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**Historical avenues of research in Russian forest typology:
ecological, phytocoenotic, genetic, and dynamic
classifications**

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1 Historical avenues of research in Russian forest typology: ecological,
2 phytocoenotic, genetic, and dynamic classifications

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8 Abstract

9 The Russian Federation is one of many countries that have signed the Montreal Protocol and Pan-
10 European Forest Process. These initiatives are aimed at harmonizing national forest inventory
11 systems with criteria and indicators for sustainable forest management. In Russia, the classification
12 of forest type is at the heart of national forest inventory systems. For various historical reasons,
13 Russian scientific advancements in the field of forest typology remain little known in the rest of the
14 world. This paper is aimed at addressing this deficiency. Here, we provide an overview of the main
15 trends in the field of forest typology studies in the previous political states of the Russian Empire,
16 the Soviet Union, and the Russian Federation from the end of nineteenth to the beginning of the
17 twenty-first centuries. We detail the principles that formed the basis of the most significant forest
18 type classifications. We also perform similarity and differences analyses comparing approaches
19 used by members of different scientific schools in the field of forest typology. The historical
20 relationship between ecological, phytocoenotic, genetic, and dynamic forest type classifications are
21 discussed, as well as the reasons for the prevalence of certain forest type classifications in different
22 regions of Russia.

23 *Keywords: forest typology, ecological, phytocoenotic, genetic, dynamic, forest type classification,*
24 *fields of research, Russia*

25 Introduction

26 The Russian Federation is a member of the Montreal Protocol and the Pan-European Forest
27 Process international agreements (The Montréal Process 1995; 2015; The Pan-European Forest
28 Process 1993). The aim of these initiatives is to harmonize national forest inventory systems to the
29 level of international criteria and indicators for sustainable forest management (Brand 1997;
30 Castaneda 2000). In Russia, as in many other countries that have acceded to these agreements, the
31 national forest inventory (NFI) system is based on nationally determined concepts of forest types
32 (Chirici et al. 2011). The species composition of tree stands, understory vegetation, and living
33 ground cover, as well as abiotic site factors may be used as criteria for the allocation of a forest to a
34 specific forest type. Forest type classifications result from the collection and organization of
35 information on forests to be used for sustainable forest management (Barbati et al. 2006; Barbati et
36 al. 2007; Barbati et al. 2014).

37 According to the FAO, the forest area of the Russian Federation constitutes more than half
38 of its total area, and one-fifth of the total area of forests in the world (Forests and the forestry sector,
39 2003; Annual Report, 2011). Forestry and the forest industry were important elements in the
40 economic structure of the Russian Empire and the USSR in the past (Rogovtseva, 2016), and they
41 remain important in the Russian Federation now. In our country, conceptions of forest type have
42 evolved significantly over the last 150 years, from a view of it as a homogeneous (for some
43 parameters) forest parcel to the concept of forest type as an object in which the homogeneity of
44 origin (genesis), the processes of development and dynamics have a higher priority than
45 homogeneity of forest sites in a space. In other words, from the idea of forest type as an object in
46 space to the idea of forest type as an object in time. Despite significant scientific achievements in
47 the field of forest typology, many aspects of forest-type classifications created by Russian scientists
48 are still little known outside Russia. This may be attributed to the rather long period when Russia
49 was a closed country.

A comparative analysis of the development of forest type classifications within the main avenues of forest typological studies allows us to trace the convergence of initially different approaches taken by researchers of different scientific schools. This is a good example of harmonization of approaches through a broad scientific discussion at the expert level, leading to a better understanding of alternative points of view and improvements to the forest typology classifications espoused by each. In our view, the harmonization of national forest inventory systems at the level of criteria and indicators for sustainable forest management should also take place in the context of a wider international discussion, primarily at the expert level in the form of publications in international journals, including joint scientific papers. We believe that Russian forest typologies and aspects of their use are still insufficiently known outside Russia. This is the issue that this paper seeks to address.

The aim of this paper is to describe the main avenues of forest typology research followed in Russia since the end of the nineteenth to the beginning of the twenty-first centuries.

Origin of forest typologies in Russia

Classification of forest types is an essential element of a practicable forest management system, and their implementation requires a relatively high level of development and must be supported by law. Despite the fact that legal regulation of human relationships with forest use in Russia existed from the eleventh century, the formation of a legislative framework for forest management in the Russian Empire only began from the decree of Peter I (Peter the Great), the first Russian emperor (Rogovtseva 2016; Tiyaikin 2014). The decree of Peter I on November 19, 1703 (Peter I 1703) regulated the use and protection of forests for shipbuilding purposes on the basis of qualitative and quantitative criteria (Rogovtseva 2016). This document (Peter I 1703) represents the beginning of regulatory frameworks for forest management in the Russian Empire. However, the notion of forest types and their management in Russian forestry developed much later.

The concept of forest type first appeared in France and it was further developed in Germany (Brain 2011). The first forest type classifications were developed in Germany in the late eighteenth

to early nineteenth centuries (Luganskiy, et al. 2010; Risin 2009; Scriyabin 1970; Sukachev 1960; Sukachev 1964). By the end of the nineteenth century and in the early twentieth century, this concept was then adopted by Russian researchers and foresters (Gutorovich 1912; Serebrennikov 1912). Professor G. F. Morozov studied the experience of Russian and German foresters, and concluded that contemporary forestry practices followed an assortment of rules with few of them pertaining to a scientific background. Prof. Morozov decided that this system of rules must be amended to a new branch of knowledge that combined forest management with a scientific understanding of the biological nature of the forest. The name he gave for this discipline was "Lesovedenie" (Kolesnikov 1970), which can roughly translated to Forest Science and Forestry in English.

