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TECHNICAL CONTRIBUTION

The Eurosiberian Transect: an introduction to the experimental region

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ABSTRACT

An introduction is given to the geography of Russian forests and to the specific conditions of the study sites located along the 60° latitude east of Moscow (Fyedorovskoe) near the Ural Mountains (Syktivkar) and in Central Siberia near the Yennisei river (Zotino). The climatic conditions were similar at all three sites. The main ecological parameter that changes between European Russia and Siberia is the length of the growing season (230 d above 0 °C NE Moscow to 170 d above 0 °C in Central Siberia) and to a lesser extent precipitation (580 mm NE Moscow to 530 mm in Central Siberia). The experimental sites were generally similar to the regional conditions, although the Tver region has less forest and more grassland than the central forest reserve, and the Komi region has slightly less wetland than the study area. The Krasnoyarsk region reaches from the arctic ocean to arid central Asia and contains a significant proportion of non-forest land. The boreal forest of west and east Yennisei differs mainly with respect to wetlands, which cover almost half of the land area on the west bank. All sites are prone to disturbance. Heavy winds and drought or surplus water are the main disturbance factors in European Russia (a 15-20 yr cycle), and fire is the dominating disturbance factor in Siberia (220-375 yr for stand replacing fires).

1. Introduction

The Eurosiberian Project was planned to focus on the boreal forest belt of Eurasia, which covers the area between about 53 and 67°N from the Atlantic coast of Norway at 5°E to the Pacific coast at 170°E. The region is relatively uniform with respect to species cover. *Picea abies* of Europe is replaced by *Picea obovata* in Finland and the NE of European Russia, which then dominates together with *Abies alba* in the dark coniferous taiga of European Russia and *Abies sibirica* in Siberia. Dark coniferous taiga occurs with a different set of species again in the Amur region. *Pinus sylvestris* is the tree species with the largest range of global distribution for any tree species. It is an early successional species along the whole region and dominates on nutrient-poor sandy soils and on bogs. In contrast, *Pinus sibirica* is a central Siberian late successional species forming monotypic stands mainly in wet sites. The genus *Larix* occurs with a range of species in a region almost as broad as that of *P. sylvestris*, but it dominates forests mainly on permafrost soils

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and in the continental climate of East Siberia (Walter, 1974).The deciduous trees of *Betula* and *Populus* are important throughout the boreal forest belt depending on disturbance. *Betula pendula* and *B. pubescens* are early successional species in many regions of European Russia and Siberia. *Populus tremula* follows disturbance on nutrient-rich and drained soils.

It is quite clear that it is impossible to cover such a large geographic range experimentally. Given the fact that initial information did exist for the East Siberian *Larix* forest (Utkin, 1965; Schulze et al., 1995; Hollinger et al., 1998; Kelliher et al., 1997; 1998), and that the European region is covered by a number of experimental networks (Schulze, 2000; Valentini, 2002), the present study concentrates on sites ranging from European Russia to the Yenisei river in Central Siberia. These sites are located at the Central Forest Reserve (56°27′N, 32°57′E) about 300 km northwest of Moscow; near Syktyvkar (61°23′N, 52°17′E) located about 400 km East of the Ural Mountains; and in the Central Yenisei region near Zotino (60°44′N, 89°09′E) a village located about 100 km south of the inlet of the Podkameniaya Tunguska into the Yenisei.

2. Climatology of the Eurosiberian boreal forests

In contrast to the European climate, which is dominated by westerly winds in summer, the main wind pattern changes in the Ural region where climate is dominated by northerly winds from the arctic ocean in summer and by southerly wind patterns in winter (Myachkova, 1983). This wind pattern continues across Siberia, and it enhances the continentality of climate from west to east. The main ecological parameter that changes from west to east is the length of the growing season and climate continentality (Table 1). Average day temperatures are above 0 °C for about 200-230 d in the taiga zone of European Russia and decrease to about 170 d in central Siberia. Compared to this change, all other climatic parameters change relatively little (Fig. 1). Annual average July temperatures are fairly uniform (19 and 20 °C) along the 60°N latitude and highest day temperatures on record are above 36-40 °C, but comparisons are difficult because of different observation periods. Also, minimum temperatures are not that different: -45 °C has been measured in European Russia, which is physiologically not so different from -56 °C in West Siberia. Average rainfall and its range are similar, but decrease slightly from European Russia to West Siberia (600-530 mm). Rainfall decreases further towards the east to 100-250 mm in Yakutia. Locally higher rainfall occurs at the rise of the Central Siberian plateau east of the Yenisei (>600 mm). Orléan near Paris served as reference for tropospheric measurements of marine background. The average annual temperature at Orléan was 11 °C and rainfall was 723 mm.

