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DEVELOPMENT OF THE DATABASE "FOREST VEGETATION OF NORTHERN EURASIA" AT THE CENTER FOR FOREST ECOLOGY AND PRODUCTIVITY OF THE RUSSIAN ACADEMY OF SCIENCES

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The formation of databases of digitized vegetation relevés and the publication of content about them promote cooperation between researchers in solving problems of biodiversity analysis, the exchange of the used data, and, thus, the increase in research representativeness. The article is devoted to the review of the origin and use of the database of relevés of forest vegetation and considers the tasks in which it is used. The current stage of work is characterized as follows: improvement of the database structure, features of the stored information, replenishment of the database, issues of administration, and cooperation organization. Based on the analysis of current trends in the vegetation science and taking into account the features of information stored in the database, the relevant scientific problems, for the solution of which the use of the database is promising, and technical tasks that need to be solved to ensure its continued use were formulated.

Key words: *boreal and hemiboreal forests, vegetation relevés, electronic database, forest vegetation classification, biodiversity analysis*

The formation of databases of digitized vegetation relevés is one of the important aspects of work in the modern vegetation sciences (Mucina, van der Maarel, 1989; Mucina et al., 1993; Matveeva, 2008; Schaminée et al., 2009; Golub, 2011; Dengler et al., 2011; Chytrý et al., 2016; Bruelheide et al., 2019). It expands opportunities to analyze the structure of phytodiversity (at the coenotic and taxonomic levels) and to identify spatial, ecological, and chronological patterns in it, as well as to estimate the environmental significance of various plants. The publication of information on existing databases of vegetation relevés promotes cooperation between researchers and the development of more informed solutions to these problems, by increasing the representativeness of the used data.

Since the opening of the new institute of the Russian Academy of Sciences (1991) – the Center for Forest Ecology and Productivity (hereinafter – CEPF RAS), its employees have been involved in the creation of an electronic database of forest-vegetation relevés, including data from European Russia and neighboring territories (Khanina et al., 1991; Zaugol'nova, Khanina, 1996; Smirnova et al., 2006) The general structure of the database was developed in cooperation with

the institutions of the Pushchino Scientific Center of the Russian Academy of Sciences: the Institute of Mathematical Problems of Biology (IMPB of RAS; now a branch of the Keldysh Institute of Applied Mathematics of RAS) and the Institute of Physicochemical and Biological Problems of Soil Sciences of RAS (IPCBPSS of RAS, now a separate division of the Pushchino Scientific Center for biological research of RAS) in the early 1990s. It included 2 data tables and some reference lists (lookup tables) to fill in some fields in the data tables. The GBDSp data table was intended for storing lists of species with values of their projective cover (by the scale of Josias Braun-Blanquet, see below) in different layers of the forest community. The separate fields of this table also indicated the phenological states, the features of the species positions in the community, and the values of heights and diameters for tree species. For the unified input of species names, a coded reference list of Latin names of vascular plants and bryophytes (Komarov et al., 1991; Zaugol'nova, Khanina, 1996; Khanina et al., 1999; Balandin et al., 2000) was developed and linked to the corresponding field of the table, compiled based on current nomenclature reports (Cherepanov, 1995; Ignatov, Afonina, 1992). The GBDescr data table was intended for storing general information about the implementation of relevés (place and date, author, size of the inspected area) and characteristics of ecotopes (position in relief, moisture regime, and soil texture, nature of microrelief, presence, and nature of traces of land-use, etc.) and layers in forest communities (total projective cover). For the unified filling in of fields with ecotope characteristics in this table, reference lists were also used: coded reference lists of terms most commonly used in relevés of plain forests.

The database was implemented in the database management system (DBMS) Data Ease for the MS-DOS operating system (OS) (Khanina, 1997), which supported a specific data storage format. This DBMS allowed creating, storing, and, if necessary, combining many separate sets of relevés with each other, developing procedures for performing routine operations with relevés: for example, calculating various aggregated indicators or exporting data to formats used by other MS-DOS programs. The relevé database interface included two forms for entering and viewing data corresponding to the two main tables. The reference block of the relevé database was gradually supplemented with tables with the characteristics of plant species: points in ecological scales (Vorobiev, 1953; Ramensky et al., 1956; Tsyganov, 1983; Ellenberg, 1974, 1995; Landolt, 1977), information about the types of ecological strategies (Grime et al., 1988), and belonging to ecological-coenotic groups of plant species (Smirnova et al., 2004; Smirnov et al., 2006; Smirnov, 2007). In this regard, the database interface was also supplemented with procedures for calculating the spectra of relevés by the composition of ecological and ecological-coenotic groups, and types of strategies. To calculate the estimates of relevés in environmental scales, data was exported to the text format with field separators (Comma Separated Value – CSV) and transferred to a specialized external program Ecoscale (Grokhlina, Khanina, 2006).