Morozov created a scientific and theoretical basis for forestry and forest management, with the concept of forest types at the heart of his theory. He used advances from different fields of science: Dokuchaev's genetic soil science, Darwin's theory of evolution, and general knowledge from many branches of botany and geography (Kolesnikov 1970). The results of Prof. G. F. Morozov's research became central to all main forest type classifications that were developed in the Russian Empire, the Soviet Union, and the Russian Federation.

Basic approaches to forest type classification and stages of forest typology development in Russia are described in detail in many papers and books (Denisov 2008; Dylis 1973; Dyrenkov 1989; Ivanova 2010, 2013, 2014; Manko 2013; Morozov 1925; Pogrebnyak 1955; Risin 2009; Sukachev 1957 1972; Smolonogov 1998, 1999). Researchers identify the following periods and main advancements in Russian forest typology research: the period prior to Morozov's study; Morozov's theory of forest types; ecological or ecological-silvicultural forest typology (Krudener's forest type classification; classification of forest types of E. V. Alekseev and P. S. Pogrebnyak); phytocoenotic typology (Sukachev's forest type classification); genetic or geographic and genetic forest typology of B. A. Ivashkevich and B. P. Kolesnikov, as well as Melekhov's dynamic forest typology.

Morozov's theory of forest types

The understanding that some types of forests occurred in conjunction with specific site conditions and were composed of particular species assemblages existed before the first science-based forest type classifications were created. Consequently, the first classifications usually used vernacular names of forest types. The forester G. Gafelder proposed one of the first classifications of forest types for Kurland in 1835 on the basis of the quality of soils (Luganskiy et al. 2010). Some regional forest type classifications were developed in the late nineteenth to early twentieth centuries by the following foresters: G. G. Hartig, A. F. Rudzskiy, N. K. Genko, I. I. Gutorovich, D. M. Kravchinskii, V. D. Petropavlovskiy, P. P. Serebrennikov, and A. S. Rozhnov (Alekseev 1915; Luganskiy et al. 2010; Migunova 2009b; Morozov 1912; Pogrebnyak 1955; Risin 2009). The results of their research and practical experience in creating forest inventories, which is reflected in their classifications of forest types, served as the basis for the theoretical generalizations in the field of forest typology, and the further development of more sophisticated forest typologies.

Prof. Morozov offered a set of fundamentals which were the core of his theory of forest types (Morozov 1925). According to his proposals the classification of forest communities should be based on the following forest-forming factors: 1) ecological properties of tree species; 2) attributes of the geographical environment such as climate, geology, topology, and soil; 3) the biosocial relationship between plants which helped form the forest community, as well as the relationships between plants and animals; 4) historical and geological factors; and 5) human impacts. The last of the described factors was temporarily excluded by Morozov himself from the analysis, but these fundamentals were used by many followers in their forest type classifications.

Morozov believed that the grouping of soils on the basis of soil weathering types was one of the key processes, which determined all the other processes. To Morozov (1925), the importance of soil weathering as a soil forming process was clearly evident (Morozov 1925). He also noted the fact that forests were a geographical phenomenon, and that it was necessary to take into account these facts when establishing a classification system for forest types.

Prof. Morozov also proposed the following hierarchy of units for a classification system: zones, subzones, regions, subregions, forest areas and forest types. The zones and subzones are arranged more or less in parallel latitudes, whereas regions and subregions may occur across different latitudes in any direction. He regarded any classification unit as a phenomenon of biogeographical, biosocial, and historical factors, and that the stable existence of a forest is only possible when its internal processes remain consistent with the geographical environment (Morozov 1925). Ultimately, around the 1920s Morozov developed a system of scientific statements that were important in forming a number of national forest type classifications described below.

Prof. Morozov proposed that schemes based on site conditions be referred to as natural or genetic classifications, whereas those based on other attributes be referred to as artificial schemes (Alekseev 1915). Later this proposal was modified by B. P. Kolesnikov (1961). He suggested the use of three groups of forest type classifications: artificial, natural and genetic (Kolesnikov 1961), which became terms currently in use in Russian forest science.

Classifications that existed in the period prior to Morozov's research relate to the artificial category, whereas natural classification is based on the statements designed by Morozov. The authors of natural classification schemes posit the need to consider the dynamics of forests, but their genesis is not deeply reflected in classification schemas (Kolesnikov 1961). Genetic classifications are more advanced than natural classifications as they are devoid of the latter's inherent shortcomings, yet still take into account genesis as well as different stages of forest dynamics.

Initial ecological avenues of research in forest typology: Krudener's forest type classification

One of the first classifications of forest types based on Morozov's statements was developed by A. A. Krudener (Krudener 1916). This classification adopts an ecological direction of research into the field of forest typology (Migunova 2002). Krudener emphasized soil conditions and built a classification of forest types for European regions of Russia using a deductive method. He divided this area into climatic zones, subzones, regions, and subregions. Zoning was carried out using the following parameters: air humidity and temperature conditions that affect soil forming processes;

minimum and maximum air temperature; the origin and composition of aqueous solutions; water balance; accessibility of nutrients for plants; duration of the growing season; and features of snow cover. He considered that orographic factors have to be automatically taken into account with the use of such zoning in a study area (Krudener 1916).

Krudener analyzed geological layers in defined climatic regions in order to understand the genesis and creation of the soil formation in the areas close to the root systems of trees. He then analyzed the soil composition and its water regime according to macro- and micro-relief. He characterized groups of sand, clay, stony deposits and humus, as well as combinations thereof, associated with the relief and water regime. These factors in combination with the forest community determined the type of forest (Krudener 1916).

