soils (Tandelov 2012), about the migration of chemical elements between adjacent ecosystems along a geochemical catena (Titlyanova 2008) and about assessing the fertility of typical soils used for agriculture (Smolentseva et al. 2014; Fig. 4). Afonin et al. (2008) developed an interactive agricultural ecological atlas of Russia, which contains important pedologic criteria such as soil types, humus contents and rooting depths. Another important topic of soil scientific research is studies about the status and rehabilitation of technogenic soils (Ermolov et al. 2011). This is related to agronomic

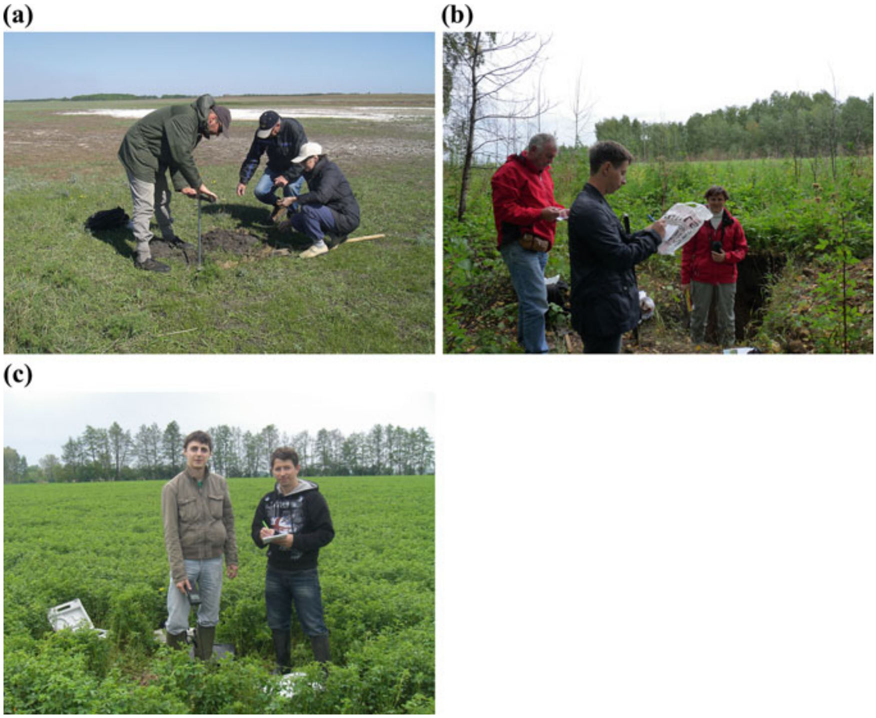

Fig. 4 Assessment of soil conditions in a Solonetz–Solonchak soil association of the Kulunda Steppe (**a**) and a Phaeozem–Chernozem association in the Pri–Ob Forest steppe (**b**). The underlying cooperation between the Institute of Soil Science and Agrochemistry (ISSA) in Novosibirsk and the Leibniz Centre for Agricultural Landscape Research in Müncheberg (Germany) was aimed at harmonizing methods for the taxonomic and functional evaluation of soils. **c** Young scientists measured soil and water quality parameters as part of this project

questions in so far as the cropping of perennials is often the best rehabilitation solution (Chuprova 2006).

A great deal of research not cited here has been done in numerous local institutes of the Russian Academies of Sciences (RAS) and Agricultural Sciences (RAAS).

