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Anthropogenic soils and landscapes of European Russia: Summer school from sea to sea—A didactic prototype

Viacheslav I. Vasenev[1] | **Marina V. Slukovskaya**[1,2,3] | **Zhongqi Cheng**[4,5] | **Anna A. Paltseva**[1,4,5] | **Thomas Nehls**[6] | **Maria V. Korneykova**[1,7] | **Ivan I. Vasenev**[1,8] | **Olga N. Romzaykina**[1] | **Kristina V. Ivashchenko**[1,9] | **Dmitry A. Sarzhanov**[1] | **Yulia L. Sotnikova**[1] | **Oleg V. Ryzhkov**[10] | **Lilia A. Alaeva**[11] | **Anton V. Belik**[11] | **Tatiana A. Devyatova**[11] | **Sergey N. Gorbov**[12] | **Olga S. Bezuglova**[12] | **Andrey. V. Dolgikh**[1,13] | **Pavel I. Konstantinov**[1,14] | **Anastasia V. Konstantinova**[1] | **Alexey M. Yaroslavtsev**[1,8] | **Marina S. Chernyshova**[1] | **Tatiana Morin**[15] | **Alexey V. Ryazanov**[1] | **Dmitry D. Gosse**[16] | **Elvira A. Dovletyarova**[1]

[1] Dep. of Landscape Design and Sustainable Ecosystems, RUDN Univ., Moscow, Russia

[2] Lab. of Nature-inspired Technologies and Environmental Safety of the Arctic, Federal Research Centre Kola Science Centre of Russian Academy of Sciences, Apatity, Murmansk Region, Russia

[3] Tananaev Institute of Chemistry and Technology of Rare Elements and Mineral Raw Materials—Subdivision of the Federal Research Centre Kola Science Centre of Russian Academy of Sciences, Apatity, Murmansk Region, Russia

[4] Dep. of Earth and Environmental Sciences, Brooklyn College of The City Univ. of New York, Brooklyn, NY, USA

[5] PhD Program in Earth & Environmental Sciences, The Graduate Center of The City Univ. of New York, New York, NY, USA

[6] Technische Univ. Berlin, Berlin, Germany

[7] Institute of North Industrial Ecology Problems—Subdivision of the Federal Research Centre, Kola Science Centre of Russian Academy of Sciences, Apatity, Murmansk region, Russia

[8] Moscow Timiryazev Agricultural Academy, Russian State Agrarian Univ., Moscow, Russia

[9] Institute of Physicochemical and Biological Problems in Soil Science, Russian Academy of Sciences, Pushchino, Moscow Region, Russia

[10] The Central Chernozems State Biosphere Reserve named by V. Alekhin, Zapovednoe, Kursk Region, Russia

[11] Dep. of Ecology, Voronezh State Univ., Voronezh, Russia

[12] Southern Federal Univ., Rostov-on-Don, Russia

[13] Institute of Geography, Russian Academy of Sciences, Moscow, Russia

[14] Faculty of Geography, Lomonosov Moscow State Univ., Moscow, Russia

[15] New York City Urban Soils Institute, New York, NY, USA

[16] Faculty of Soil Science, Lomonosov Moscow State Univ., Moscow, Russia

Abbreviations: 3MUGIS, Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils; IRGA, infrared gas analyzer; SOC, soil organic carbon; XRF, X-ray fluorescence.

Correspondence
Viacheslav I. Vasenev, Dep. of Landscape Design and Sustainable Ecosystems, RUDN Univ., Moscow, Russia.
Email: vasenyov@mail.ru

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Abstract

Field excursions and trainings are considered a key component of education programs in soil and environmental sciences. They allow mastering students' practical skills in sampling and onsite assessments and improve understanding of ecosystem integrity and complexity. Urbanization has a substantial impact on soil properties and functions; however, field courses focused on urban soils are rare. We present a didactic prototype and the outcomes of the "Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils (3MUGIS)" summer school—the first educational tour observing anthropogenic soils and landscapes along the bioclimatic gradient in European Russia, from tundra to dry steppes. Didactic learning was based on a studying-by-doing approach; students were involved in environmental assessment in multiple regions varying in climatic and socioeconomic features. Considering the high spatial heterogeneity of urban ecosystems, we used express techniques (portable X-ray fluorescence, infrared gas analyzers) for onsite soil analysis at multiple replicas. The data collected were discussed with local and international experts from Russia, Germany, the United States, and France in the context of regional environmental problems (e.g., pollution, soil degradation, and urban expansion). Students discovered zonal changes in vegetation (e.g., increasing tree height and diversity from north taiga to forest steppes) and soil properties (e.g., a gradual increase in pH and changes in soil organic C), as well as urban-specific processes and features (e.g., urban heat island effect or soil artifacts). The overall student feedback was very positive (50.8% excellent, 36% good); some specific organizational issues will be addressed for future 3MUGIS summer schools.

1 | INTRODUCTION

Field work is traditionally considered an essential part of environmental education (Bögeholz, 2006). Field classes give students a better understanding of the ecosystem processes and functions and illustrate complex interrelationships among ecosystem components (Rudman, 1994). Field training enables mastery of practical skills in environmental surveys, monitoring, and environmental impact assessment (Orion, 1993). In addition to professional knowledge and skills, field excursions contribute to student's self-organization, support team building and soft skills development, and restructure hierarchies in student–teacher communication patterns (Ryazanova & Zaykov, 2018). Compared with many environmental disciplines, soil science requires and contains one of the most significant field components in its curriculum (Janzen et al., 2011).

The basic concepts of a traditional morphopedogenetic soil science relate soil genesis causally to the following soil-forming factors: climate, geology and relief, biota, time, and human impacts (Dokuchaev, 1883; Jenny, 1941). Accordingly, soil science studies are related to field observations of characteristics resulting from the soil-forming factors and their dynamics in time and space (Brevik & Hartemink, 2010; Krupenikov, 1992). In the field, given the context of the soil pit in the landscape, students learn by systematizing inductively experienced knowledge and cross-checking with classroom and textbook knowledge. In that sense, field work marks important steps—learning by doing and learning by teaching peers—in the phases of learning in soil science (Dewey, 1911; Grzega & Waldherr, 2007). As a result, soil excursions representing soil geography and addressing the spatial patterns in soil-forming factors have been an integral part of soil science courses in Russia, Germany, and the United States since the beginning of the 20th century (Miller, Brevik, Pereira, & Schaetzl, 2019; Simonson, 1997).