Krudener developed a classification table with a title translated into English as "The main types of soils and typical soil conditions, depending on the moisture (water drainage), air (air drainage) and the nature of the upper soil layer (acidic, neutral, muddy humus, peat), forming certain types of forest due to combination of the mineral substrates and tree stands" (Krudener 1916). This table summarizes what he perceived to be the most important classification parameters for forest type determination. Krudener's forest type classification covers a huge area of about seven million hectares, ranging from tundra areas of the Far North to the forests of the Caucasus Mountains. Data sets from six thousand forest plots and the use of a large number of anecdotal descriptions forests were used for building Krudener's typology. This table was used for several decades (Migunova 2002).

A generalized schema of Krudener's classification table is shown in Fig. 1. It consists of two parts: the upper part marked with letter *A*, and the bottom part marked with letter *B*. Part *A* includes five indicators: 1 - hygrometric group, 2 - mineral substrate and soil, 3 - the nature and degree of moisture, as well as drainage, 4 - the nature of the topsoil, and 5 - the access of oxygen to the soil (aeration). Part *A* has a rather complicated structure. Some of the above five indicators may consist of two to four parts (rows). Vertically, the table is divided into three major groups of indicators: I -

types of upland meadow terraces, II - floodplain and gallery types, III - types as a result of the rapid or gradual bogging process or reverse process. Part *A* of the table is an irregular network of cells of different sizes (Fig. 1). This part of the table is shown in Fig. 1 partially because of its large size. The fragment colored gray (Fig. 1) is shown in detail in Fig. 2.

Part *B* of Krudener's classification table consists of seven rows, which contain petrographic physical-mechanical groups (substrates) and 16 columns, which are combinations of soil and subsoil types (Fig. 1). The groups of these combinations are the following: 1 - sand (for forest type *bor* in Russian), 2 - sandy loam (or forest type *subor* in Russian), 3 - clay (or forest type *ramen* in Russian), 4 - fine sand or sandy sediments underlain by clay substrates (or forest type *suramen* in Russian), 5 - fine sand or sandy sediments underlain by rocky substrates (or forest type *melkiy bor* and *subor* in Russian); 6 - fine loam (clay) deposits underlain by rocky substrates (or forest type *melkiy ramen* on the rocky substrate); 7 - fine loam (clay) deposits underlain by sandy substrate (or forest type *melkiy ramen* on a sandy substrate). Krudener chose the vernacular names for groups of soils and subsoil types, which are given in parentheses above.

Each column of Part *B* of the classification table corresponds to a set of the characteristics in Part *A*. The combination of moisture and air availability of the substrate from the upper part (Part *A*), to the substrate that is shown in the lower part (Part *B*) is a certain type of soil. For example, column three of the lower part (Fig 2) corresponds to the following set of characteristics from the upper part: types of upland meadow terraces with constant moisture, fresh, i.e. moderate humidity with good drainage; with acidic humus; with a lack of air availability in the soil.

For the Western provinces of the Russian Empire, Krudener described in detail each type of soil and subsoil, the hydrological regime of the territory, as well as characteristics of the woody vegetation (tree stand and undergrowth). In addition, he developed a schematic for each type of soil and hydrological condition. A sample of this drawing with relief cross sections and forest types is shown in Fig. 2 (Krudener 1916).

Krudener created the first science-based Russian classification scheme of forest types, using the theoretical statements developed by Prof. Morozov. Krudener's classification played a very important role in the further development of forest type classifications in Russia. The advancements of Krudener have been used by numerous researchers to create their typologies. One of the most well known of these is the classification scheme of A. A. Alekseev–P. S. Pogrebnnyak.

Subsequent ecological avenues of research in forest typology: the forest type classification of E. V. Alekseev and P. S. Pogrebnnyak

The forest type classification of E. V. Alekseev and P. S. Pogrebnnyak used ecological (Migunova 2002) and or ecological-silvicultural (Kolesnikov 1974) lines of research. This classification has been developed on the basis of the results of the separate researches performed by Prof. Morozov and A. A. Krudener (Migunova 2002). E. V. Alekseev created a classification of forest types for the central part of Ukraine. He defined six groups of forest types using Krudener's classifications of soil conditions, as well as adding the characteristics of stands, undergrowth, and live ground cover (Merzlenko 2005). Subsequently, his line of research was supported by P. S. Pogrebnnyak and D. V. Vorobiov (Migunova 2009a, 2009b; Pogrebnnyak 1955 1968; Schepotiev 1970; Sukachev 1957).

The edaphic grid of habitats is used to determine the forest type in the classification scheme of E. V. Alekseev–P. S. Pogrebnnyak. Trophic groups are shown on the horizontal axis, groups of soil moisture conditions on the vertical axis (Fig. 3). The trophic groups in the columns differ from each other in nutrient contents, and were referred to as “trophotopes” by Pogrebnnyak himself (Pogrebnnyak 1955). Each group was designated by a name and letter (A - bor, B - subor, C - mixed subor, D - dubrava), differed from each other by edaphic (soil and subsoil) moistening, and were referred to as “gigrotopes.” Each gigrotope was designated a name and number: 0 - xerophilous (very dry), 1 - mesoxerophilous (dry), 2 - mesophilous (fresh), 3 - mesohygrophilous (moisty), 4 - hygrophilous (moist), 5 - ultrahygrophilous (wet).

P. S. Pogrebniyak defined habitats or edatopes as forest sites with the same edaphic conditions. Each habitat can be characterized by a certain trophotope and gigrotope. Forest type is defined as a combination of trees, living ground cover species, and edatope. The symbols for typical tree species and the names of typical indicators for living ground covers are drawn on the grid. These factors together comprise P. S. Pogrebniyak's forest type classification scheme (Fig. 3).

This approach was further developed in research by D. V. Vorobyev. He developed a classification model for climate assessment in the form of a grid, the coordinate axes of which are indicators of the heat and humidity of the climate. Within homogeneous climate zones, forest types are determined using an edaphic grid that allows a forester to systematize typological diversity of forests (Migunova, 2002, 2007).

