

**СЕЛЕКЦІЯ, ДЕНДРОЛОГІЯ**

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**APPLICATION OF GIS TECHNOLOGIES FOR ACCOUNTING PLUS TREES**

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The article presents the results of one of the work stages to create a database of tree improvement units of forest species in Ukraine. The stage concerns the accounting of plus trees. The study aimed to improve the ordering of the information on plus trees, their accounting, survey, and use as tree improvement units. The improvement was made using free software (Python, JavaScript) and a relational PostgreSQL database with the PostGIS module. Based on the methodology of plus trees database development, instructions for using the software were compiled. A webpage that displays information on plus trees, including their location on subcompartments was created. The webpage provides also summary information on plus trees in a certain Forest Enterprise or region, upon request. At present, the database contains information on plus trees in seven regions (Kharkiv, Poltava, Sumy, Dnipro, Zaporizhzhia, Luhansk, and Donetsk), which is about 25% of the country's plus tree stock.

**Key words:** forest genetic resources, database, portal, webpage, tree improvement units.

**Introduction.** The source base for the seed orchards' creation are plus trees, the selection of which in natural and artificial stands was started in the 40s of the last century in Sweden (Romeder & Shenbakh 1962). Nowadays, the use of reproductive material of plus trees has become an integral part of forest seed production in many countries of the world (Baliuckas 2004, Rosvall et al. 2011, Nakada 2022).

In Ukraine, works on the selection, propagation, and testing of plus trees began in the 1950s under the leadership of S. S. Piatnitskyi and became widespread in the early 1970s. At that time, scientists of the tree improvement laboratory and research branches of Ukrainian Research Institute of Forestry and Forest Melioration (URIFFM), together with employees of forestry enterprises, selected about four thousand plus trees of 34 species (Davydova 1967, Piatnytskyi 1967, Molotkov et al. 1982). Later, when implementing the Forestry Seed Production Development Programme for 2010-2015, additional selection of plus trees was carried out (Los et al. 2015). Currently, about 5,000 plus trees are registered by the Ukrainian Forest Seed Centre (UFSC).

Nowadays, an area of forest genetic resources (FGR) conservation activity is the systematization of information on gene pool conservation units in electronic databases. At the same time, it should be noted that the existing international databases mainly relate only to units represented by populations (stands), which are visualized as polygons on the map. For example, one of the first computerized information systems on forest tree improvement units was created in Denmark in 1974. Later, Norway, Sweden, and Finland implemented the Danish system, and in early 1979, a joint Scandinavian research project was launched to develop and coordinate Nordic forest tree improvement information systems (Ditlevsen 1979). Currently, in Europe, the EUFGIS (the European Information System on Forest Genetic Resources) (EUFGIS 2023) under the auspices of EUFORGEN (European Forest Genetic Resources Programme) (EUFORGEN 2023), in which Ukraine also participates, serves as a documentation platform linking national forest genetic resources (FGR) inventories (Neyko et al. 2019). This information system provides cartographic information on the conservation of forest genetic resources in Europe and access to detailed data on genetic conservation units of forest tree species in different countries. However, in this case, we are talking only about forest stands or areas where populations of tree species with a national conservation status are concentrated. Equally important is to process information for plus trees, which are represented on the map by a point with fixed geographical coordinates.

Starting from the first years of plus tree selection, schematic plans of tree location on the subcompartment were provided when preparing the documentation (Passport of Plus Tree). In the

last century, such schemes were made by hand. The plan should have indicated the distance to the plus trees from the distance post and/or fire break, but unfortunately, some plans do not contain such information. As an example, we demonstrate a scheme of the location of pedunculate oak (*Quercus robur* L.) plus trees in compartment 94 in the Vovchansk State Forest Enterprise (Fig. 1, a).



**Fig. 1 – Examples of plus trees location plans (Compartment 94 of Khotimlyanske forestry in Vovchansk State Forest Enterprise): a – in the “Passport of Plus Trees No. 6 – 10” (selected in 1973), b – in the “Passport of Plus Trees No. 128, 129” (selected in 2017), c, d - in the GoogleEarth**