A large number of relevés in the 1990s and early 2000s were collected in cooperation with the Department of System Ecology of Pushchino State Institute of Natural Science. Master's degree students and postgraduates of the department were trained in methods of geobotanical research, by participating in expeditions under the leadership of the staff of the CEPF RAS, Doctor in Biological Sciences O. Smirnova, and Doctor in Biological Sciences L. Zaugol'nova, and then in the work on entering into the database the relevés made in the expeditions, under the guidance of the database administrator – an

employee of the IMPB of RAS, PhD L. Khanina. For several years, geobotanical research was also carried out together with the Department of Biology of the Institute of Natural sciences and Pharmacy of the Mari El State University and the Department of Geobotany of the Faculty of Biology of the Moscow State University. At the CEPF RAS, the database on the Data Ease DBMS platform was used by PhD students and other employees to work with their vegetation relevés. Based on accumulated relevés and using lookup tables and base procedures, the analysis of the ecology of the species (Smirnova et al., 2004; Smirnov et al., 2006; Smirnov, 2007) and plant communities (Smirnova et al., 1997; Zaugol'nova, 1999; Zaugol'nova et al., 1998, 2000a, b; Evaluation of..., 2000; Smirnova, Korotkov, 2001; Zaugol'nova, Bekmansurov, 2004; Smirnova et al., 2006; European..., 2017, Smirnova et al., 2018; Khanina, 2019) was conducted. An important part of the analysis of the relevés was their use in the development of the classification of forest vegetation in European Russia and the Urals based on different approaches: ecological-floristic (Zaugol'nova, Morozova, 2004a, b; Morozova et al., 2008; Zaugol'nova et al., 2009) and ecological-coenotic (Zaugol'nova, Morozova, 2006; Zaugol'nova, 2006-2010; Zaugol'nova, Martynenko, 2012).

One of the incentives for Russian phytocenologists to use electronic databases was the international school on the basics of working with the Turboveg DBMS (Hennekens, 1995), developed by Stephan Hennekens, an employee of the Institut voor Bos en Natuur (Wageningen the Netherlands), held in Ufa (Republic of Bashkortostan, Russia) in 1997. At that time, the Turboveg DBMS was adopted by the international working group European Vegetation Survey as a standard for maintaining vegetation databases and data exchange (Schaminée, Hennekens, 1995; Schaminée et al., 2009). The school was held based on the Bashkir State University together with the University of Lancaster (United Kingdom of Great Britain); E. Tikhonova, one of the authors of this article, took part in the work of this school. Due to the agreement of the Turboveg developer and the Institut voor Bos en Natuur (Wageningen the Netherlands), there was a practice of the free distribution of this DBMS in the countries of the former USSR for scientific and educational purposes, as a result of which, the CEPF RAS began to use it as well.

The widespread adoption of Windows OS and programs written for it with graphical interfaces that provide the average user with procedures for solving a wide range of routine tasks has led to the emergence of a user community who prefer working with data in such programs. An important step in the development of electronic databases of vegetation relevés was the release of the Windows version of the Turboveg DBMS (Hennekens, Schaminée, 2001). In the 2000s, phytocenologists of the CEPF RAS used the Turboveg and MS Access DBMS developed for Windows, and in parallel converted most of the old sets of relevés from the Data Ease format to the text format with field separators (csv or txt formats).

The purpose of this paper is to present the prospects for further development of the database and plans for its use, based on what has been done from the beginning of the 2000s to the present.

MATERIALS AND METHODS

To write this article, the authors discussed and summarized the accumulated experience of working with the database of vegetation relevés of the CEPF RAS and improving its structure, compiled a description of its current content, analyzed scientific publications on the trends in the development and application of electronic databases of vegetation relevés in Russia and abroad, and current problems of vegetation science.

RESULTS

Since the late 1990s, collecting of relevés in field expeditions has been carried out by PhD students and employees of the CEPF RAS. Since the beginning of the 2000s, in the preparation of the monograph "Eastern European Forests: Holocene history and modernity" (2004) and electronic resources "Forest coenofond within European Russia" (Zaugol'nova, 2006–2010) and "Guide on forest types in European Russia" (Zaugol'nova, Martynenko, 2012), the base has also been expanded with digitized relevés and summary tables, relevés of various publications (see the list in Supplementary materials).