Although the Alekseev-Pogrebniyak classification uses an edaphic grid of habitats, tree stands and living ground cover species for forest type determination, in practice this typology has been widely adopted in regions where particular edatopes correspond, as a rule, to particular types of stand; an edatope type determination on the basis of the edaphic grid is thus sufficient to determine the forest type.

Phytocoenosis avenues of research in forest typology: Sukachev's forest type classification

The phytocenosis line of research in forest typology was created by V. N. Sukachev along with his numerous contemporaries (Denisov 2008; Luganskiy et al. 2010). Sukachev made an important statement regarding forest typology, which translates into English as "plant communities that are grouped into types, must have homogeneous direct-impact factors, i.e., must have biologically equivalent habitats" (Sukachev 1972). The difficulty in measuring many of these factors, such as the mineral and water regime of the soil, the soil's oxygen supply, and the interaction of these and other factors which influence the phytocoenosis of huge areas, inspired him to create a forest type classification using indirect measurements of these factors, i.e., using characteristics of forest association. He proposed to use species composition as an associated measurement, the spatial distribution, and developmental stage of species, as well as a set of forest

parameters of tree stands at a certain age: the average diameter, the shape of trunks, stand density, the maximum degree of crown closure, total basal area of trees, and standing crop (Sukachev 1972). One of the most important indicators of forest phytocoenosis is renewal, where a forest type can only be maintained as long as it is ensured forest renewal. Changing the type of phytocoenosis can occur if forest renewal is terminated, or new and different tree species are emerging in the undergrowth. Assessing the similarity of directly acting factors and their levels of impact on phytocoenoses is based on indirect factors: climate, topography, rocks, soil, groundwater level, the environment of the habitat, and human and animal impact (Sukachev 1972).

V. N. Sukachev proposed that the determinants of forest type were those species that determine the layering, phenology, and the presence of certain synusiae. These most important species should play an important role in the composition of each layer and its phenology. The homogeneity of the properties of a phytocoenosis that unite it into one forest type necessitates the application of the same forest management practices. The usefulness of a phytocoenosis is based on the natural and economic conditions. Sukachev proposed to use two kinds of parameters that could reveal forest units: natural-historical and economical.

Defining homogeneous forest areas based on a range of natural and historical factors was more important than defining them based on economic factors, as grouping forest parcels into management units on the basis of economic categories depended upon potentially short-term economic goals. Therefore, forest type in the interpretation of V. N. Sukachev was a natural-historical concept (Sukachev 1972), independent from the viewpoint of economic purposes.

V. N. Sukachev gives the following definition of a forest type: a type of forest is an association of forest parcels (i.e. forest ecosystems), homogeneous in composition of tree species, other vegetation levels, fauna, a range of site quality conditions (climate, soil and hydrological), the relationship between plants and the environment, forest reproduction processes, and corresponding stages of succession, and therefore requires uniform forest management practices under the same

economic conditions. A type of forest under these conditions can therefore be considered as a type of forest biogeocenosis (Sukachev 1972).

Under particular forest site quality conditions Sukachev understood the following: the area possesses a uniform set of ecological factors (climatic and soil-hydrological) affecting plant growth. However, within an area the same type of site quality conditions can support several forest types, yet at the same time, each forest type has its own specific set of soil and climatic conditions, as these are dependent upon the vegetation that is present (Sukachev 1957).

Climate, soil, and vegetation influence each other. Excluding anthropogenic factors, it is possible to identify two groups of factors that are linked to climate and soil. V. N. Sukachev believed that inclusive of all edaphic conditions, the most important in terms of the effects on plants is soil chemistry, followed by moisture and aeration. The concentrations of beneficial and harmful minerals, which effect soil acidity, are the most ecologically significant for plants out of all the chemical properties of soil. Within a homogeneous climatic zone, soil reaction is determined by the mineral composition and humidity, i.e., salt and water regimes are the predominant edaphic factors. The third important factor mentioned above, is soil oxygen supply. It depends on soil aeration, which is mostly inversely related to drainage. However, even in conditions of excessive moisture the soil can be sufficiently provided with oxygen as long as water is able to move through the soil.

A variety of combinations of these three factors for boreal forests is limited. The high relative humidity of this climate zone leads to the prevalence of wet soils and a lack of extremely dry soils. These soils are generally leached, and their nutrient status depends on their humidity and mechanical consistency. Excessive stagnant moisture in the soil leads to the formation of peaty soils with a reduced availability of nutrients. Dry soils on the other hand are leached to a lower extent, and consequently contain more nutrients.

V. N. Sukachev developed a generalized classification scheme for the combination of factors described above. This scheme is divided into four quarters (Fig. 4). The first quarter corresponds to loamy, well-drained soils. The second quarter corresponds to overflowing moist soils with an

adequate supply of nutrients and oxygen, and a neutral or acidic soil solution. The third quarter corresponds to excessively wet and poorly drained soil with a minimal amount of minerals available to plants, and a pH lower than 7. The fourth quarter corresponds to dry and well-drained soils with low acidity and good aeration (Sukachev 1972).

The understory vegetation may be a good indicator of the impact of complex direct acting factors (Cajander 1933). V. N. Sukachev suggested the use of genus names of trees and full species names of herbaceous and shrubby plants, as well as some parameters of site quality conditions, such as the structure of tree layers in a forest type name.

Sukachev's forest type classification was widely used in different regions of the Soviet Union, especially in the lowland forests of the taiga and steppe zones of the European area of Russia. Sukachev's scheme represented the creation of the final stage of a natural classification of forest types in the Russian Empire and the USSR.

Genetic avenues in forest type classifications

Large-scale industrial use of forests has led to a decrease in the area of natural forests and to an increasing role for anthropogenic forests. Classical approaches to classifying natural forest types (relatively stable and homogeneous) became insufficient for considering their anthropogenic dynamics. Consequently, natural classifications have been replaced by more sophisticated genetic classifications of forest types (Kolesnikov 1974).