Today, field work is considered among the main principles of soil science education (Field et al., 2011). Based on a stakeholder survey, understanding variability in soil properties and processes as well as skills in soil mapping were the core body of knowledge in soil science (Field, Yates, Koppi, McBratney, & Jarrett, 2017). Almost every soil science program in the world includes field classes and excursions, the content, duration, and intensity of which depend on the student level (i.e., undergraduate or graduate), specialization (e.g., soil classification and systematization, geography, geomorphology, etc.), and regional specifics. For historical and geographical reasons, soils of Russia have always attracted field excursions for local and international students. Lomonosov Moscow State University, Timiryazev Agricultural Academy, and Saint Petersburg State University organize annual soil field excursions covering zonal soils from southern taiga to semidesert zones, also reflecting the vertical soil zoning in the foothills of Crimea or the Caucasus (Aparin & Matinian, 2006; Prokofyeva, Malisheva, & Alekseev, 2006). Field excursions to study soils and landscapes of European Russia (Kuzyakov, 2013) and west Siberia (Barsukov & Siewert, 2007; Siewert et al., 2014) have been organized for German students and mixed groups of students from different countries. Although the content of field excursions could be very different, they all are focused on agricultural or natural undisturbed soils and landscapes (Siewert et al., 2014). The focus on natural and agricultural ecosystems is very understandable, considering that throughout most of its history, soil science has been concerned primarily with agriculture and food production (Bouma & Hartemink, 2002; Brevik & Hartemink, 2010).

The 21st century brings new challenges for soil science, and urbanization is among the most significant (Pickett et al., 2011). Urban soils and their properties, functions, and ecosystem services become more and more relevant for the environment and society (Morel, Chenu, & Lorenz, 2015; Vasenev, Van Oudenhoven, Romzaykina, & Hajiaghaeva, 2018; Vasenev et al., 2019). Recognizing the importance of urban soils has changed the traditional view of soil science education and triggered the development of new courses on urban soil description, assessment, and modeling (Pavao-Zuckerman & Byrne, 2009). Although the number of urban soil courses has substantially increased, field courses and excursions focused on urban soils are lacking (Diochon et al., 2016). This gap constrains the comprehensiveness of soil scientific knowledge and limits the skills and competencies of graduates for several reasons. First, urban soils are very heterogeneous and dynamic in time and space (Pouyat, Szlavecz, Yesilonis, Groffman, & Schwarz, 2010). More fundamentally, their pedogenesis cannot be explained by causal soil pedogenesis concepts but only by historical description of the anthropogenic impact. Urban soil formation is dominated by the anthropogenic factor, and the functions of urban soils are mainly human oriented (Kuzyakov & Zamanian, 2019). Urbanization results in substantial anthropogenic interruptions of soil properties and functions over a very short time period compared with the time needed for pedogenesis in natural soils. Mapping and assessment of urban soils require new approaches and tools, allowing for high-frequency and nondestructive observations at multiple points (Bray, Rossel, & McBratney, 2009; Kessler, 2006). Second, urban soils are mainly man-altered or manmade; therefore, knowledge on soil modeling, engineering, and management are needed to understand and design their properties and functions (Lehmann & Stahr, 2007; Smagin, 2012). Finally, urban soils are exposed to the influence of complex environmental factors of natural but mainly anthropogenic origin. Functions and ecosystem services of urban soils can be studied and understood only in the context of the urban environment, ecological problems, and human needs, which can be very specific for different countries and regions (De Kimpe & Morel, 2000; Gerasimova, Stroganova, Mozharova, & Prokofieva, 2003; Pickett & Cadenasso, 2009; Vasenev et al., 2017).

A field summer school, presenting urban soils and landscapes in comparison with natural counterparts over a climate, relief, and chronosequence and in the context of region-specific environmental problems and socioeconomic features, could fill this educational gap and contribute to understanding urban soils as a natural and socioeconomic phenomenon. This paper presents concepts and contents of the “Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils (3MUGIS)” field summer school as an innovative educational tool to study anthropogenic soils and landscapes from Barents to Azov Seas and from tundra to dry steppes. The 3MUGIS summer school has been annually organized since 2017, but the new “Sea to Sea” format was implemented in 2019 for the first time. This paper presents the principal educational and research innovations of the summer school and the feedback from participants.

Core Ideas

- 3MUGIS field tour focused on anthropogenic soils and landscapes from tundra to dry steppe.
- Anthropogenic soils and vegetation were studied in comparison with ones in natural ecosystems.
- Region-specific environmental and socioeconomic features and problems are discussed.
- Fieldwork focused on express techniques is relevant for the assessment of urban ecosystems.

2 | METHODS OF THE SUMMER SCHOOL ORGANIZATION AND IMPLEMENTATION

The international 3MUGIS summer school aimed to provide an international and interdisciplinary platform to study the properties, functions, and ecosystem services of urban soils and green infrastructure across zonal climatic gradient and in the context of the regional environmental, economic, and cultural specifics. Considering the high heterogeneity and dynamics of urban soils and ecosystems, the school aimed to complement conventional field descriptions and classification with advanced techniques of fast and nondestructive analysis. To achieve these goals, the summer school was organized in two interrelated parts: 1 wk of on-campus classes (22–26 July 2019) followed by a 2-wk field tour (27 July–11 Aug. 2019). Five days of on-campus classes included lectures, seminars, and practical training focused on four main topics: (a) interactions between urban soils and vegetation, (b) soil pollution and risks for human health, (c) modeling and engineering soil constructions, and (d) monitoring and management of urban soils and green infrastructures. Prior to the field tour, introductory lectures were given regarding tour route, logistics, regional geological, geomorphologic, climatic, and soil conditions, socioeconomic and cultural features, as well as basic principles of field work.

2.1 | 3MUGIS route and site description

The field tour lasted 16 d and covered a distance of >3,000 km. The tour route crossed five bioclimatic and soil zones and included 12 settlements, from Teriberka village on the shore of Barents Sea (69° N, 35° E) to Taganrog town on the Azov Sea (47° N, 38° E) (Figure 1).

The zonal bioclimatic conditions ranged from tundra to dry steppes. Mean July–August air temperatures varied from 11 °C in Monchengorsk (67° N, 33° E) to 23 °C in Rostov-on-Don (47° N, 39° E). However, the observed temperature differences were much more drastic, with a minimum of 6 °C on 15 July in Murmansk (68° N, 33° E) and a maximum of 32 °C on 8 August in Rostov-on-Don. Mean monthly precipitation of 82.5 mm in July–August was typical for Pushchino (mixed and deciduous forests), whereas Rostov-on-Don had the driest conditions. Zonal soils ranged from Cryosols and Podzols in the north to Chernozems and Kastanozems in the south. The sequence of zonal soil types was clearly illustrated by spatial patterns in basic topsoil properties (i.e., pH_{H2O} and soil organic carbon [SOC] content). Soil pH_{H2O} gradually increased from 4.0 in Podzols and Histosols (tundra and north taiga) to >7.0 in Calcic Chernozems (dry steppes). Less variability was shown for SOC, with a minimal 2% in Retisols (south taiga) and maximal 6% in Haplic Chernozems (steppe). Urban soils had an opposite pattern: pH_{H2O} in all settlements was neutral or slightly alkaline, whereas SOC ranged from 3% (Pushchino) to 11% (Murmansk) (Figure 2).