In some cases, when the trees were located at a significant distance from the specified benchmark points, mistakes were made and it took a long time to find such a tree in the field. Schemes were drawn up mainly for each plus tree separately, even when there were several in the subcompartment. At the same time, the location relative to other plus trees was not always taken into consideration. The geographical coordinates of the trees were not indicated in the Passports, because at that time there were no devices for their precise determination. With the advent of GPS navigators capable of receiving satellite signals under the crowns of trees, it became possible to determine the coordinates of plus trees. In 2000–2005, during the implementation of the international project “Genetic recourses of broadleaf forest tree species in Southeastern Europe” in Ukraine, the geographical coordinates of the vast majority of plus trees of deciduous species were determined, and the first electronic schemes of their location on the territory of the subcompartments were created in the MapInfo software (Voytyuk et al. 2005, Volosyanchuk et al. 2002, 2009, Hayda et al. 2008, Yatsyk et al. 2006, 2008, Los et al. 2007, 2011). In previous years, the absence of reliable and exact information about the plus trees’ location during inventory research caused difficulties of their searching in the stand. Identifying numbers on trees was also sometimes difficult, especially if they had not been renewed for a long time. In some cases, there have been facts of replacing plus trees with other trees.

Later, for the newly selected plus trees, printed schemes of their location, mostly made in MapInfo, were added to the plus tree passports. Fig. 1, b shows the location scheme of the

pedunculate oak plus trees selected in 2017 in the same subcompartment № 94 in the Khotimlyanske forestry in Vovchansk State Forest Enterprise with the refined GPS location of trees No. 8–11 selected in 1973. The exact coordinates also made it possible to put the plus trees on a map of the area in GoogleEarth, which made it easier to find the trees in the field. Figs. 1, c, d show the location of the same trees in the forest area in GoogleEarth.

After the scientists in the Department of New Information Technologies of URIFFM implemented the website Geoportal: Forests of Ukraine, it became technically possible to add information on plus trees and combine data on tree locations and their characteristics in a united electronic database.

The study aimed to improve the organization of information on plus trees, their accounting, survey, and use as improvement units by applying free software (Python, JavaScript) and the PostgreSQL relational database with the PostGIS module.

**Materials and Methods.** In 2021, as part of the work on creation a database of Ukrainian tree improvement units, one of the work stages was to develop software and methodology for forming the plus trees database and to provide a user manual. In particular, a data schema was created to store both attribute and geographical information on tree improvement units in Ukraine. The schema (Fig. 2) has been added to the *postgres "geodjango"* database (User manual, not published).



**Fig. 2 – The general data scheme of tree improvement units (User manual, not published).**

When developing the scheme based on information from the Passports of plus trees or the results of inventory studies carried out by researchers from the Department of Tree Improvement, the complex subordinate structure of the units was taken into consideration. As an example, plus trees are located in a plus stand, which is also part of the gen reserve. Therefore, the proposed scheme contains two data tables:

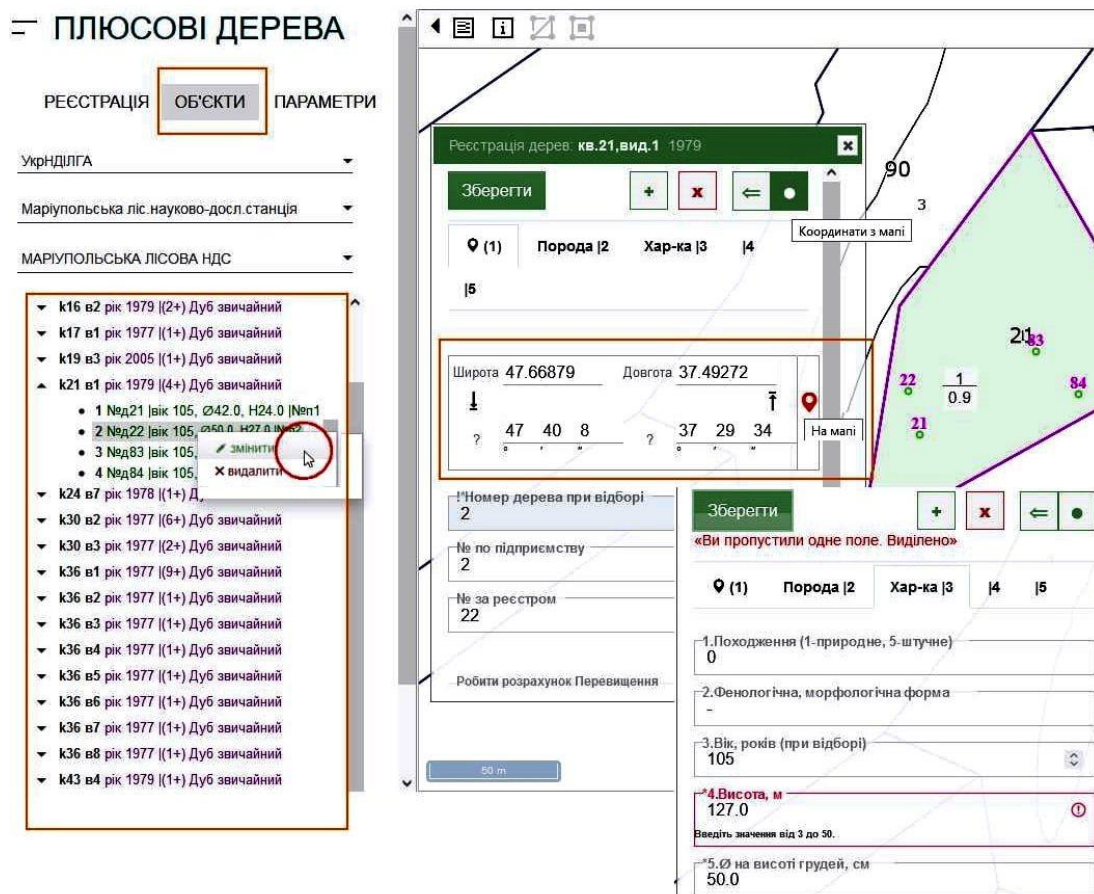
- 1 – for polygonal tree improvement units;
- 2 – for plus trees.