For use in expeditions, a geobotanical relevé form has been composed (Methodological..., 2010: pp. 358-363), which allows formalizing and unifying the characteristics of the conditions in which the community grows. When composing this form, the agreement of the form sections with the relevé database fields was conducted: refined and enhanced base reference lists characterizing the conditions in which the forest community is growing was included in the form as the options of filling, from which it is possible to choose and mark the most appropriate ones. Due to the wide variety of characteristics of conditions that occur in nature, for many of them, some additional fields (in the format of the text of unlimited size) for filling in unformalized notes were created in the database, along with the field associated with the reference list and filled in with standard values.

In the reference list of flora associated with the field of species names in the database table, the nomenclature of bryophytes was updated based on more modern Russian checklists (Ignatov et al., 2006; Konstantinova et al., 2009), and the list of lichens was expanded (Urbanavichjus, Urbanavichene, 2004). To speed up the verification and unification of the nomenclature of species in different sets of relevés, the SpeDiv program is used (Smirnov, 2006), in which it is also possible to calculate the characteristics of the species diversity of relevés, their spectra of ecological-coenottic groups and estimates in various ecological scales.

In 2014, the CEPF RAS registered a database of vegetation relevés in the state Register of Databases under the name "Forest Vegetation of Northern Eurasia" (registration certificate No. 2014620258 dated February 12, 2014; Zaugol'nova et al., 2014). The use of the database is regulated by the approved Regulation on the Bank of forest-vegetation data (phyto-database) of the CEPF RAS. The principles of use are similar to those adopted in the European Vegetation Archive (EVA; Chytrý et al., 2016). To receive relevés, researchers must submit an application to the database administrator, describing the purpose and methods of the planned study, the timing of its implementation, the list of participants, publications that are planned to be prepared based on its results, the total amount of data that will be involved in the analysis, and the characteristics of the requested relevés. The administrator, if the authors of the relevant relevés agree to the transfer, will arrange for the conclusion of an agreement on creative cooperation of the applicants with the CEPF RAS. The relevés are provided for use free of charge, but only for the specified period of execution of the claimed research, in other words, they should not be used after this time and/or for other purposes, and should not be transferred to persons who do not participate in the claimed research. In addition, a mandatory condition for use is the reference of applicants when publishing the results of their research to the CEPF RAS database and the publications of the authors of relevés about the collecting or previous analysis of the same data.

Currently (4Q of 2020), the database contains 5,467 primary relevés, among which 59.4% are original (collected by the CEPF RAS team on expeditions; approximately 200 of these relevés were published afterward) and

40.6% are digitized from Russian and foreign publications of 1928–2012 (about a 16% of the digitized relevés duplicate the contents of other databases known to the authors). Relevés are grouped into sets according to geographical and chronological principles: usually, a set contains materials from one expedition or one publication. The register of relevé sets and the Regulation on the database of relevés are available on the website of the CEPF RAS (URL: http://cepl.rssi.ru/rid-2/). Applications for the use of the database materials can be sent to its administrator Braslavskaya (*t.braslavskaya@gmail.com*). When preparing the files for sending, the applicants' wishes about the format are taken into account.

The geographical coverage of the database is represented by the diagrams in the figure. Shown in the legend as a generalized category, the regions of the European part of Russia include Arkhangelsk, Bryansk, Vladimir, Voronezh, Leningrad, Murmansk, Novgorod, Smolensk, Tver, and Yaroslavl Regions, and the Republics of Tatarstan and Udmurtia (each of these regions is presented by less than 3% of the relevés); regions of West Siberia – Tyumen, Krasnoyarsk Territory, Khanty-Mansi and Yamal-Nenets Autonomous Districts. Geographical coordinates were determined by researchers using GPS navigators for 43.6% of the relevés. For 7.7% of the relevés digitized from publications, the coordinates are defined using topographic maps or electronic maps of Google and Yandex (positional accuracy ranged from 1–2 up to 20–30 km). For the rest of the relevés, the coordinates are not specified yet. Fifty-one percent of the relevés contained in the database are made on an accounting area of 100 m^2, 42.1% – on an area of more than 100 m^2, 2.7% – on an area of fewer than 100 m^2; for 4.2% of the relevés, the accounting area is not known (the latter category includes only relevés from publications). Surface slope and its exposition are specified in 25% of the relevés, verbal description of the relief position is given for 16.1% of the relevés; the presence of bare rock or water on the surface is mentioned for less than 1% of the relevés. Information about the texture and/or other characteristics of the soil are given for less than 2% of the relevés, traces of fires, and/or current or past land-use are given for 8.9%.