The field tour aimed to give an overview of soil, bioclimatic, and socioeconomic conditions of the European Russian regions. Soils and landscapes in each region were studied with regard to key issues of anthropogenic development and in comparison with natural references (Table 1). Anthropogenic landscapes of the subarctic region were represented by Teriberka, Murmansk, Monchegorsk, Kirovsk, and Apatity settlements located on the Kola Peninsula. The territory is very rich in ores and minerals and is therefore one of the leading mining industrial centers in the Russian polar region. Severe climatic conditions combined with heavy pollution result in degradation of vegetation and soils; therefore, remediation of the polluted areas is among the main priorities (Slukovskaya et al., 2019). Anthropogenic sites were compared with the undisturbed landscapes observed in the Lapland Nature Reserve and Alpine Botanical Garden. Undisturbed southern taiga was observed in the Central Forest Nature Reserve in Nelidovo (Tver' region). Forest stands in this reserve have remained unmanaged for almost a century. Regular tree windfalls result in specific mesorelief and formations of Retisols on windthrows (Vasenev & Targul'yan, 1995). In contrast, green areas of the Moscow megapolis, located in the same southern taiga zone, are managed and maintained, which simplifies the vegetation structure and affects soils, dominated by man-altered or constructed soils (Vasenev, Avilova, Tikhonova, & Ermakov, 2020). Anthropogenic effects on mixed and deciduous forests and soils were investigated by comparison of the town Pushchino with natural forests in the Oka River valley. The Central Chernozemic region, including the cities Kursk and Voronezh, has the most fertile soil resources in Russia and therefore has always been an important center of agriculture. Ongoing urbanization, including an expansion of the two largest cities, Kursk (population ~400,000) and Voronezh (population > 1,000,000), has had a clear negative impact on Chernozems, considered among the most fertile soils in the world (Sarzhanov et al., 2017). During the 3 d in this region, 3MUGIS students had a chance to compare urban soils formed on buried Chernozems with the natural references under the virgin steppe. Urban–rural interactions remain an essential factor influencing soils and landscapes in the Rostov region in the Russian south. With a population of >2 million, the Rostov metropolitan area is one of the largest in the Chernozemic soil zone. To illustrate this issue, urban soils, including soil constructions under a golf course, were compared with undisturbed natural soils.

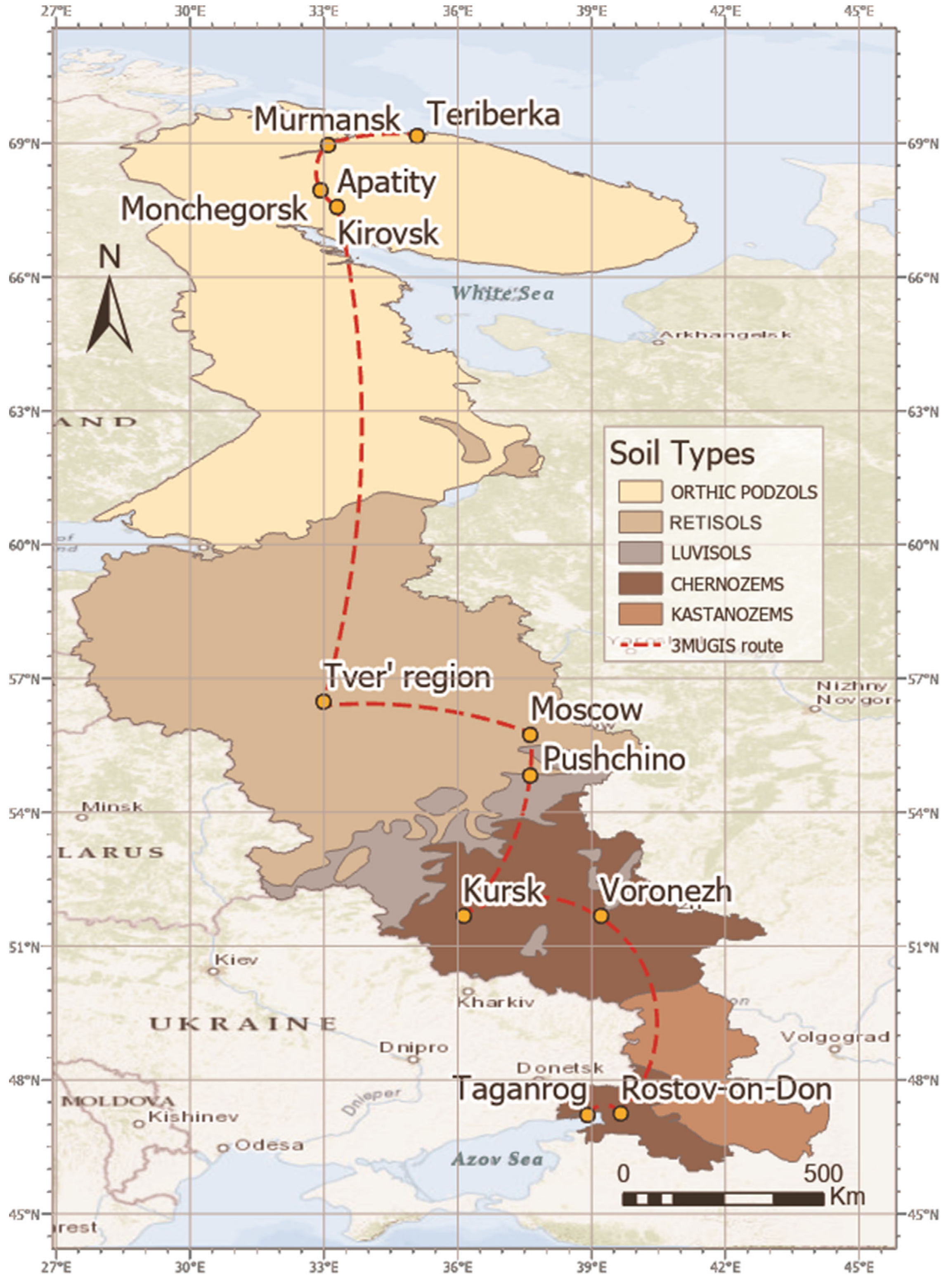

FIGURE 1 Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils (3MUGIS) 2019 field tour route

2.2 | Monitoring and assessment of soils and green infrastructures

To obtain practical skills in monitoring soil characteristics and green infrastructure, two to five research plots were studied in each region. At least one research plot from natural and anthropogenic landscapes was investigated for each region. The following characteristics were investigated: (a) soil morphological and chemical properties; (b) soil temperature and moisture; (c) soil