The tables are interconnected by a unique key consisting of the following fields: region code, forest enterprise code, forestry code, compartment number, subcompartment number, type of tree improvement unit code, year of selection/establishment, and tree species. In 2022, Ukraine's forest

management system was reformed. The organizational structure has been changed; in particular, the functions of state forest enterprises are now performed by newly established regional branches.

When entering the data, the codes of the enterprises (regional branches) on whose territory the plus trees are located were determined; this coding corresponds to the generally accepted one in the forest inventory. The scheme also includes several reference tables. In addition, attribute and geographical information of forest inventory are used.

The full functioning of the developed system for plus trees involves printing schemes of the location of the unit, generating summary information and vector files (*kml*, *geojson*) on request, as well as an interactive demonstration of these units on a web page (Fig. 3).



**Fig. 3 – An example of the plus tree data entering on the portal page “Plus trees”**

Simultaneously with the data entry, the verification algorithms and web page design were modified. An algorithm for converting coordinates to the WGS84 system was used.

In cases where the unit is a single tree within the territory of a subcompartment, information on its geolocation is especially important. Even according to the current requirements (Guidelines for Forest Seed Production 2017), the Passport of a plus tree should be accompanied by a scheme of its location on the territory of the subcompartment with an indication of the distance relative to the compartment network (for plus trees selected before 2010) or geographic coordinates (for plus trees selected after 2010), such information is not always available. In such situations, the work of entering the information about plus trees becomes more complicated and requires additional field research.

The database of plus trees contains the basic information from plus trees' Passports or selection/inventory data from the reports of the Department of Forest Tree Improvement, URIFFM, of previous years, namely the following indicators:

- Species name
- Tree number at the enterprise (regional branch)
- Tree number in the State Register
- Latitude, N degrees
- Longitude, E degrees
- Year of selection
- Age, years (as of the year of selection)
- Total height of the tree, m
- Tree diameter at 1.3 m height, cm
- Trunk volume, m<sup>3</sup>
- Excess of height over the average indicators of the stand, %
- Excess of diameter over the average indicators of the stand, %
- Height of the knotless part of the trunk, %.
- Crown diameter, m
- Condition, points
- Tree category
- Type of bark