The first attempt to create a genetic classification of forest types was made by B. A. Ivashkevich for the forests of the Far East of the USSR (Kolesnikov 1961, Manko 2009, 2013). However, the principles that formed the basis of the genetic approach for forest type classifications were formulated in 1905 by an unknown author under the pseudonym of "Doubting" (Smolonogov 1998). Later, research in the field of genetic typology was continued by A. S. Yablokov, A. A. Molchanov, A. K. Denisov, and V. V. Popov (Kolesnikov 1961).

The term genetic classification of forest types was introduced by B. A. Ivashkevich in 1923 (Manko 2013). The term genetic emphasizes the genesis of types of forest biogeocoenosis in this

forest typology, i.e., priority of successional changes of one biogeocoenosis over other ones (Manko 2009). In addition, the heritability of forest structure is understood at the phytocoenosis level rather than at the individual or population-genetic levels (Sannikov 2009; Sannikov et al. 2012).

The basis of the genetic approach to the classification of forest types is the concept of forest forming processes, which covers all forms of the Earth's forest cover over time (Kolesnikov 1974; Smolonogov 1995a). Forest forming processes include the well-known global processes related to the emergence, dynamics and destruction of forest vegetation under the influence of endogenous and exogenous factors (Manko 2012). The processes of development and dynamics plays a more important role in genetic forest type classifications than the homogeneity of stand composition, structure and other parameters, which are used for forest type identification in natural classifications. A forest type defined in the framework of the genetic approach is seen as a stage of the forest forming process. At the same time, morphological homogeneity of forest parcels may comprise the individual stages of the development of forest types based on the interpretation of B. A. Ivashkevich and B. P. Kolesnikov.

According to B. P. Kolesnikov, a forest forming process is expressed in the following forms of forest succession: 1) age succession, observed over a period of ontogenesis of one forest generation; 2) recovery succession, due to the strong impact of exogenous factors (fire, storm damage, forest felling, insect infestations); 3) alluvial succession; and 4) centuries-old or phylogenetic succession. The concept of indigenous and secondary forest types has existed in natural forest types classifications. However, only the genetic classification scheme includes the relationship between forest types in the form of a successional series of phytocoenoses through time.

B. P. Kolesnikov defined the following changes in phytocoenosis under a genetic scheme: naturally reversible short-term and long-term recovery successions, as well as naturally irreversible succession. After exogenous impacts on an indigenous phytocoenosis the first two types of reversible successions return it to their original type. These successions display different durations

of time intervals. Irreversible succession changes from an indigenous forest type to a stable secondary forest phytocoenosis.

Kolesnikov provided a scientific basis for the selection of the following three forest forming periods in Russia: forests existing before agricultural effects; existing forests which have been spontaneously used by humans; forests that were planned for human use (Kolesnikov 1961; Smolonogov 1995*b*). These classes allow researchers to take into account the level of anthropogenic impact on forests used in research. The use of these forest classes was due to the need to take into account specific features of forest forming processes from different eras in human history. He also developed a classification of taiga zone forests with regard to the human impacts they have been subjected to (Kolesnikov 1974). At its core, this scheme consists of three major classes: virgin forests, undisturbed forests, and modern forests.

B. P Kolesnikov (1974) gives the following definition of the forest type: forest type is defined as a stage of forest formation (biogeocoenotic, evolutionary) that takes place within the boundaries of a certain type of site condition (type of ecotope), on the territory of a particular (physical and geographical) region, over a period equal to at least one generation of forest forming species. In his opinion, the analysis of forest type should be implemented on the basis of the relatively stable parameter of the generational time of a dominant forest species, i.e., from birth to death, in an area relating to a specific type of forest site condition. Forest type in the genetic classification consists of a series of biogeocoenoses succeeding one another in time (Kolesnikov, et. al. 1974).

It should be noted that in natural classifications the forest type and forest biogeocoenosis are considered as synonyms, whereas a forest type in the genetic classification is a broader concept. Forest type in the genetic typology corresponds to the set of forest biogeocoenoses over time, i.e., the set of types of forest in the interpretation of V. N. Sukachev (Smolonogov 1998).

The genetic approach to the classification of forest types did not make natural typologies redundant, but instead completed them. Currently, the classifications of B. A. Ivashkevich–

B. P. Kolesnikov used the achievements of Sukachev's classification. Sukachev's forest types were used as stages of development for the current versions of Ivashkevich's and Kolesnikov's genetic typology. Thus, in the classification scheme of the genetic typology the duration and direction of different types of successional changes for each Kolesnikov's forest types is shown.

In the classification systems of biogeocoenosis combined with practical typologies, systematic units can be applied in the form of geographical and chorological areas (Timofeev-Resovskii 1961). This principle is also used in genetic forest typologies. For example, unlike Sukachev's phytocoenotic classification, genetic forest typologies are strictly regional (Sochava 1961; Smagin 1973). Consequently, before the creation of classification scheme for forest types, zoning territory according to the influence of complex factors on forests was the common practice. Schemes of forest types created for low-level taxonomic units were created in such a way as to facilitate this (Kolesnikov et al. 1974; Sedikh 2005; Smolonogov 1995a).

The genetic approach to the classification of forest types have only been briefly described above. To consider the principles underlying the genetic approach, annotate the findings of practitioners in this field, and to consider prospects for future developments would require a separate publication.