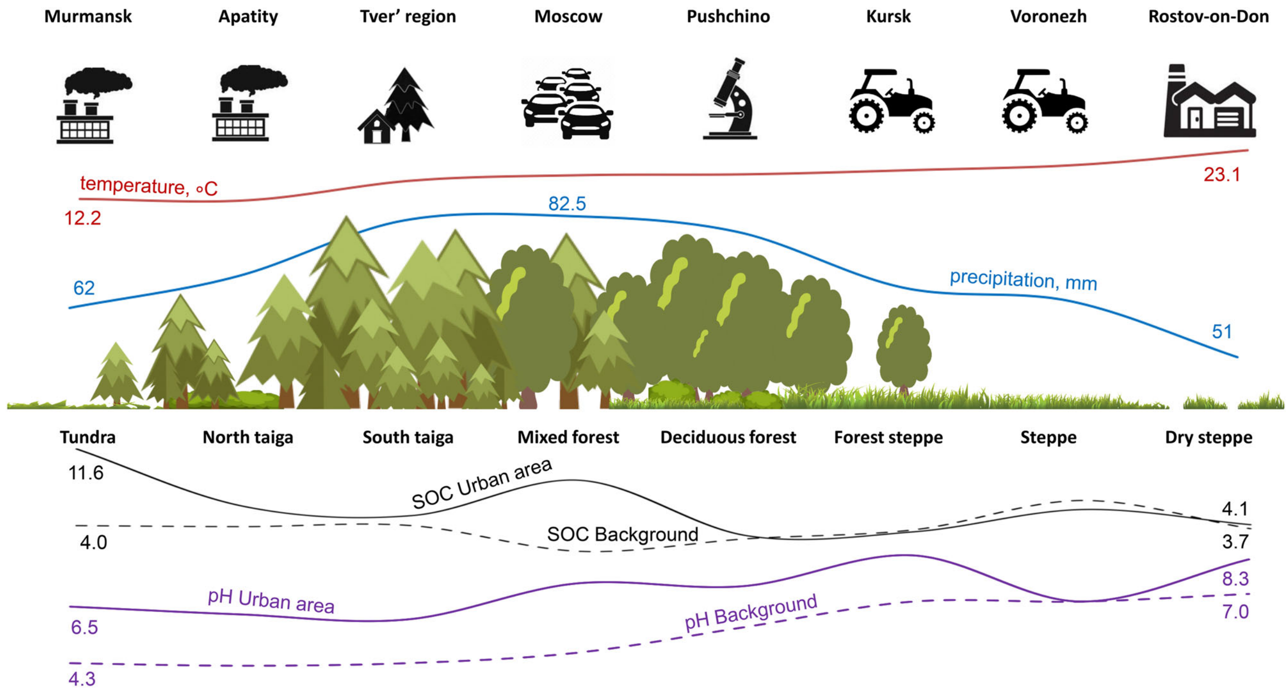

FIGURE 2 Landscape zones, climate conditions, and topsoil (0–10 cm) properties of the Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils (3MUGIS) sites (aggregated from Gavrilenko, Ananyeva, & Makarov, 2013; Sarzhanov et al., 2017; Vasenev et al., 2019). SOC, soil organic C

TABLE 1 Settlements visited by the Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils (3MUGIS) field tour

No.	Settlement	Population	Bioclimatic/soil zone	Natural references
1	Teriberka	573	Tundra/Cryosols, Podzols, Histosols	Alpine Botanical Garden
2	Murmansk	287,847	Forest tundra/Podzols and Histosols	
3	Monchegorsk	41,145	North taiga/Podzols and Histosols	Lapland Nature Reserve
4	Kirovsk	26,020		
5	Apatity	54,667		
6	Nelidovo	18,102	South taiga/Retisols	Central Forest Reserve
7	Moscow	12,678,079		
8	Pushchino	20,696	Mixed and deciduous forests/Luvisols and Luvic Phaeozems	Natural forest sites
9	Kursk	452,976	Forest steppe/Chernozems and Phaeozems	Central Chernozemic Reserve
10	Voronezh	1,058,261	Steppe/Haplic Chernozems	Botanical garden, Venevitinovo natural area
11	Rostov-on-Don	1,137,904	Dry steppe/Calcic Chernozems	Botanical garden, Tanais natural archeological area
12	Taganrog	248,643	Dry steppe/Calcic Chernozems	

FIGURE 3 Mastering skills in advanced techniques of soil and plant monitoring by using (a) portable temperature sensor iButtons, (b) infrared gas analyzer (IRGA), (c) soil moisture probe SM-300, (d) portable X-ray fluorescence (XRF) analyzer, (e) electrical conductivity (EC) meter and (f) Tree Talker

respiration; and (d) vegetation state. Conventional approaches included field description of soil profiles (FAO, 2004) and visual tree assessment for vegetation conditions (Callow, May, & Johnstone, 2018). These approaches are widely used to give a qualitative analysis of soils and vegetation as landscape components, but they have a limited potential to analyze and quantify processes and functions of soil and vegetation, especially in a highly variable and dynamic urban environment. Therefore, field training mainly focused on new tools and techniques, whereas the conventional approaches were considered as references.

Soil temperature was measured with an accuracy of 1 °C by iButton temperature sensors (Figure 3a; Malevich & Klink, 2011; Ojeh, Balogun, & Okhimamhe, 2016). In each plot, soil temperature was observed at four depths (surface and 5, 10, and 20 cm) for a minimum of 24 h, with the frequency at each depth recorded every 15 min. Soil respiration was measured by infrared gas analyzer (IRGA) EGM-5 (PP System, Figure 3b) in 5–10 locations in each plot. Soil moisture was measured at the same points with a SM-300 probe (Delta T, Figure 3c). Considering soil contamination by heavy metals and salinization by deicing reagents among the main anthropogenic impacts on urban soils, heavy metal contents were analyzed by X-ray fluorescence (XRF) spectroscopy (portable XRF analyzer, Olympus Vanta, Figure 3d), and soil salinity was determined by electroconductivity (portable EC meter, HANNA, Figure 3e). Tree physiology and stability were analyzed by the new generation equipment Tree Talker (Nature 4.0). Tree Talker allows monitoring such parameters as stem temperature and moisture, sap flow, and canopy light transmission (Valentini et al., 2019). Data are transmitted via wireless LoRa (long-range) connection to the router (TT-Cloud) with an hourly frequency (Figure 3f). These technologies made it possible to perform onsite, express, nondestructive, and high-frequency characterization and monitoring of urban soils and ecosystems.