2 Factors Promoting or Constraining Scientific Progress

2.1 Traditions in Landscape and Agri-environmental Research

Russian science, including landscape research, is based on great and largely stand-alone traditions (Antipov et al. 2006; Shaw and Oldfield 2007). Only two outstanding persons from the last century shall be mentioned here: the geographer V.V. Dokuchaev, who recognized he natural laws of soil formation and was the originator of the modern soil science, and the geographer L.S. Berg, who developed the Landscape–Geographical Zones of the USSR. Until now, national traditions and scientific schools play a particular role in the Russian research field of landscape science including contributions from physical geography, soil science, agricultural science, biological science and others. The emphasis on Russian research traditions is based on and associated with some political and social developments in the country, in particular with those of the recent past, the former USSR. The huge dimensions of the country, backward information flow and technologies, and the continued use of the Russian language may have had some negative side effects. It is still a deficit of many research papers and dissertations in agriculture, soil and environmental sciences that some progress achieved by the international research community was not known or not seen as worth consideration. On the other hand, much important work by Siberian scientists is not known abroad because of language barriers. For example, the Sochava Institute of Geography in Irkutsk is conducting a long-term (>50 years) geo-biochemical monitoring programme over numerous sites in Siberia and neighbouring countries (Antipov et al. 2006; Nechaeva et al. 2010).

2.2 Institutional Research

The Russian Federation operates a huge scientific network for understanding processes and monitoring land and water resources. It is the largest national network worldwide dealing with landscape research. The Russian Academy of Sciences (RAS) and the Russian Academy of Agricultural Sciences (RAAS) comprise several hundred research institutes under general Russian or local control. Additionally, based on the federal structure of Russia, a number of universities and academies deal

Fig. 5 International communication and cooperation is key to scientific progress in landscape research. The photograph shows participants of an international symposium about water quality monitoring, organized by the Limnological Institute Irkutsk in November 2013. *Photo* Marco Natkhin

with research and education in science and agricultural science. The Siberian branches of the RAS and RAAS are responsible for landscape and agri-environmental research over Siberia. Environmental problems in Russia have grown over the past 25 years (Shaw and Oldfield 2007). Landscape scientists therefore have a lot to do to monitor and combat these problems in their landscapes.

Some examples of particularly active scientific groups in the field of landscape and agri-environmental research of Siberia are the Limnological Institute in Irkutsk, Fig. 5, the Sukachev Institute of Forest in Krasnoyarsk, the Institute for Water and Environmental Problems (IWEP) in Barnaul (Fig. 6) and the ISSA in Novosibirsk (all Siberian branches of the RAS). The Geo-Network Department of the Pryanishnikov All-Russian Institute of Agrochemistry (VNIIA) in Moscow is going to establish a new generation of an agri-environmental monitoring system for Russia and to rebuild monitoring stations in Siberia and the Far East. Scientists at the above institutes are involved in highly advanced research technologies and methods and high-ranking scientific publications. They are closely linked with the international scientific community and active in several national and international projects.

The Russian Academy of Sciences (*RAS*): RAS was the highest scientific institution in Russia, conducting basic research about the technological, economic, social and spiritual development of the country (IAP 2013). RAS incorporated 410 scientific institutes belonging to 9 specialized scientific departments, 3 regional divisions and 14 regional centres, RAS employed almost 100,000 people. In the period of 2001–2007 the total publishing output of RAS amounted to 60,000 book and journal titles, most of them edited by the RAS "NAUKA" Publishing House. Its scientists participate in international scientific cooperation and are active in various international organizations such as the United Nations, UNESCO, UNEP, IAEA,

Fig. 6 Research vessel of the Institute for Water and Environmental Problems (IWEP) in Barnaul. It is located on Lake Telozkoye in the Altai Mountains to monitor water quality and sediment

WHO and WMO. RAS researchers are in demand as top scientific experts by the industry and the business community. RAS has full membership relations with about 50 international non-governmental organizations (IAP 2013). Akademgorodok at Novosibirsk is the scientific centre of Siberia (Fig. 7).