Table 1. *Comparative overview of climatic conditions and landcover at the three experimental sites*[a]

	Fyedorovskoe		Syktivkar	Zotino	
Position	56°27′N, 32°57′E		61°23′N, 52°17′E	60°44′N, 89°09′E	
Climate	VV	VL	SK	Sym	Bor
Temperature annual average (°C)	3.9	4.9	0.4	-3.7	-3.8
Highest measured day *T*		40.8 (1885)	35.3 (1885)		36.1 (1999)
Lowest measured day *T*		-45.7 (1940)	-46.6 (1973)		-56.0 (1987)
Monthly average max *T*	19.6 (1972)	22.1 (1985)	21.5 (1988)	21.5 (1988)	21.8 (1967)
Monthly average min *T*	-20.5 (1987)	-17.8 (1987)	-25.5 (1955)		-36.0 (1969)
Precipitation annual average (mm)	629	545	503	530	536
Absolute max (mm)	850 (1953)	877 (1902)	746 (1923)	746 (1923)	745 (1986)
Absolute min (mm)	391 (1963)	289 (1926)	321 (1896)		364 (1938)
Growing season > 10 °C (d)	127	134	132	93	91
> 0 °C (d)	218	245	196	168	173
Snow cover (d)	131	207	188	207	207
Index of continentality	55		62	82	

[a]The weather stations Veliki Luki: VL (1881-1998) and Vyshnii Volochek: VV (1880-1990) were taken as reference for Fyedorovskoe. Syktivkar weather (Sk) station (1888-1989) was reference for the flight region south of Syktivkar. The stations Sym: SY (1937-1989) and Bor: BO (1936-1989) are taken as reference for Zotino. Gorchinsky index of continentality k = (annual temperature amplitude)/sin(latitude).

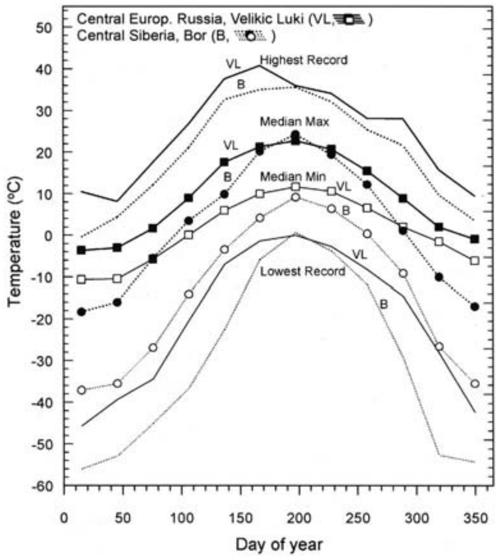

Fig. 1. Seasonal course of highest and lowest record, and of median monthly maximum and minimum temperatures of the weather stations in Velikie Luki (Central European Russia) and of Bor (Central Siberia).

3. Forest zone

Russia uses a classification of forest land categories which does not correspond to that used by the FAO (2000), thus both sets of data are compared in Table 2. According to Shvidenko and Nilsson (1994), the area of Russian Forest Fund (in 1993) of 1180.88 million ha is divided into forest land (886.54 Million ha) and non-forest land (i.e. mostly unproductive areas such as bogs, rocks, water reservoirs, and areas of special designation such as pastures, arable lands in the forest zone, etc.) covering 294.34×10^6 ha. The forest land is divided into forested area (or closed forests, 763.50×10^6 ha) and unforested areas (areas designated for forest but temporarily not covered by forest due to disturbances such as fire, dead stands, un-regenerated logging areas, grassy glades, and barrens) of 123.04×10^6 ha in 1993. The total growing stock volume on forested area is 80.676×10^9 m^3 (about 20 Gt C).

The forested area (closed forests) (Table 2) is about 45% of the total Russian territory (Alexeyev and Birdsey, 1994; Alexeyev et al., 2000).

The European forested area contains about 22% of the total forest area and 26% of the total growing stock volume of Russia; 66% of the forested area is located in East Siberia and in the Far East, carrying 60% of the growing stock. The total carbon stock of above - and below-ground phytomass is equivalent to about 28 Gt C (FAO, 2000). The FAO estimates of the phytomass of Russian forests are based on very rough and aggregated data, which underestimate the phytomass of the Russian forest by about 15%. Detailed inventory data quantify the phytomass to be about 33 Gt C for the entire country (Shvidenko et al., 2000). Russian estimates of phytomss vary by ±2-4% (Alexeyev et al., 2000; Isaev et al., 1995).