Dynamic avenues of research in forest type classification

Not considering the anthropogenic factors that impact on the dynamics of forests is a shortcoming of natural typologies. I. S. Melekhov proposed a forest type classification on the basis of Sukachev's typology. His point of view on what constitutes a type of forest is similar in concept to the genetic typology of B. A. Ivashkevich and B. P. Kolesnikov. He believed that the forest type should be considered in space and time, i.e., it is a stage or series of stages in the development of the forest (Harin et al. 2005; Luganskiy et al. 2010). The dynamic typology takes into account exogenous and endogenous changes in the forest, accounting for the possibility of a transition from one forest type to another, as well as the relationships between the stages within the same forest type. Successional changes on clearings are the result of regeneration changes. Regeneration of the

initial stage corresponds to the type of felling, which is determined by a combination of forest conditions, evaluated using parameters of plant associations, which depends on the original type of forest present before timber felling took place (Ulanova 2009).

I. S. Melekhov distinguishes the following stages of forest development: the stage prior to the formation of forests (types of forest felling and burnt places); the stage of forest formation; the stage of a mature forest; subsequent stages comprising new types of forests (Sennov and Griyazkin 2006). Dynamic classification—unlike the classification of B. A. Ivashkevich–B. P. Kolesnikov—is not used as a deterministic scheme for changes of forest types.

B. P. Kolesnikov believed that I. S. Melekhov's classification of types of felling and burnt forest areas (Melekhov 1961), was a special case for the classification of the initial stages of reforestation in the course of their developmental regeneration changes, or digressive stable successions, therefore Melekhov's dynamic classification can be attributed to genetic forest type classifications (Kolesnikov 1974).

Regional specificities in the use of forest type classifications in Russia

Almost all the classifications described above, with the exception of Krudener's forest typology, are currently in use in forestry and forest management in the Russian Federation and neighboring countries (former Soviet republics). In different regions of Russia, one of the classifications described above usually prevails. This is due to the following reasons: differences in the influence of environmental factors on vegetation cover; regional characteristics of forest management; the history of scientific schools in the field of forest typology (Farber 2014; Ivanov et al. 2012; Ivanova 2011; Kolesnikov 1974).

In the taiga zone, forest inventories were carried out mostly in untouched forests, so the features of undisturbed living ground cover in combination with the position of the forest parcels in the relief allowed a forester to receive an objective description of soil conditions from the beginning of data collection. Sukachev's classification is very suitable for such forests (Ivanov et al. 2012).

The classification of E. V. Alekseev and P. S. Pogrebnyak has spread in Ukraine, Belarus and in the forest-steppe regions of Russia (Senov and Griyazkin 2006). In Ukraine, forest site conditions depend to a great extent on soil fertility (Farber 2014). In addition, artificial restoration of disturbed forests after felling, fires, plowing, soil erosion, grazing, and mowing are very important tasks. Live ground cover in these forests does not represent the history of soil conditions. Under these circumstances, researchers and foresters were focused on the identification of trophic levels and soil moisture, the species composition of forest stands, and the potential for generating sustainable and productive forests (Ivanov et al. 2012).

Principles of forest classification designed for the lowland forests of the taiga and forest-steppe zones of the European part of the USSR did not give satisfactory results for the mountain multispecies mixed forests of the Manchurian botanical-geographical region of the Far East (Kolesnikov, 1956). B. A. Ivashkevich noted that the diversity of forests in even a small area of this region - about 1000 square kilometers, say - is no less than in the entire forest belt of the European part of Russia (Kolesnikov, 1956). The genetic approach to forest-type classification allowed B. A. Ivashkevich to solve this problem. He created the first genetic forest-type classification for mountain and valley forests in the Far East (Manko, 2013). His disciple and follower B. P. Kolesnikov developed Ivashkevich's ideas of the genetic approach in forest typology. They have been successfully used to create classifications of types of forest in the Urals and in the mountainous regions of Siberia, as well as classifications for cedar (pine apple) forests in the Far East.

The characteristics of the main forest type classifications in the Russian Federation are given in the table. The data in this table enables comparison of the classifications by a number of key indicators: the scope of the term "forest type", the parameters used to determine forest type, the account taken of succession dynamics and the effect of a number of anthropogenic factors, as well as the level of implementation of each classification in forest inventory and forest management practice. The table shows how approaches to forest type classification have improved.

A series of all-USSR and All-Russian meetings and conferences of forest scientists and foresters was held from the fifties to the early nineties of the twentieth century. They tried to unify their positions on the different forest-type classifications and create a single forest typology (Dyrenkov, 1989; Manko 2012; Rysin, 2009; Farber 2014). This consensus had not been reached, despite the convergence of some positions on specific issues. However, in the course of scientific discussions lasting several decades, there was a significant rapprochement of the positions of different scientific schools, allowing researchers to propose improvements and create more sophisticated forest typologies. We consider the genetic forest type classification of B. A. Ivashkevich and B. P. Kolesnikov one of the most advanced forest typologies in the Russian Federation today, one that takes account of the progress made in the area of forest type classifications.

Conclusion

Forest typology in the Russian Empire and later in the Soviet Union and the Russian Federation has gone from empirical, strictly applied classifications of forest types to theories based on a complex scientific discipline. Understandings of forest types evolved from the concept of homogeneous forest parcels in space to the concept of the forest type as a series of closely interrelated stages of forest development in time – i.e., genetic types of biogeocoenosis within a forest type. It has formed several lines of research and created the following forest type classifications: ecological or ecological-silvicultural (classifications of A. A. Krudener and E. V. Alekseev–P. S. Pogrebnyak); phytocoenotic (classification of Sukachev); genetic (classification of B. A. Ivashkevich and B. P. Kolesnikov); and dynamic (classification of I. S. Melekhov).

In the ecological and phytocenotic approaches in the field of forest typology, a type of forest is considered as spatial entity, i.e. they view forests on the basis of their homogeneity in space. Forest-type classifications based on these approaches are called natural. In E. V. Alekseev and P. S. Pogrebnyak's classification, more attention was paid to the determination of site conditions. In V.