2.3 | Course organization and evaluation

To provide enough time for practical training, as well as to support teamwork, field tour participants were organized into two teams with 11 members each. Each team was coordinated by a mentor (appointed from the organizers) and a team leader (one of the team members selected by all team members). The team mentor was responsible for educational content, whereas the team leader was in charge of organizing teamwork throughout the entire trip. Prior to the trip, students were provided with materials describing climatic, soil, landscape, socioeconomic, and cultural features of the visited regions. During the field tour, additional data on soil and vegetation were collected by students using conventional and advanced monitoring techniques at the research plots. Subgroups within each team were responsible for measuring different indicators (e.g., soil temperature, soil respiration, and visual tree assessment). All the data collected by the subgroups were integrated and discussed during daily team meetings. The rotation of responsibilities among subgroups allowed each team member to master all monitoring techniques. On the final day in each of the five regions (i.e., subarctic, south taiga, mixed and deciduous forests, central Chernozemic region, and Russian south), a closing lecture was given by local experts with an academic and practical background in environmental studies and management. These lectures, in addition to course materials and self-collected data, gave students the full information needed for their team project. The team project was completed at the final destination of the field course in Rostov-on-Don during the last 3 d of the course. For the project, students were asked to address geographical patterns and socioeconomic regional specifics by comparison of soil and vegetation properties of the observed natural and anthropogenic landscapes. The final project was presented in front of a committee composed of course organizers and local experts, and the scores for the summer school were given based on the project's overall quality.

After the course was completed, participants were asked to evaluate the quality of teaching, research work, social program, and organization. The link to the questionnaire was published on the Facebook page of the summer school. The survey was divided into three blocks. The first block included questions about the participants (country, education level, specialty). The second block focused on the summer school and its general evaluation. The third block focused on the eight stages of the summer school: the theoretical and practical parts in Moscow and the field tour regions. For this purpose, a five-point numerical scale was used, with 1 being unsatisfactory and 5 being excellent. Specific complains and suggestions were also collected by open questions.

3 | RESULTS AND DISCUSSION

3.1 | Studying the diversity of anthropogenic versus natural soils across the bioclimatic gradient

Classical approaches in soil and landscape geography were adapted to the studying of specific urban environment. Therefore, digging soil pits and describing soil profiles were the starting exercise in each region. During the course, students observed changes in zonal soils, and in comparison with anthropogenic soils, from tundra to dry steppe regions. The patterns observed at the natural sites are consistent with classical understanding of soil zonality. The depth of the litter and humus horizons increases from 7 to 10 cm in Albic Podzols to almost 100 cm in Haplic Chernozem Pachic, and then decreases to 80 cm in Calcic Chernozem. The lowest SOC content of topsoil (0–10 cm) was observed in Retisols and Luvic Phaeozems, whereas SOC contents in Podzols and Chernozems were higher. However, the processes of carbon accumulation in these soils were different. High SOC contents in steppe conditions are the result of intensive humification of grass and root biomass, whereas the reason for a rather high topsoil SOC stock in the tundra and north taiga is slow mineralization hampered by cold climate. The difference between these processes was discussed with the students onsite (while observing soil profiles) and during seminars (based on chemical properties, including different quality of organic matter in different soil types). Anthropogenic soils differed considerably from the zonal references and with each other, but the following urban-specific properties were observed for all urban soils (Figure 4): (a) abundance of anthropogenic inclusions (e.g., particles of bricks, rubber, and plastic); (b) neutral or slightly alkaline pH caused by dust deposition from building construction and industries; and (c) high SOC content resulting from organic amendments (e.g., peat, compost, and sewage sludge).

These observations are consistent with literature on urban soil properties in these and other bioclimatic zones (Lorenz & Lal, 2015; Prokof'eva et al., 2014; Rossiter, 2007; Vasenev & Kuzyakov, 2018) and highlight the anthropogenic nature and intrazonality of urban topsoils. In contrast, subsoil properties were more site specific and likely inherited from background soils and sediments. The specific properties of urban soils were discussed with students in relation to the processes and factors behind urban soil formation. Further, properties, processes, and functions of anthropogenic and natural soils were studied based on the descriptions and dataset in the guidebook (obtained by conventional soil survey methods) and data collected by students onsite (using mainly advanced technologies of rapid and nondestructive analysis). The main results are summarized in Table 2. The most interesting cases and patterns are discussed below.

3.2 | Soil properties and functions

3.2.1 | Soil temperature

A traditional temperature distribution from the soil surface down the profile following the Fourier laws of heat distribution in soils was clearly observed in the most southern location of the field tour, Rostov-on-Don, where the surface temperature is high enough. On the Kola Peninsula, in contrast, deeper horizons were warmer than the surface horizons, exposed to the unusually cold weather conditions during 3MUGIS-2019 with daily average air temperature 6–8 °C lower than the long-term mean. Comparison between urban and reference natural sites illustrated the heat island effect—a mesoclimatic anomaly with higher temperatures at the urbanized sites compared with suburbs and natural areas (Lokoshchenko & Korneva, 2015; Oke & Fuggle, 1972). Regional specifics of urban heat island effect and its consequences for soil and vegetation were discussed with students during seminars.

3.2.2 | Soil carbon dioxide fluxes and elemental composition

Data on soil chemical properties obtained by conventional analytical methods prior to the course and available in the 3MUGIS guidebook were complemented by monitoring