4. Comparison of the study regions

4.1. The Central Forest Biospheric State Reserve

The Central Forest Reserve is located in the Tver region of Central European Russia, in the southern taiga sub-zone (Vygodskaya et al., 2001). The region is part of the Valdai heights, which are the main divide between the Caspian and the Baltic watersheds in the pleistocene plain between Belorussia and the Urals, called the Russian plain. It is a hilly region ranging between 220 and 280 m a.s.l. with gentle slopes of non-calcareous loam covering carbonate-containing morains. The loamy areas lead to podzolic soils and bogs. Water from the calcareous morains may reach the soil surface locally. Thus soil type and groundwater chemistry depend on the nanorelief and result in a mosaic structure of soils and vegetation. Rivers and creeks generally originate from bogs. Watersheds are not well defined.

The Central Forest Reserve was founded in 1931, and in 2000 it consisted of 245 km^2 core region and a buffer zone of 430 km^2. The main part of the Central Forest Reserve has not been managed in recent history. Only the southern part was logged in the 1950s, and this part is presently dominated by *Betula* and *Populus.* The part of the *Picea* forest is to certain extent a secondary forest growing on abandoned fields of the 17th and 18th centuries (Karpachevskii, 1981). The susceptibility of the area to wind may in part result from old plough horizons. The potential natural vegetation is most likely a mixed broadleaf/coniferous forest.

Climatologically, the region is located in a transition between European oceanic and continental climate. North Atlantic air masses alter in a 3-7 d cycle with cold polar air masses. Late frost may occur until early June, and early frost by late August. Thus, a large short-term variability in weather is characteristic for the entire taiga zone of the Russian Plain.

Table 2. *The Russian forest zone*[a]

	Area (10^6 ha)	
Total Area Russia	1709.8	100.0%
Total land area	1637.7	95.8%
Forest and other woodlands (FAO)	886.5	51.9%
Forest (FAO)	816.5	47.8%
Forested area (Russian classification)	763.5	44.7%
Other land (FAO)	821.2	48.0%

Ecoregions	Area (10^6 ha)	Phytomass (10^6 tC)
Forest tundra	108.4	1640
Boreal forest	508.8	18940
Mixed forest	13.1	640
Sub-boreal forest	134.5	6510
Total	764.8	27730

	Alexeyev and Birdsey		Shvidenko and Nilsson	
Economic Regions	Forest area (10^6 ha)	Phytomass (10^6 tC)	Growing stock volume (10^6 m^3)	Net growth growth (10^6 m^3)
European Russia				
Prebaltic	0.3	15.6	46.6	1.3
Northern	76.0	2733.1	7935.4	114.5
Northwestern (incl. Komi)	10.4	551.8	1583.9	29.2
Central (incl. Tver)	20.3	1044.4	3109.6	77.5
Volgo-Vjatsky	13.3	614.2	1862.7	48.3
Central-Chrnozemny	1.5	78.6	213.8	7.1
Povolshsky	4.8	221.9	596.8	17.2
Northern Caucasus	3.7	281.2	662.3	13.1
Uralsky	35.8	1647.2	5099.8	109.8
Total Europe	166.0	7188.0	21110.9	417.1
Asian Russia				
West Siberia	90.0	3401	10950.3	113.0
East Siberia (incl. Kras.)	234.5	9587	27658.2	250.1
Far East	280.5	7805	20957.0	185.3

[a]Total Area: FAO (2000) and Shvidenko and Nilsson (1994); regions, growing stock volumes (Alexeyev and Birdsey, 1994) and net stem growth (Shvidenko and Nilsson, 1994).

Temperatures range between an average monthly minimum of -20 °C in January and a maximum of 20 °C in July. Precipitation has a 15-20 yr cycle between dry and wet periods, but rainfall may change even from year to year between 400 mm in a dry and 800 mm in a wet year. The rapid change between Atlantic and polar air masses results in frequent heavy storms. Heavy windthrow occurs with a periodicity of about 9-15 yr. Despite the general humid climate, periodic droughts are characteristic in summer when continental air masses from the SE reach the study region.