Researchers and PhD students of the CEPF RAS characterized the participation of species in each layer of the community with values of the projective coverage on the scale of J. Braun-Blanquet (1964): r and + – less than 1%, 1 – 1–5%, 2 – 6–25%, 3 – 26–50%, 4 – 50–75%, 5 – more than 75%. In national publications that appeared before the 1990s, the participation of species is often indicated values of abundance on the scale of O. Drude in the interpretation of V. Sukachev (1972): un (unicus) – one each, sol (solitarius) – in small quantity, sp (sparsus) – small participation (species cover less than 5% of the area), cop (copiosus) – abundantly (big participation: species cover 5% of the area and more) distinguishing the increasing gradations cop1, cop2, and cop3, soc (socialis) – forms a solid background. Researchers of the Komarov Botanical Institute also used a scale with points from 1 to 6 in their relevés (Korchagin, 1940: p. 35). During digitizing, the authors' values of species abundance in the published old relevés were transferred into values of the Braun-Blanquet scale, taking into account the expertise, resulting from the study of the woods with a similar geographic location and species composition, and the coverage of the respective layer. At that, database executors tried to save information about various types of the origin abundance values in files that have a text format with separators. The lists of identified bryophytes and lichens are given in 53.8% of the relevés. Information about the height and/or diameter of trees – in 14.3%, the age of trees – in 9.3% of the relevés; characteristics of the horizontal structure of the crown cover canopy – in less than 1% of the relevés.