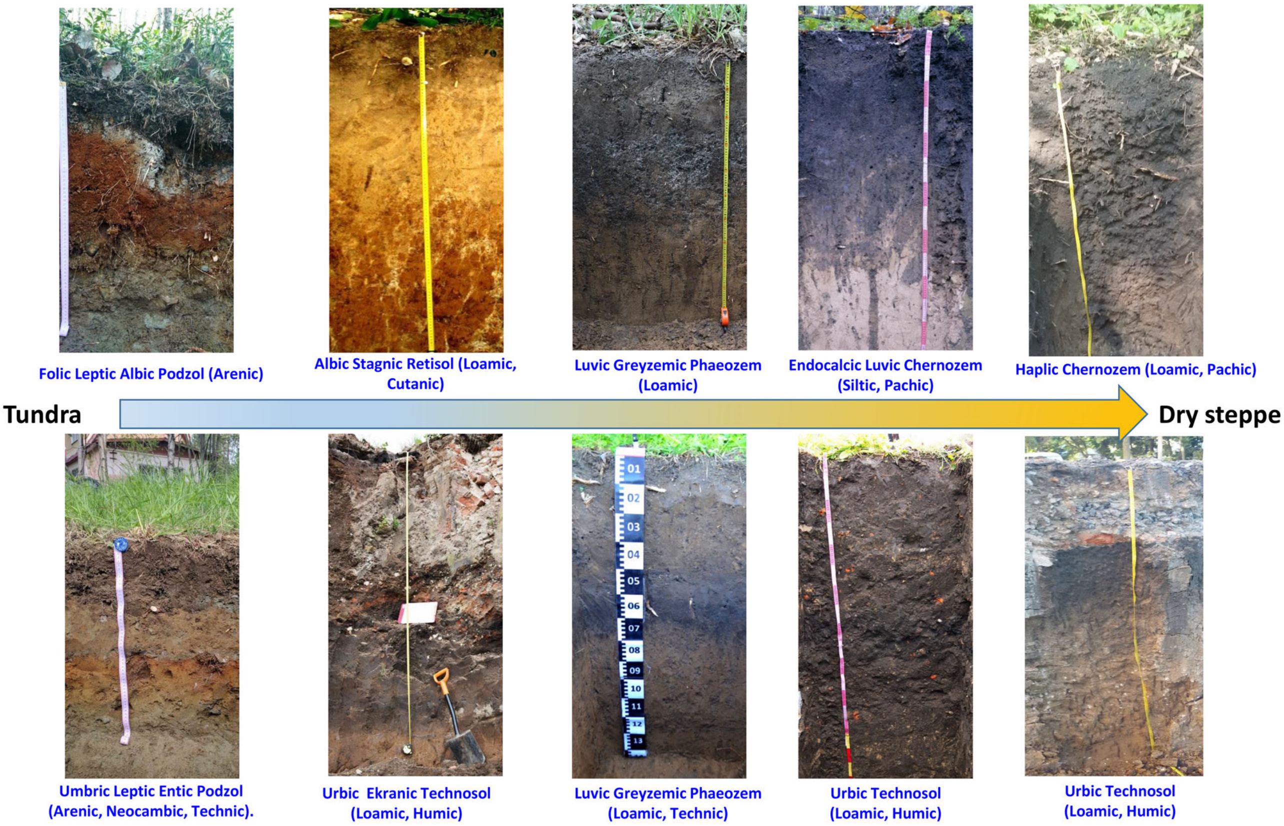

FIGURE 4 Anthropogenic and natural soil of bioclimatic zoned observed during Monitoring, Modeling, and Management of Urban Green Infrastructure and Soils (3MUGIS) field tour

TABLE 2 Selected results of soil and vegetation survey

Bioclimatic zones	Daily average soil surface temperature		Soil respiration		Tree height (for the case of *Betula pendula*)	
	Urban	**Natural**	**Urban**	**Natural**	**Urban**	**Natural**
	°C		mg C-CO_2 m^2 h^{-1}		m	
Tundra and north taiga	10.3	12.5	107 ± 15	88 ± 11	6 ± 2	7 ± 2
South taiga	17.2	16.5	210 ± 27	123 ± 22	25 ± 6	24 ± 3
Broad-lived and mixed forests	No data	No data	253 ± 35	201 ± 31	24 ± 3	24 ± 2
Forest steppes	19.7	21.2	160 ± 15	210 ± 28	27 ± 4	No data
Dry steppes	25.6	23.2	145 ± 8	133 ± 10	24 ± 4	No data

results collected onsite: IRGA for soil respiration and XRF for soil elemental composition. Observations of soil respiration in 5–10 spatial replicates for each site showed a clear pattern with maximal soil respiration in deciduous forest areas and minimal respiration in north taiga and dry steppes. This pattern can be explained by corresponding climate conditions and SOC stocks. Soil respiration in northern taiga is hampered by low temperature and water-logging, whereas dry and hot conditions limit soil respiration in dry steppes. Deciduous forests provide the most favorable climatic conditions, which in combination with rather high SOC stocks result in intensive soil respiration. Variability in soil respiration within a research site is mainly driven by patterns in land cover and management: respiration of soils under managed lawns is considerably higher than under shrubs and under trees.

Soil screening by XRF focused on heavy metals and trace elements (Chakraborty et al., 2019). Students had an opportunity to observe contrasting levels in heavy metal contents (e.g., the industrial barren near Monchegorsk vs. the reference forest site). This illustrated the advantage of using portable XRF for a qualitative assessment of soil pollution (Kalnicky & Singhvi, 2001). Concentrations of heavy metals at the background site did not change significantly

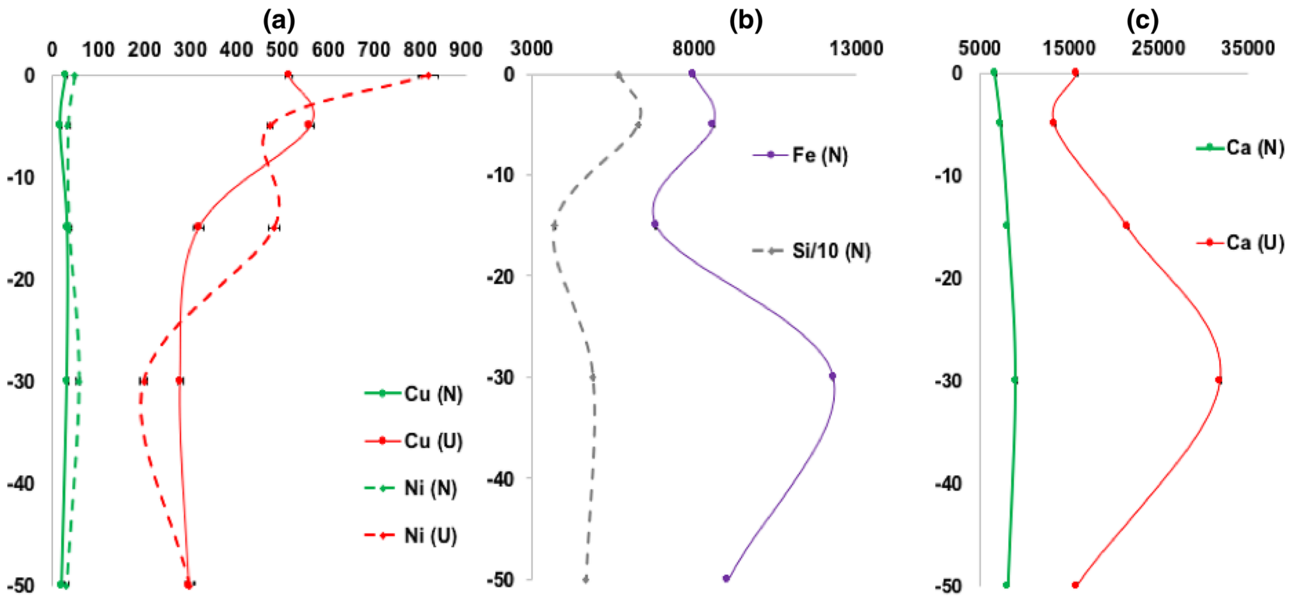

FIGURE 5 Profile distributions of (a) Cu and Ni, (b) Fe and Si (divided by 10 to standardize with Fe), and (c) Ca measured onsite by portable X-ray fluorescence (XRF). Letters in parentheses refer to urban (U) and natural (N) sites. All contents are in milligrams per kilogram of soil

down the profile, whereas copper (Cu) and nickel (Ni) accumulation in topsoil was clearly demonstrated at the industrial site (Figure 5a). To explore new opportunities of XRF in soil monitoring, students were asked to measure the profile distribution of iron (Fe) and silicon (Si) in Podzols and Retisols, and calcium (Ca) in Chernozems, to help understand the dominant soil-forming processes. In Podzols and Retisols, Si accumulation in the E (eluvial) horizon and Fe accumulation in the B (illuvial) horizon were observed. In Chernozems, maximum Ca concentrations coincided with the highest amount of new carbonate formations. In urban soils, maximum Ca content coincided with anthropogenic horizons containing lime deposits and gravel (Figures 5b and 5c).