The Russian Academy of Agricultural Sciences (*RAAS*): RAAS was the highest self-governed scientific organization of Russia, and responsible for agricultural research (UEAA 2006). It comprised 199 research institutes (year 2000) and 24 agricultural pilot stations, more than 400 pilot farms, 46 semi-industrial enterprises, and 47 breeding and biotechnological centres. About 14,200 scientists worked in research. RAAS owned 5.8 million ha of land for experimental farming including 1.7 million ha of cropping land. Livestock was more than 360 thousand cattle, 130,000 pigs, 65,000 sheep and 1.6 million heads of poultry. RAAS was structured into eight branch departments; one regional department, three scientific and methodological centres, a Siberian branch and regional centres in Siberia and

Fig. 7 Sculpture in Akademgorodok near Novosibirsk, the scientific center of Siberia and headquarter of the Siberian branch of the RAS. *Photo* Ralf Dannowski

the Far East. RAAS had an extended internal structure including administration departments for planning and coordination, a science organization section, an international relations department, pilot plants, a land and estate registration department, a construction and material provisions department, libraries and a printing press (UEAA 2006).

2.3 International Progress in Landscape Sciences

Internationally, research about the functioning of landscapes has experienced a rapid evolvement over recent years. Landscape research is based on a transdisciplinary view (Wiggering et al. 2006; Van Huylenbrok et al. 2007; Mander et al. 2007; Helming et al. 2011; Hermann et al. 2011). Landscape hydrology, soil hydrology and soil science are basic disciplinary compartments of landscape research studying water and soil altering processes in landscapes (Schindler et al. 2010; Lischeid and Natkhin 2011; Lischeid 2014a). As Western Europe is one of the leading agricultural regions worldwide and intensive agriculture significantly impacts on resources and ecosystems (Mueller et al. 2014a; Eulenstein et al. 2014), agri-environmental monitoring has to deliver data for detailed studies and decisions. Modern monitoring and evaluation tools have been developed and applied for research into landscape processes everywhere. Examples of those methodologies include measurement systems for gas, water and solute fluxes (Juszczak et al. 2013; Funk et al. 2014; Meissner et al. 2014; Schindler and Mueller 2010; Schindler 2014a, b). Siewert and Kučerik (2014) further developed thermogravimetry in soil science and identified the thermographic fingerprints of Siberian soils. Statistical methods for process identification and quantification from monitoring data (Lischeid 2014b), and sophisticated ecosystem models (Schaldach and Priess 2008; Wenkel et al. 2013; Nendel 2014) have provided quantifications and forecasts of ecosystems' responses. Improved sensor and data-processing technologies in remote sensing enable the spatio-temporal monitoring of large regions (Hese and Schmullius 2008; Gessner et al. 2012; Klein et al. 2014). Soil science has developed new assessment frameworks as a basis for assessing soil processes (WRB 2006, 2014; Zech et al. 2014) and functional performance (Mueller et al. 2010; 2014c). Drought has been identified as a main crop yield limiting process worldwide (Brown 2012; Mueller et al. 2012). Raising water productivity is thus a crucial item in the global struggle for food security (Brown 2012). Technologies for managing agro-ecosystems have to be based on principles of conservation agriculture (Kassam et al. 2011; Meinel et al. 2014; Suleimenov et al. 2014). Water savings in irrigated agriculture can be provided by sophisticated computer programs and new technological developments (Djanibekov and Sommer 2014; Michel and Dannowski 2014). Advanced irrigation technologies (Evans 2014) enable site-specific water distribution over fields and further improvements to water and fertilizer efficiency. Methods have been developed for evaluating grassland quality, as well as new grazing methods for protecting soils and vegetation from degradation (Behrendt et al. 2014; Mueller et al. 2014b, c). In order to prevent groundwater pollution from agriculture, methods for groundwater monitoring and risk assessment are now available (Dannowski et al. 2014; Eulenstein et al. 2014; Godbersen et al. 2014).