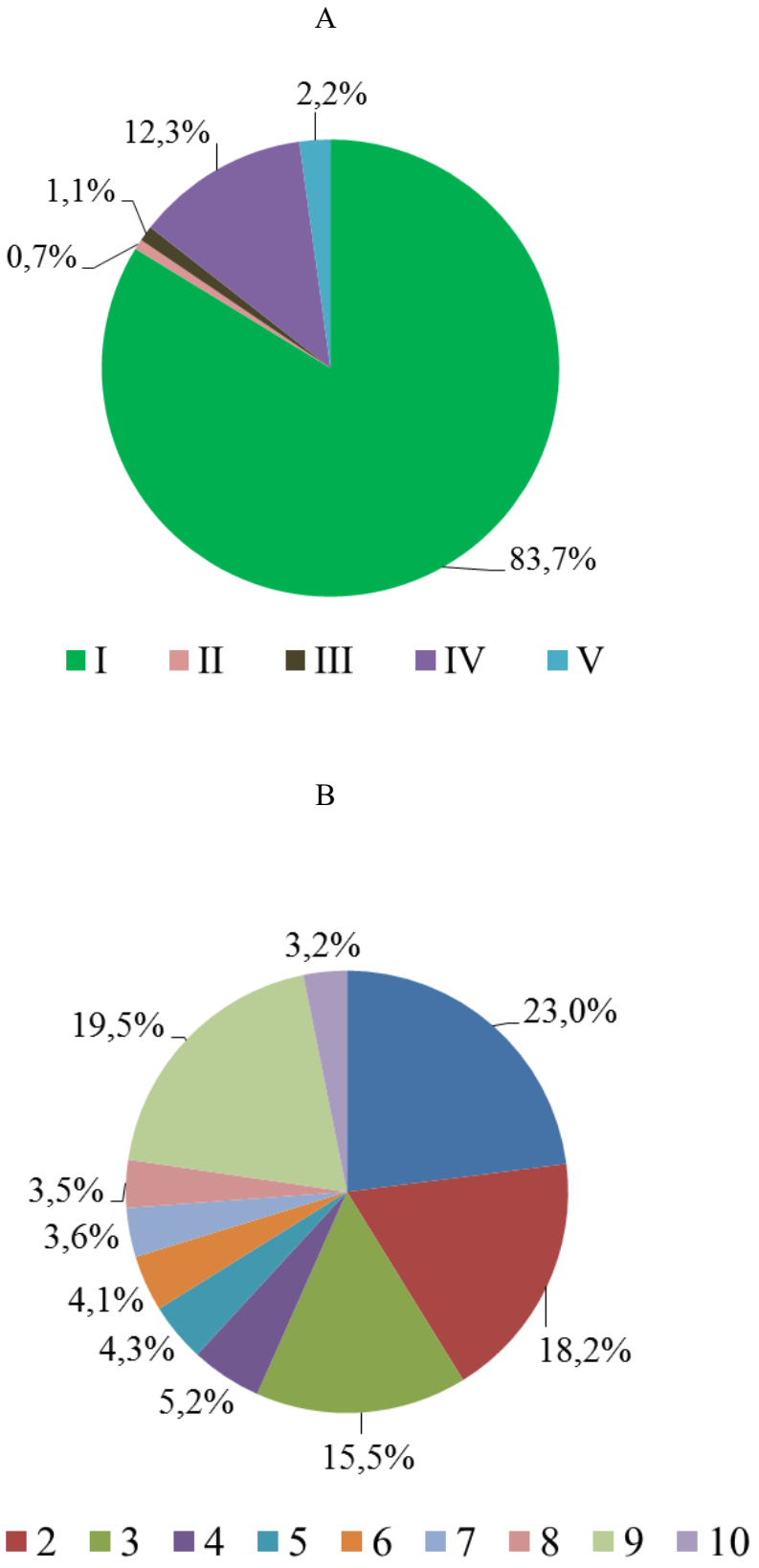

Figure. The geographical data structure in the database "Forest Vegetation of Northern Eurasia". A – distribution by country (I – Russia, II – Ukraine, III – Latvia, IV – Poland, V – Norway). B – distribution by regions of Russia (regions: 1 – Moscow, 3 – Kostroma, 4 – Sverdlovsk, 6 – Vologda, 7 – Perm, 8 – Kirov; republics: 2 – Komi, 5 – Karelia; 9 – other regions of the European part of Russia, 10 – regions of West Siberia)

The development of the Turboveg DBMS contributed to the international cooperation of phytocenologists of the CEPF RAS – participation, together with other Russian phytocenologists, in the creation of the European Boreal Forest Vegetation Database (EBFVD), included in the Global Index of Vegetation Databases (GIVD; Dengler et al., 2011) and EVA (Jašková et al., 2020): identifier EU-00-27. As a result of the work done for this purpose, the fraction of relevés of the "Forest Vegetation of Northern Eurasia" database uploaded to the Turboveg DBMS was increased to 50.6%. The primary objective of creating the EBFVD is the development of a harmonized classification of boreal forests in Europe based on an ecological and floral approach.

DISCUSSION

In the initial period of computer use in the analysis of vegetation relevés, it was necessary to simultaneously form databases of the relevés themselves and reference databases for the species found in the relevés (their nomenclature and various characteristics). At the same time, many simple algorithms for analyzing relevés, such as calculating summaries of species diversity or indices based on species characteristics, could be implemented directly in the DBMS interfaces; the development of such tools in databases was considered an important aspect of work (Zaugol'nova, Khanina, 1996). However, different types of multivariate relevé analysis were usually required to be conducted in the specialized programs (Novakovsky, 2006), for example, PCOrd (McCune et al., 2002), Juice (Tichý, 2002), vegan (Oksanen et al., 2013), implementing the stable operation of complex algorithms. After a while, it has also been found useful to combine algorithms for calculating more and more diverse biodiversity indices in specialized programs, such as PAST (Hammer et al., 2001). As a result, an important advantage of database interfaces was not the presence of "built-in" algorithms for any calculations but a variety of automated data layout procedures, including export to specific formats of external programs. This trend was evident when working with a base of vegetation relevés of the CEPF RAS in Windows OS: the calculation of characteristics in the species diversity of the relevés and their spectra of ecological-coenotic groups, as well as estimates of relevés in different ecological scales, began to be conducted in the program SpeDiv (Smirnov, 2006). The program loads lists of species from vegetation relevés in the format of an inflated table, to which they can be exported from various DBMSs. The reference lists used by the SpeDiv program with estimates of plant species in ecological scales and an indication of species belonging to ecological and coenotic groups are the same as in the EcoscaleWin program (Zubkova et al., 2008; Khanina et al., 2014) – the version of Ecoscale modified for Windows.