3.3 | Vegetation analysis

Tree survey and visual tree assessment at the sites revealed the main patterns in vegetation diversity and condition between the regions. Subarctic sites had the lowest diversity with three to four tree species per site, whereas the maximal diversity was deciduous forests and forest-steppes with >20 species per site. Tree stands in the northern towns (Monchegorsk, Kirovsk, and Apatity) were very dense, which was caused by the regional-specific guidelines in urban greening—more plants per area unit aimed to compensate for tree mortality from winter frosts. Small size is another specific feature of northern green stands. Students were asked to compare the average height of *Betula pendula* Roth (one of the few species observed in all regions). Although the age of the trees were similar, trees in Apatity were shorter than half of those from other regions.

At several sites, tree survey and visual tree assessment (VTA) results were complemented by high-frequency monitoring of tree condition and physiology performed by Tree Talker technology. Considerable differences in average daily and seasonal sap flow were found for different species, with higher fluxes in deciduous trees compared with coniferous trees (Figures 6a and 6b). Younger trees also had lower sap flow than adult trees of the same species (Figures 6c and 6d). The influence of anthropogenic load on tree physiology was analyzed via comparison of diameter growth at the sites with different levels of disturbance. Tree diameter growth at the highly disturbed sites (e.g., sites exposed to soil overcompaction by high recreational activities, or air and soil pollution due to proximity to high traffic roads) was 40–60% lower than at undisturbed sites (Figure 6e). A comparison of the results obtained from Tree Talkers with those obtained by other approaches showed good agreement and confirmed the robustness of the monitoring results. For example, a significant positive correlation was found for the normalized difference vegetation index (NDVI), calculated based on Tree Talker data and a more traditional remote sensing approach (Figure 6f). So far, Tree Talker technology is very novel and is implemented at a limited number of sites. Students were able to test this technology at selected sites but could not compare the data between the bioclimatic zones. Further development of the technology will allow expansion of the existing monitoring network and be an even more valuable part of the 3MUGIS field school.

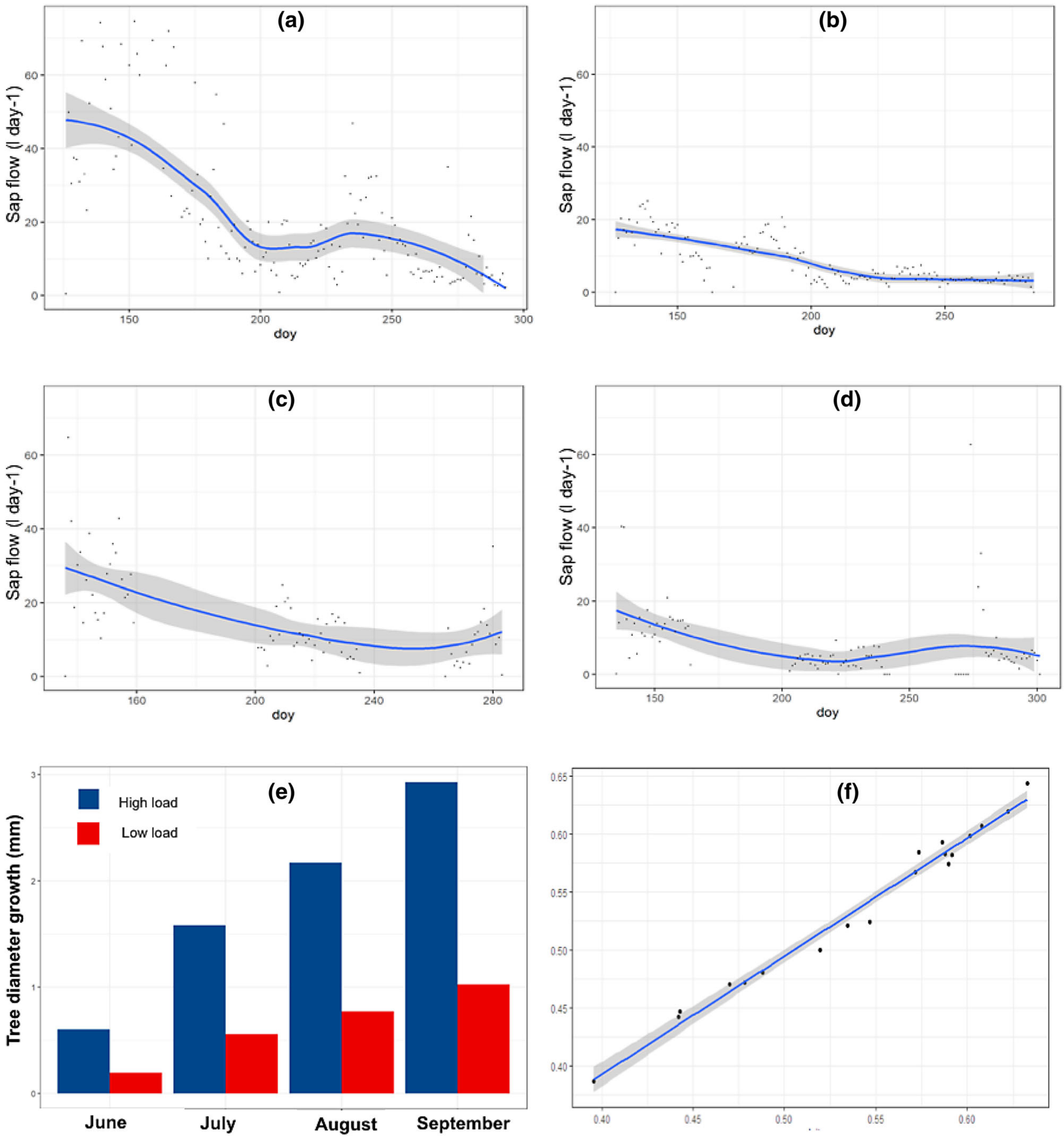

FIGURE 6 Indicators of tree physiology were obtained using Tree Talker technology at the Moscow site: (a) seasonal dynamics of sap flow of (a) *Acer platanoides* L. compared with (b) *Picea abies* (L.) H. Karst.; sap flow of (c) old and (d) young *Tilia cordata* Mill. trees; (e) tree diameter growth at the sites with different anthropogenic load; and (f) the correlation between normalized difference vegetation index (NDVI) measured by Tree Talker and remote sensing