Not only the contents of research but also its organization and structure have changed in West European countries. Some former research fields such as soil mapping, environmental monitoring, construction of research equipment, or plant and animal breeding are no longer part of public research but instead in the hands of other state or private institutions. Transferring this system to research institutes located in the former GDR at the beginning of the 1990s enabled a better division of work, more creative research and a faster transfer of new methods into practice. Public State or Federal institutions provide soil functional mapping and act as connectors between research and practice (Hennings 2013). Companies such as Eijkelkamp Agrisearch Equipment, UGT Müncheberg, UMS Munich and others have developed leading technologies for environmental and agri-environmental monitoring jointly with leading researchers (Eijkelkamp 2014; Hertel and von Unold 2014; Meissner et al. 2014).

Since the 1990s some Russian scientists have benefited from the achievements of the international scientific community. Novel research methods have become available to those scientists who were able to integrate into international research networks and projects (Kerzencev and Meissner 2006). Knowledge of the English language was a main precondition. Lately, a new generation of Russian scientists has emerged, characterized by some typical features:

- Good disciplinary education based on great knowledge and traditions of Russian geography, soil science and hydrology as taught at the leading universities of Moscow, Tomsk, Barnaul and a few other cities
- Well linked with the international community, working in international trans-disciplinary cooperation projects and organizations (for example, the European Union programme "International Association for the promotion of cooperation with scientists from the independent states of the former Soviet Union—INTAS")
- Applying and developing modern research technology and methodology
- Aware that landscape research is a scale issue on both the temporal and spatial scales
- Able to apply both bottom-up and top-down processes and to handle large amounts of data to quantify them
- Publishing in international journals.

These characteristics are same as those of leading scientists in the international community. Consequently, some of these scientists work on international projects and/or abroad. It is a challenge for Russian science to integrate them into their new academic system.

2.4 The Reform of the Russian Academic System

The Russian research landscape is in a difficult transition phase. The Academy of Sciences, Academy of Medical Sciences and the Academy of Agricultural Sciences have merged to form a new Academy of Sciences under a Federal Law from 2013: "On the Russian Academy of Sciences, the reorganisation of the state academies of sciences and amendments to certain legislative acts of the Russian Federation". A new governmental body was founded, the Federal Agency for Scientific Organisations (FASO, Russian term ФАНО) responsible for all academic institutions by the decree "On the Federal agency for research organisations" (Schiermeier 2013). The reason for this reform was to create more effectiveness in science (Polterovich 2013; Voswinkel 2014). The current scientific system faces several challenges such as ageing of the academic staff, lack of publications in ranked international journals, bad presentation of institutes in the Internet or suboptimum international cooperation. These deficits have been recognized for some years and target settings have been developed in the Siberian Federal District (Table 1).

Table 1 Target settings for the development of innovations in Siberia (Strategy 2010, excerpt)

Indicator	2015	2020
Number of persons working in research and education	59,000	61,000
Proportion of young researchers (<40 years old) %	22	27
Number of international research centres	15	20–23
Proportion of internationally rated scientific journals %	5	7
Number of patents	3600	4200

Are those target settings still true and realistic? The reform was needed, but the way to operationalize it could become a problem. The new RAS will be an academic club without administrative power and service units. In the case of the former RAAS this means expropriation from all research stations and lands, and could have unforeseeable consequences for all running long-term trials. Overall and generally, freedom and independency of research could be threatened by administered reforms that are not based on the expertise of main stakeholders. Insecure basic financing for scientific institutes bears risks for high-quality research due to brain drain and more bureaucracy (Yablokov 2014).

New initiatives of international scientific–technical cooperation in landscape research would be very important for stabilizing the situation at this critical stage. It must be based on genuine partnership at eye level. This is currently still possible.

2.5 *Effects of the Market Economy on Ecosystems and Research Efficiency*

The Russian market economy capitalizes Siberian resources of gas, oil and minerals by wasteful mining and other industries with benefits for urban areas and with damage to the environment (Newell 2004). Rural regions of solely less profitable branches such as forestry, agriculture and fishery suffer from recession and the breakdown of their infrastructure. Farmers' acceptance of abandoning soil-destroying agriculture and following scientists' advice is low under these conditions.