During the work with vegetation data in the DBMS Data Ease, the task of the storing results of plant-population studies in the database has a small priority, although originally it was planned (Zaugol'nova et al., 1993; Zaugol'nova, Khanina, 1996). When working in the MS Access DBMS, a separate table and reference lists of ontogenetic stages and levels of vitality associated with its fields were developed. Due to the need to combine different types of data in the database (vegetation relevés and the results of population records), the relationships between them were analyzed and a more complex hierarchical structure of the database was developed: information about the geographical tagging of all research points was placed in a separate table – the register of places. Each entry in the register of places is

linked to entries from a subordinate table – the register (list) of accounting sites; sites related to the same place may differ in size and the nature of the research conducted on them (Methodological ..., 2010). This improvement of the database is possible due to the simple ways provided to the average user by the MS Access DBMS interface, to configure the database structure flexibly including a different number of tables in it and selecting their connecting fields independently. However, to automate many operations that are necessary for working with relevés (for example, exporting to the formats of widely used programs that perform geobotanical data analysis), the procedures that are specially programmed by the user are necessary, and the programming tools built into MS Access do not work consistently enough.

The Turboveg DBMS (Hennekens, Schaminee, 2001) is specialized for working with geobotanical data; therefore, it has been widely used internationally (Schaminée, Hennekens, 1995; Schaminée et al., 2009). To a large extent, it is provided since some parameters of the database structure are rigidly fixed and cannot be changed by an average user. Thus, there can be only two main data tables (a relevé register and an inflated table of species list), reference lists for filling in are provided only in a few standard fields of these tables, and the user cannot change the content of most reference lists. At the same time, several versions of the flora species list are supported, corresponding to the traditions of geobotanical research in different countries, including a version for use in Russia and the former USSR countries, recently updated for the second time (Korablev et al., 2020). The user also has the opportunity to create additional fields of different formats in both data tables so that researchers can preserve any special traditions of performing relevés that they consider important for themselves, and enter this non-standard information into the database. Turboveg serves as a good illustration of the trend towards distinguishing between purely technical data operations and data analysis tools. This DBMS has conveniently automated routine operations of import and manual input of relevés, their storage, layouts, and export to the formats of specialized programs for statistical analysis and classification; the set of implemented procedures is updated periodically in the new versions of the program.

During the further work with the "Forest Vegetation of Northern Eurasia" database, the conversion of various sets of relevés to the Turboveg DBMS format will continue. At the same time, many years of administration experience show that it is necessary to provide for a forced change of the DBMS in connection, for example, with the mass introduction of other operating systems and/or changes in the policy of developers. Thereby, first, storing backups of all sets of relevés and all reference reference lists in the form of the file system in text format with the field separator (csv, txt), allowing the use of data at any event, is still relevant. Second, it requires cooperation with programmers in the development of new specialized DBMS for solving geobotanical problems, taking into account the accumulated experience.

Currently, the main area of using the relevés stored in the database "Forest Vegetation of Northern Eurasia" can be the classification of forest vegetation (mainly North and East European), mapping the areas of its syntaxons. Both of these tasks are still far from a satisfactory solution (Plugatar et al., 2020). The general context in which they are addressed is the analysis of geographical patterns in the biodiversity structure. To do this, it is possible to consider the variation of the values in various indexes calculated based on the species composition of relevés, and in such tasks, the database materials can also be used. Phytocenologists of the CEPF RAS plan

to conduct research on these topics independently and participate in them as much as possible, including, as necessary and possible, field research to collect new relevés.

The above summary of the characteristics of ecotopes (the position in the relief, information about the soils, the mode of land-use) shows that the database contains not much information about the conditions in which the studied forests grew. The spatial (by geographical coordinates) linking of the places where relevés were executed with the attribute information of various digitized thematic maps and zonation schemes, as well as spatial digital models of certain landscape components, can help to fill in the missing information to some extent. To do this, it is planned, first, to conduct a targeted search for such thematic map data sources of information about the regions of European Russia and neighboring territories, and, second, to continue determining geographical coordinates for relevés made without the use of GPS navigators but containing detailed information about the georeference. The information on ecotopes obtained in this way, subjected to a thorough expert assessment of its accuracy, can be used in the regional and interregional comparative analysis of biodiversity.

CONCLUSION

The base of vegetation relevés of the CEPF RAS was created and actively used to solve various problems in the study of ecology and geography of plant species and plant communities, the patterns of biodiversity of the forest cover of Northern Eurasia. The accumulated data is still in demand in Russian and international geobotanical research; steps are being taken to organize wider cooperation in the use of this data. Due to the passage of time, their importance may increase if the geographically, environmentally, and chronologically systematic collection of new data and the improvement of tools for technical work with them continue.

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Supplementary materials

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