The vegetation (Table 3) represents a transition between the southern taiga (with nemoral species such as *Tilia*, *Acer* and *Ulmus*) and the boreal mixed forest of conifers and small leafed species (*Betula* and *Populus*). Dominant species on waterlogged and on well drained sites (39% of the area) is *Picea abies* and the hybrid *P. fennica* (*P. obovata* × *abies*). Small-leaved deciduous forests of *Betula* and *Populus* cover 32% of the area. *Pinus* (9%) is confined mainly to bogs, and *Alnus* (2% of the area) follows the flood plain of creeks (Karpov, 1973, Miniaev and Konechnaia, 1976; Karpov and Shaposhnilkov, 1983).

Main disturbance factors which caused secondary successional forest were windthrow and logging in the 1950s. A larger fire occurred in 1939. In 1990, 31-50%

Table 3. *Landcover and soils in the study regions (Glebov, 1969; Stakanov, 2000) and data by the authors*[a]

		Fyedorovskoe CFR	Tver region	Syktivkar site	Komi region	Kras region	Zotino region	
							West	East
Landcover	Total (km^2)	246	84100	2500	415900	25988415	2500	2500
	Forest (%)	81	49	60	73	49	56	80
	Picea abies/obovata	39	11	15	45	16	9	28
	Pinus sylvestris/sib.	9	12	33	17	27	35	20
	Small-leaved	32	27	12	11	6	<1	51
	Wetland (%)	17	16	40	27	10	44	<1
	Grassland (%)	<1	35	<1	<1	41	<1	<1
Disturbance	Type	storm/drought		fire	fire	fire	ground/ crown fire	fire/storm + insect
Fire/storm/drought frequency (yr)		9-15/15-20		n.d.	n.d.	n.d.	35/220	375/150
Soil type		podzol/Gley/peat		podzol/Gley/peat		podzol	podzol	brownearth
Soil substrate		loam		sand/loam		sand	sand	loam
Aboveground biomass (tC ha^{-1})		50-60			32-61		50-150	50-200
Leaf-area index		5			n.d.		1-2	4
Soil carbon	(0-1 m)	68-250			n.d.		15-34	84
Soil nitrogen	(0-1 m)	5			n.d.		2-3	7

[a]CFR, Central Forest Reserve, n.d. not determined.

of the forest was moderately affected, and 26% of the forest was severely affected by wind. Individual tree deaths by insects are additionally related to periodic drought (Vygodskaya et al., 2002).

Long-term flux measurements take place in two forest types of contrasting soil and moisture regime and in a raised bog.

Site 1 represents the *Sphagnum-Vaccinium myrtillus* community on peaty soil (30-50 cm depth of peat). The water table reaches the soil surface in spring. Thus the forest is *characterized* by poor soil aeration, low pHH_2O (3.5-3.8) and low nitrogen content (0.5-9.9 kg ha^{-1}). Soil C content is 197 tC ha^{-1} in the peat layer but reaches on average 202-248 tC ha^{-1} for soil profiles to 1 m depth on bog-podzolic soils. The ground flora is dominated by *Vaccinium myrtillus* and a moss layer of *Sphagnum girgensohnii* and *S. magellanicum*. The forest stand is 160-170 yr old and has an above-ground wood biomass of 53 tC ha^{-1}.

The second site is a well drained soil with pHH_2O between 3.7 and 4.3. Nitrogen content is between 27-58 kg ha^{-1}. Soil C-content is about 68 tC ha^{-1} t (organic layer plus mineral soil to 1 m). This forest contains *Tilia* as associated tree species and a rich herbaceous flora (*Stelaria holostea*, *Galeobdolon luteum* and *Pulmonaria obscura*). The spruce trees are about 150 yr old with an aboveground wood biomass of 60 tC ha^{-1}.

Additional flux measurements took place (1998-2000) on a raised peat bog (Kurbatova et al., 2002, this issue) and in a windthrow area (Knohl et al., 2002).

4.2. The Syktivkar region

No ground measurements took place in the Syktivkar region. The area which was used for flights is dominated by *Pinus sylvestris* representing the southern taiga, although the climatic region is part of the European middle taiga. Due to soil conditions the southern taiga vegetation extends north into the middle taiga at that location. The forest is managed by a company operating a nearby cellulose plant.

4.3. The Zotino region

The Zotino region consists of two distinct subregions, the *Pinus sylvestris* forests west of Yennisei and the dark coniferous taiga east of Yenisei (Table 3).