N. Sukachev's phytocenotic classification, greater attention was paid to description of phytocoenosis components and identification of live ground cover species or other characteristics of the site conditions. Later, the Alekseev- Pogrebnnyak classification also developed in the direction of taking account of regional specifics in the growth of forest vegetation, and taking account of succession dynamics. V. N. Sukachev did a large amount of productive work on the study of successional dynamics of forest communities, but in his classification they figured, essentially, only as a number of theoretical propositions.

Forest typologies that support the view of a forest type as a spatio-temporal entity are called genetic. This term is used because in these typologies genesis and the similarity of the processes of forest development have priority over homogeneity (morphological uniformity) of forest parcels. The forest-type classifications of B. A. Ivashkevich and B. P. Kolesnikov, and the dynamic classification of I. S. Melekhov, meet these requirements. A number of significant shortcomings of natural typologies were eliminated in genetic and dynamic typologies. This applies above all to the account taken of recovery and age succession in the forest, as well as to the impact of some anthropogenic factors.

The development of forest typologies in Russia, which took place within a broad scientific discussion, is an example of a harmonization process encouraging the development of forest type classifications within the main directions of forest typological research. The harmonization of national forest inventory systems at the level of criteria and indicators for sustainable forest management should also take place in the context of broad international discussions. It will enable a better understanding of the features of national forest inventory systems used in different countries, and enable individual countries to adopt the most advanced features of equivalents in other countries when improving their own forest inventory and management systems.

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Part A (categories for different moisture and aeration levels of soil substrates)			I – types of upland meadow terraces					II – gallery and inundated types				III – types as a result of gradually developing bogging processes							
	1	hygrometric group																	
	2	mineral rock and upper soil horizons																	
	3	degree and nature of soil moisture, drainage																	
	4	nature of upper soil horizon																	
	5	aeration of soil																	
Part B (categories of single or two-layered soil substrates)	n	petrographic, physical-mechanical group (soil substrate)	combination of types A+Bn	1	2	3	4	5	6	7a	7b	8	9	10	11	12	13	14	15
	1	single-layer soil substrates: sand (pine forest type – bor)	-	fresh non-raw humus bor	fresh raw humus bor	sodden raw humus bor	sodden non-raw humus bor	oaty bor					podborie (wet subor)		-			bor over a bog	wet bor
	2	loamy sand (pine-fir forest type – subor)	-	fresh non-raw humus subor	fresh raw humus subor	sodden raw humus subor	sodden non-raw humus subor	oaty subor					podborie (wet subor)		-			subor over a bog	wet subor
	3	loam (dark coniferous forest – ramen)	-	fresh non-raw humus ramen	fresh raw humus ramen	sodden raw humus ramen	sodden non-raw humus ramen	oaty ramen					po-drameni e (wet ramen)		sagra (swamp subor)			ramen over a bog	wet ramen
	4	double-layered soil substrates : shallow sandy deposits with layer capacity up to 1.07 meters, underlaid by clay – shallow pine forest (bor) or pine-fir forest (subor) on the clay substrate (Mixed spruce forest type – suramen)	-	fresh non-raw humus suramen	fresh raw humus suramen	sodden raw humus suramen	sodden non-raw humus suramen	oaty suramen					see above		-			suramen over a bog	wet suramen
	5	shallow sandy deposits with layer capacity up to 1.07 meters, underlaid by stony deposits – shallow pine forest (bor) or pine-fir forest (subor) on the stony substrate	-	see above	see above	see above	see above	see above					see above		-			see above	see above
	6	shallow loamy (clay) deposits with layer capacity up to 1.07 meters, underlaid by stony deposits – shallow spruce forest (ramen) on the stony substrate	-	see above	see above	see above	see above	see above					see above		-			see above	see above
	7	shallow loamy (clay) deposits with layer capacity up to 1.07 meters, underlaid by sandy deposits – shallow spruce forest (ramen) on the sandy substratum	-	see above	see above	see above	see above	see above					see above		-			see above	See above

Fig. 1. Generalized scheme of Krudener's classification table of types of habitat conditions and forest types (Krudener, 1916). The figure is an irregular grid comprising cells of different sizes. Owing to the large size of Krudener's original table, we have left the upper part un-filled. These cells are colored gray, and their contents are shown in Fig. 2.

296x209mm (200 x 200 DPI)

Part A (type of different moisture and air accessibility levels of soil substrates)	1	hygrometric group	I								II								III																	
			types of upland meadow terraces																types as a result of gradually developing bogging process																	
			with a stable moisture regime																with a constant nature of moistening																	
			flood-free areas																																	
			mineral substrate with different degree of podsolization																																	
2	mineral rock and upper soil horizons	mineral substrate with different degree of podsolization																mineral substrates with expressed podsolization																		
																		for upper soil horizons																		
																		humus and peat																		
																		continuously wet conditions																		
3	degree and nature of soil moisture, drainage	moderate moistening with good drainage (fresh conditions)				little excessive moistening with an impeded drainage (sodden conditions)								continuous excessive moistening with a bad drainage (constantly crude conditions)				constantly wet conditions																		
														with a weak constant water run-off																						
4	nature of upper soil horizon	with upper soil layer																raw humus and peat below it with a thickness up to 0.35 meter								humus and peat below it with a thickness up to 0.7 meter										
		raw humus				raw humus																														
5	aeration of soil	row air access into the soil				row air access into the soil is less than in 3)								without air access into the soil				low or inhibited air access into the soil																		
n	petrographic, physical-mechanical group (soil substrate)	combination of types A+Bn	1	2	3	4	5	6	7a	7b	8	9	10	11	12	13	14	15																		
3	single-layer soil substrate:																		podrumenie (wet ramen)																	
	Loam (dark coniferous forest – ramen)		fresh raw biomass ramen				moist raw humus ramen												sogra (swamp suber – wet pine forest with foliage species)

fresh ramen on the plane elevated land moist ramen on the lowland podrumenie sogra																																				

Fig. 2. The upper part of Krudener's (1916) classification table of types of habitat conditions and forest types, corresponding to the cells colored gray in Fig. 1. The schematic indicating the position of the forest types in the relief is shown at the bottom.