3.4 | Course evaluation and student feedback: Success of the didactical concept

Participants from Germany, the United States, and Russia made up 60, 30, and 10%, respectively, of the respondent sample. This proportion is representative of participant composition and illustrates its internationality. The overall grade of 4.2 (out of 5.0) was given for 3MUGIS-2019 organization. Organization of research and educational activities, including self-organization of teams and guidance by experienced academic supervisors and local experts, was rated as very effective (34.7%) and effective

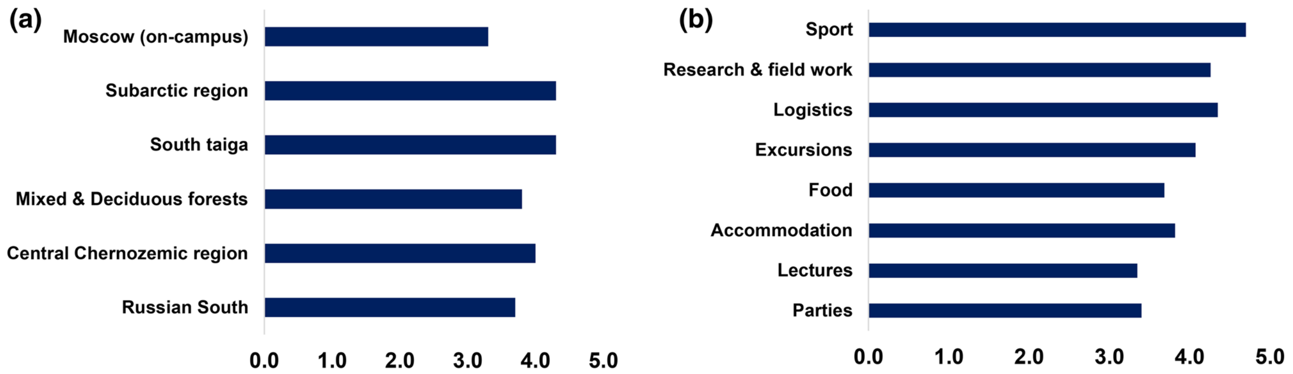

FIGURE 7 Course evaluation results organized by (a) activities and (b) locations

(57.1%). Despite the complex logistics of the tour with different types of transportation (airplane, bus, train) and long trips (up to 6 h), the evaluation of logistic organization was very positive: 50.8% excellent, 36% good. In comparison, feedback on food quality was the most diverse: 27.5% excellent, 33.3% good, 23.2% satisfactory, 11.6% bad, and 4.3% extremely bad. Likely, this can be explained by highly variable food preferences of the participants, 40% of whom were vegetarians and vegans. Although this information was considered when planning the tour, some places in small towns and villages are not used to provide special vegetarian menus. In this regard, the school organizers will pay special attention to catering and preliminary discussion of the menu with representatives of cafes and restaurants along the school's route for the next tours. Social activities including sightseeing, sports, and parties were positively evaluated by 76% of respondents. However, the estimates differed considerably among different sites. For example, an excursion to Teriberka village on the shore of the Arctic Ocean received a 100% positive rating, whereas <25% liked the excursion to Russian State Agrarian University. Sports activities, including traditional Russian banya (sauna), were a nice addition to the educational activities and received 90% positive ratings. The resulting ranking of the locations and activities summarized in Figure 7 will be considered to adjust the tour route and organization for future summer schools.

Ten teachers from Russia, France, Germany, and the United States took part in different segments of the excursion. Five of them contributed throughout the trip. The group comprised experts in botany, geology, geochemistry, soil sciences, climatology, planning, and environmental sciences. The didactic concept included onsite discussions among teachers, between teachers and students, and among students. The discussions covered different classification concepts, regional aspects, and various soil scientific details. Teachers often shifted their roles from explaining to asking, from experts to newbies, and shared their cultural experiences while being exposed to new culture. All students, from college sophomore to M.Sc. and Ph.D. students, had the opportunity to learn directly from experts in different disciplines.

4 | CONCLUSIONS

The 3MUGIS summer school is an international field course, teaching and studying the formation, functioning, and spatial–temporal variability of urban soils and green infrastructures. The classical approach of soil excursions was complemented by advanced technologies for fast and nondestructive onsite measurements. To our knowledge, 3MUGIS-2019 is the first attempt to study urban soils and green infrastructure along the bioclimatic gradient from tundra to dry steppes in a field summer school format. Comparative analysis of urban and natural sites in each region gave students a unique opportunity to observe zonal patterns in climate, vegetation, and soils. It also helped them to understand the complexity of natural and urban-specific factors behind the formation and functioning of urban soils and green infrastructures.

A combination of conventional and advanced techniques gave a full picture of spatial–temporal variability of urban soils and vegetation. New advanced techniques and testing equipment, which have not been used for monitoring urban ecosystems in such a wide range of climatic conditions previously, provided opportunities to collect new scientific information and training of participants. Besides the expected results (e.g., monitoring soil respiration by IRGA or screening heavy metal contents of soils by portable XRF), soil-forming processes were able to be demonstrated by evidence including Fe migration in Podzol profiles and Ca accumulation in Chernozems.

The format of the field course combining research and education, fieldwork and social activities, guidance by experts, and self-organization in teams was taken well by the participants, evidenced by the overall high rating of the course. The organization of education facilities and logistics was very positively rated, whereas students with individual diet preferences criticized food quality. The subarctic region and especially Teriberka village (the most northern location) were the most exciting places for participants. Apparently, new research and cultural experience in this remote area were very beneficial, even though the climate conditions were harsh.

The results of the course evaluation were very interesting and motivating to the organizers, for whom 3MUGIS-2019 was also a unique professional and life experience. The 3MUGIS-2019 format proves to be a very promising educational tool to improve our understanding of the contrasting urban and natural ecosystems in different bioclimatic zones. The future 3MUGIS field courses will maintain this approach and will contribute to the goals of sustainable urban development (3mugis.org).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Viacheslav I. Vasenev https://orcid.org/0000-0003-0286-3021
Marina V. Slukovskaya https://orcid.org/0000-0002-5406-5569
Olga N. Romzaykina https://orcid.org/0000-0002-8516-2724

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