The indigenous peoples who inhabit most of Siberia are seriously threatened by mining industries and the breakdown of the infrastructure in remote areas (Osherenko 1995; Vakhtin 1998; Semenova 2007; Yakovleva 2011). Programmes are urgently needed to help the small numbers of peoples in the north support themselves (Isachenko 2013).

Framework conditions for the development of cultural landscapes are important (Ragulina 2013). They are largely lacking in Siberia and there seem to be none at all in the Far East. Poverty is not a suitable framework for the development of environmental consciousness but instead promotes unsustainable management or illegal behaviour (poaching, logging). Overall, the introduction of the market economy has not diminished but exacerbated negative consequences for the environment (Shaw and Oldfield 2007) and for the culture of indigenous peoples (Isachenko 2013).

3 Deficits of Research in Land Management and Agronomy

The analysis of publications in the area of landscape and agri-environmental research referring to Siberia over the past 25 years shows interesting results and tendencies. Great progress has been made in analysing, understanding, predicting and coping with processes and problems of ecosystem functioning under the pressure of the market economy and climate change. The international community has invested a great deal in environmental research and monitoring programmes. The focus has been on Arctic research and monitoring, climate change issues such as carbon cycling, GHG emissions and water pollution.

Research about land- and water-resource-based industries such as agriculture, forestry and fishery has been a national issue and cannot meet international standards. Agricultural research has a well-developed experimental basis in the country but poor resources, obsolete analytics and a lack of access to leading technologies worldwide. Research in agronomy is particularly based on traditions and there is a lack of modern research technology. Numerous experiments have been conducted, and valuable data generated, but this work is largely de-central. Many Russian scientists working in the field of agricultural soil and water management are also largely isolated from the international research community. No Russian researcher is active in the International Soil and Tillage Research Organization (ISTRO), the world's leading scientific organization in this field of research, producing the well-respected scientific journal "Soil and Tillage Research". Russian researchers publish mainly in Russian. Many publications in Russian are freely available online and could promote the fast dissemination of results over the country. Because the methodology of trials is classical, the equipment for trial conduction is obsolete and biophysical conditions of plant growth and results are very site-specific; there is not much to transfer to other regions. Dissemination of those local results is mainly directed to advanced farmers and authorities in the same region. However, as agriculture is in a recession it cannot benefit from this knowledge. Experimental results are potentially important for the calibration of agro-ecosystem models. However, agri-environmental modelling is still underdeveloped.

Research about land and water resources, landscape processes and environmental monitoring in the Far East region of Russia is a white spot in ground-based research and monitoring land and water resources and processes.

4 Initiatives of International Cooperation and Communication in Landscape Research

International cooperation in research and the transfer of knowledge and education has been recognized as key factor for better interlinking Russian scientists with the international scientific community. International, multidisciplinary Arctic research is a flagship of cooperation in environmental research leading to better understanding of climate changing processes and their consequences for the development of landscapes (Polyakov et al. 2014).

During recent years some progress has also been achieved regarding cooperation in agri-environmental and landscape research. For example, the German Federal Ministry of Food and Agriculture and the former Russian Academy of Agricultural Sciences created a list of mutual cooperation projects between German and Russian researchers. The German-Russian project 05/07 "Indicators of fertility and function of agricultural soils" of this list formed the basis of cooperation between several Russian and German soil scientists and agronomists. The main partners were ISSA Novosibirsk and VNIIA Moscow from Russia, and ZALF Müncheberg from Germany. This enabled joint fieldwork about soil classification and evaluation on numerous agricultural sites in both countries. Another small-budget project, "Effect of climate change in boreal and sub-Arctic ecosystems on water quality and soil functions, code 01DJ12058" was supported by the German Federal Ministry of Education and Research (BMBF) and enabled this cooperation between ZALF Müncheberg and ISSA Novosibirsk to be deepened along with IWEP Barnaul. Overall, more than 15 joint publications appeared as outcome of both projects. Unfortunately, the current reform of the Russian academic system has disrupted those effective activities.