The West Yenisei site is part of the Tulugan basin, a region of fluviatile sands, which have been deposited in front of the Samarovo ice shield. This region of fluviatile sands with patchy clay lenses extends from the east slope of the Ural mountains to the Yenisei. The sand deposits form a plateau 50-100 m above the level of the Yenisei. This plateau is dissected by smaller creeks into a slightly undulating landscape. Lakes and ponds exist wherever clay has been deposited. The valleys are covered Aapa bogs that are fed by groundwater from the surrounding sand dunes. The "upland sand region" is distinct from the flood plain of the Yenisei river, which is the 15-17 km wide margin along the large river. The flood plain contains permanent meadows close to the river and extended bogs in the course of the old river beds.

The climate of the Zotino region is continental, with -26 °C average January temperatures and temperature minima of <-56 °C. Daily maxima may reach 36 °C. North Atlantic cyclones are the main source of precipitation. The annual precipitation is also fed by a local water cycle of evaporation and convective storms. Lightning is one cause of natural fires, but fires of anthropogenic origin are becoming increasingly important. Seventy five percent of fires in the southern taiga are caused by humans (Furayaev, 1996). This fraction is probably less in the northern taiga, but still large, as it is seen from fires along logging roads.

The sand region is dominated by a forest of variable density (35%) and bogs (44%). The dominant tree species is *Pinus sylvestris*, which builds monotypic stands after fire. Ground fires may occur every 35 yr, and stand-replacing fires every 220 yr. The podzolic soils are characterized by low pH_{H_2O} of 4.7-5.3. The nitrogen content of soils is only 2-3 tN ha^{-1}. Soil C content (organic layer and soil to 1 m) is below 35 tC ha^{-1}. The aboveground biomass of >100 yr stands ranges between 50 and 150 tC ha^{-1} (Schulze et al., 1999). Depending on the fire cycle, some areas may not reach a full canopy cover but persist as open pine-lichen woodland. This situation emerges if two fires follow in close sequence in the early phase of regeneration (11% of the area). The region is significantly affected by logging: 17.2% of the pine forest area has been logged in the past 30 yr or burnt in the past 15 yr.

The area has been intensively studied by inventory methods (about 25 plots: see Wirth et al., 1999; 2000). A permanent flux tower has been established in a pristine 220 yr old Pine forest which has not been burnt for 90 yr. This forest is located at the east-facing embankment of the upland sands (soil pH 4.3-5.1, 0.8 tN ha^{-1}, 34.3 tC ha^{-1} in the organic layer plus mineral soil to 1 m deph).

Additional flux measurements were carried out in an Aapa bog (1998-2000, Arneth et al., 2001). Short term measurements took place on different stages after logging (Valentini et al., 2000; Rebmann et al., 2001)

The East Yenisei region is the escarpment of the Central Siberian Mountain range, which reaches up to 1100 m. The initial rise above the level of the west Siberian plain is about 200-300 m. The soils are weathered from Cambrian and Palaeozoic bedrock of granite, quarzites and calcareous sediments. The region near the Yenisei river is characterized by a flat plateau which is dissected by creeks and rivers. River banks may be steeply cut into the landscape.

The climate shows a distinct gradient from west to east, with the west face of the escarpment having rainfall of about 600-700 mm. Rainfall decreases towards the east of the mountain rise. The winter temperatures are similar to those on the west bank of the Yenisei, but summer temperatures are lower.

The higher rainfall and the higher cation contents of the soils of the west escarpment result in a dense dark taiga forest, which is dominated by *Betula* and *Populus* on secondary successional areas, following rare fire events. *Betula* is overgrown by *Picea* and *Abies*, which then dominate the vegetation even after disturbance by insects and wind. The fire cycle appears to be between 300 and 400 yr (Mollicone et al., 2002). Local waterlogged areas and areas without long-term disturbance are dominated by *Pinus sibirica* forest. Although the valley floors may have organic soils, there are no extended peat bogs. The aboveground biomass of forests ranges between 100-200 tC ha^{-1}. Soil pH was 4.1 and 6.4; N and C pools in the soil were higher by more than factor 10 than at the measuring site of the West bank.

Flux measurements were carried out in *Betula* forest, mixed boreal forest being in transition to a monotypic coniferous forest and in a stand dominated by *Abies* (Röser et al., 2002).

5. Conclusion

The permanent study sites of the Eurosiberian Carbonflux project represent the main forest types of European Russia and Central Siberia. Additional measurements were taken in European and Siberian bogs. Inventory and eddy flux campaign measurements in different ecotypes supported the long-term data. Thus we are confident that the ground data can serve as a model to interpret the tropospheric measurements of this project

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