297x210mm (200 x 200 DPI)

Fig. 3. Pogrebniyak's (1955) edaphic grid of types of habitat conditions and forest types: the range of trophic groups is plotted on the horizontal axis, and groups of soil moisture on the vertical axis.

297x420mm (300 x 300 DPI)

Fig. 4. The coordinate system of the generalized scheme of Sukachev's (1972) forest types classification. I - loamy, well-drained soil. II - soil with excessive moisture from flowing water, an adequate supply of nutrients and oxygen, and a neutral or acidic reaction of soil solution. III - excessively wet, poorly drained soil with a small amount of nutrients, pH < 7. IV - well-drained dry soils, low in nutrients, with low acidity and sufficient aeration. Series of forest types: Ox - Oxalidososa, M - Myrtillosa, Pl - Polytrichosa, Til - Tiliososa, Q - Quercetososa, Sph - Sphagnosa, V - Vacciniososa, Cl - Cladinosa, Ft - Fontinales, Sph.p - Sphagneta pinosa, Cr - Calcarela et Cretacea.

253x226mm (72 x 72 DPI)

Table

Comparison of features of main forest typologies in the Russian Federation

Feature	Forest type classification and author(s)			
	Ecological or ecological-silvicultural classification (E. V. Alekseev and P. S. Pogrebniyak)	Phytocoenotic classification (V. N. Sukachev)	Genetic classification (B. A. Ivashkevich and B. P. Kolesnikov)	Dynamic classification (I. S. Melekhov)
Scope of the term "forest type"	Forest type is a set of forest areas similar in soil, hydrological and climatic conditions taking into account the historical factor. It is defined according to type of forest site conditions (TFSC). Interpretations of the scope of forest type have varied over time: from the TFSC to the set of forest biogeocenoses considered within the type of forest site conditions. In practice, this typology has been widely adopted in regions where the TFSC corresponds to a certain type of forest stand; therefore, to determine the forest type, it suffices to determine the TFSC by means of an edaphic grid. Only 24 types of forest site conditions can be defined within this grid.	The type of forest is a type of forest biogeocenosis. There is no limit on the number of forest types that can be identified.	Forest type is a series of closely related types of forest phytocoenosis within the type of forest site conditions, i.e. a series of types of forest biogeocoenosis replacing each other over time. The scope of the term "forest type" is broader than in Sukachev's classification. There is no limit on the number of forest types that can be identified.	The scope of the term "forest type" corresponds to Sukachev's classification, with the addition of the stages of development of forest vegetation: types of felling and types of burnt forest area. Possibility of one forest type changing to another also added. There are no restrictions on the number of forest types that can be identified.
Forest type boundary	Along boundaries of type of forest site conditions for forest-covered and uncovered areas	Along boundaries of forest phytocoenosis only for forest-covered areas, taking into account the type of forest site conditions	Along boundaries of forest phytocoenosis only for forest-covered areas, taking into account the type of forest site conditions	Along boundaries of forest phytocoenosis for forest-covered and uncovered areas, taking account of the type of forest site conditions

Classification features used to determine the type of forest site conditions	Underlying rocks and soil (type, mechanical composition, trophicity, moisture)	Direct factors (trophicity, moistening and aeration of soil) are estimated by indirect indicators: species of live ground cover, position in relief and hydrological regime	Altitude (altitude class) for mountain areas or regional complex of forest growth conditions for plain areas; hydrological regime, topography and soils. Regionalization of territory according to forest growth conditions in genetic classification is the strictest and most elegant of the typologies presented	As in V. N. Sukachov's classification
Classification features of phytocenosis used to determine forest type	Composition of the stand within the forest site conditions, taking into account the demand of plant species for soil trophicity and soil moisture	Composition of the tree stand, indicators of living ground cover, silvicultural and taxation characteristics, bonitet; forest renewal	Uses the classification features of Sukachev's typology for forest-covered areas and the dominants of the living ground cover for non-covered sites by forest	Uses the classification features of Sukachev's typology for forest-covered areas and the dominants of the living ground cover for non-covered sites by forest
Account taken of successional dynamics	Generally, at the level of theoretical statements	Generally, at the level of theoretical statements	Both at the level of theoretical statements and in classification schemes for practical use in forest inventory and forest management. Age and recovery succession are presented in the form of a series of possible types of phytocenosis, replacing each other in time, within the specific type of forest site conditions.	Typologies of felling and burnt areas as stage of recovery dynamics preceding the formation of a forest type are developed. Transition from one forest type to another for forest-covered areas is provided for at the level of theoretical propositions
Account taken of impact of	At the level of theoretical statements for direct anthropogenic impacts;	At the level of theoretical statements for direct	Both at the level of theoretical statements, and in	Both at the level of theoretical statements and

anthropogenic factors	indirect impacts are not taken into account	anthropogenic impacts; indirect impacts are not taken into account	the classification schemes for types of cutting (with or without burning wood residues) developed for use in forest inventory and forest management; indirect impacts are not taken into account	for practical use (classification of types of felling and burnt areas); indirect impacts are not taken into account
Level of implementation in forest inventory and forest management practice; regions of implementation in the Russian Federation	Moderate (some southern regions of the Russian Federation)	Very high (European part of the Russian Federation; regions of Western and Eastern Siberia)	High (Far East, Urals, some regions of the European part of the Russian Federation, some regions of Western Siberia)	Limited use as a supplement to V. N. Sukachev's classification