Currently, the above-mentioned better-funded projects "KULUNDA" and "SASCHA" (KULUNDA project 2014) focus on sustainable land management as a main topic of agri-environmental research. Some progress has been achieved in landscape planning due to Russian–German cooperation (Koroshev et al. 2014).

Another type of initiative was started by Russian and German soil scientists almost 20 years ago. Soil scientific and ecological summer schools and field excursions through the main landscapes of West Siberia have become established as a permanent educational institution for students and scientists from abroad (Siewert et al. 2014; Fig. 9). They are also a source of inspiration for new research activities. Scientists from Irkutsk have established further summer schools and excursions through the Baikal region and exciting regions of the Far East (Chepinoga et al. 2004). The German Academic Exchange Service (DAAD) supported the participation students in those summer schools in the framework of the "go east" submission (DAAD 2014).

5 Conclusions: Knowledge Gaps and Research Needs

A lot of progress has been achieved in understanding landscape processes in Siberia and in evaluating land and water resources. However, the dynamics of alterations of ecosystems due to climate change and unsustainable human impacts requires faster progress. A lack of knowledge and absence of reliable data have contributed to the harmful treatment of land and water resources. Scientists, decision-makers and other responsible people need more reliable data. Some gaps of knowledge and deficits of agri-environmental research and monitoring are:

- A lack of measurement and monitoring technologies for net primary production (NPP), heterotroph respiration and gas exchange between ecosystems and atmosphere. Reliable and automatic high-resolution measurement of the functional performance of the Geo–Bio system by exact balancing of water, carbon, sediments and other matter fluxes (lysimeters, GHG flux measurement systems, dust measurement systems).
- Soil physics, soil hydrology and modelling the soil–plant–atmosphere system are underdeveloped. Better ecosystem models and decision support systems that consider feedback from and the complexity of processes in landscapes are needed to make climate change scenarios more reliable.
- Many remote areas in the Tundra and Taiga of East Siberia and the Far East are not sufficiently covered with monitoring technology. Remote sensing approaches have emerged but must be better linked with automatically operating ground-level monitoring stations. Airborne data also need to be combined better with process models.
- Data analysis is largely based on traditional statistical approaches which do not consider autocorrelations of processes and landscape structures. Methods of modern explanatory statistical data analysis, which allow hidden structures and processes to be detected, should be part of landscape experiments (including agricultural trials) and data acquisition.
- Reliable but simple approaches for the assessment and monitoring of the functional status of land (including crop yield potentials) consistently over different zones and regions are lacking for Russia. They should be better compatible with recommendations and standards of the EU and the United Nations Food and Agriculture Organization (FAO).
- Chemical analytics of soil, water and plants has a great tradition in Russia but needs to be harmonized with international standards and leading developments. In the case of soil analyses, sample preparation methods are often difficult to compare with EU approaches.
- Analytical methods and evaluation frameworks for the functional status of aquatic ecosystems are also in need of harmonization.
- The environmental side effects of agriculture, their risks and real extent, are still not well researched. Environmental impacts on aquatic ecosystems, water resources and air quality should be monitored, evaluated and controlled. Those systems should meet international standards.

- Principles of Conservation Agriculture (CA) have been tested in several crop trials but their complex meaning for avoiding soil degradation is still not understood by researchers and decision-makers. Also, CA is still neglected in practice due to poor resources and obsolete machinery.

Progress can be achieved by the adoption and application of new methods for measuring, assessing, modelling, monitoring and controlling landscape processes. This includes the need for both methods and technologies for basic research to understand the ecosystem, and applied agri-environmental research for a fast transfer into practice. Most of these technologies are internationally available and could help to get better data for recognizing, understanding and possibly controlling land and water resources and processes. Some of them are presented in the following chapters. Environmental data and knowledge may contribute to the formation of a higher stage of public awareness about environmental problems and a basis for impact-assessment procedures in order to find optimal site-specific solutions for science-based landscape planning. We encourage decision-makers to install a sustainable platform for scientific technical cooperation in landscape research between Russia and the EU. This would be very important to maintaining high-level research and agri-environmental monitoring of the terrestrial and aquatic ecosystems of Siberia.

Appendix: Environmental Education Abilities in Soil-Ecological Summer Schools in West Siberia

Since 1995 soil-ecological summer schools have been taking place across bioclimatic zones in West Siberia plain and altitudinal belts in the Altai Mountains. They are organized annually by a group of scientists from Russia and Germany. The main goal of the excursions was to answer growing demands for better education and research on mutual interdependencies between climate, geological substrates, vegetation cover and other factors as a tool for practical land use improvement.

The sites of the summer school are selected as a logical sequence of changing climate conditions from north to south in West Siberia including plains (horizontal climate zones) as well as mountains (vertical climate zones) (Fig. 8). They focus on landscapes of exceptional beauty and highly interesting natural objects, both with extreme emotional impact on the participants' learning abilities as a tool of long-term motivation for sustainable land use. Virgin ecosystems and sites untouched by human activity are included for simplified teaching of the complex interrelations between factors of landscape formation unconcealed by the artefacts usually caused by a long history of land use or by the wide-scale pollution in developed countries.

The introduction lectures at every site provide information about their geology, relief, climate, vegetation cover, soil formation and history of human exploration together with the main aspects of local culture and challenges of social life

Fig. 8 Typical landscapes used by soil ecological summer schools **a** Mountain desert, **b** Mountain tundra, **c** Mountain forest tundra, **d** Southern Taiga, **e** Forest steppe. The floristic diversity of forest steppe grasslands in West Siberia is still very high due to extremely low human impacts. About 60 species of vascular plants per 100 m^2 have been found at some locations. *Photos* Christian Siewert

development. They try to mediate a simple access to understanding long-term needs in local productive land use taking into account global trends.

The field lectures which follow are the main method of education at the summer school. They are dedicated to illustrating the most important local features, which are sometimes incredible to foreign participants, using easily available natural materials from the surroundings. Teaching methods include experiences by means of hearing, touching, feeling or even tasting (Fig. 9). Short walks (around one hour)

(a)

(b)

Fig. 9 Teaching soil science and soil–vegetation interactions. **a** The profile shows a Chernozem in the forest steppe. From their inherent properties Chernozems are the most fertile soils of the globe. **b** Minutes and examinations are part of the open air summer school. *Photos* Pavel Barsukov

across the countryside without trails or prepared adventures allow participants to feel the landscapes under their feet, to catch its colours, sounds and smells. The personal experience obtained this way empowers the participants to gain their own insight into the complexity of natural conditions in a most unforgettable way. This supports open discussions providing a better understanding of the details of both local and global consequences of human land use.

The teaching goals and needs determine the organizational features which support a deep personal perception of the environment. Almost the entire route of the summer school, all accommodation and meals are held outdoors. The summer school participants must adapt to the weather conditions; they have to walk, live in tents, collect their own experience and "sense of places", and they have to accept everyday life in nature as a source of ecological knowledge. A specialized service team manages daily challenges including the completion of bureaucratic demands (e.g. visa formalities and registration of foreigners), reliable transport, a supply of tasty food, most possible accommodation and the organization of cultural events. It consists of drivers, a cooking team and assistants under the supervision of Russian scientists from leading research institutes and universities.

The results are reflected in excellent evaluation results, several multiplier effects, research projects, some generous funding by different organizations, and more. The participants especially appreciate the experience they gain, which supports the long-term mitigation of global change in land use and connected job opportunities. The following photographs provide some visual impressions about these courses. More information is given in the publication by Siewert et al. (2014).

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