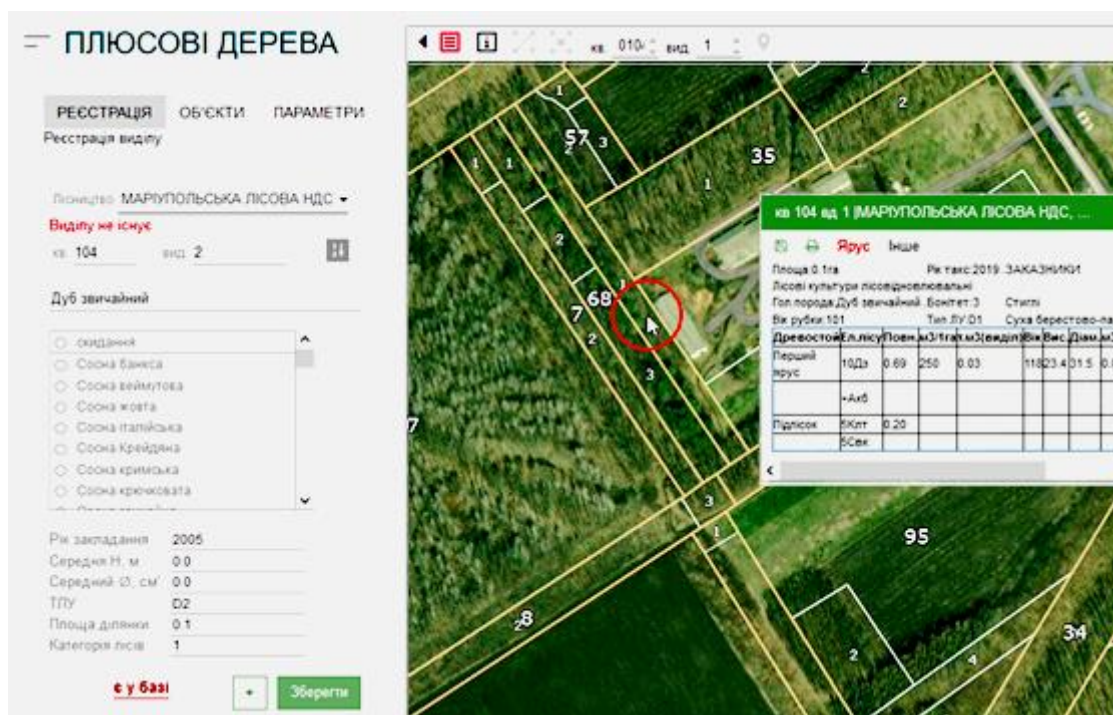
Based on the database of plus trees, a webpage was created, which is a part of the website «Лісові селекційні об'єкти України» (“Forest Tree Improvement Units of Ukraine”).

**Results.** The proposed database consists of several panels. Thus, the «Реєстрація» (“Registration”) panel contains a form for entering data for subcompartment (Fig. 4), on the territory of which there are plus trees. Before entering data on plus trees that are not included in plus stand, it is necessary first to register the subcompartment for the chosen forestry. To do this, you have to press the “+” button, and the fields “subcompartment”, “area”, and “forest category” will be cleared. After the subcompartment has been registered (by the «зберегти» (“save”) button), it is included in the data hierarchy, and plus trees can be added to it using the context menu. Figure 4 shows an example when the specified subcompartment is not available in the forest inventory database and the program displays a corresponding message. If such a subcompartment exists, the “area” and “forest category” fields are filled in automatically. All attributes are checked when entering into the database. If the entered data fails validation, a line with a corresponding warning appears.

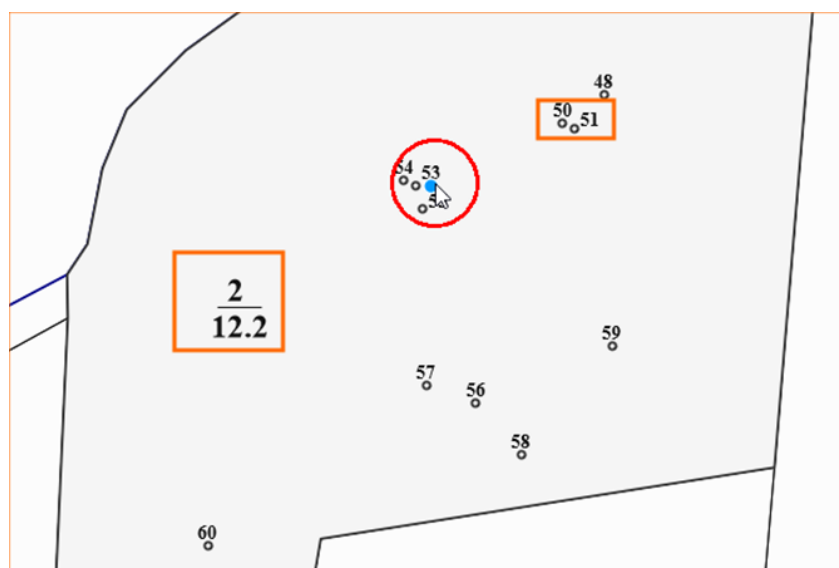
If it is necessary to change the data of an already registered subcompartment, the context menu should be used that appears when you select the subcompartment in the data hierarchy. The menu item «Змінити» (“Edit”) should be selected; for the subcompartment already included in the database, the initial input fields “compartment” and “subcompartment” will be locked; for changing them, you should click the arrow icon (next to the subcompartment number). Correction and deletion of information on plus stands is possible only on the page «Полігональні селекційні об'єкти» (“Polygonal tree improvement units”). For deleting, it is necessary to use the context menu of the registered subcompartment.

Printing a scheme of the plus trees' location is possible by choosing the option «Підготовка до друку» (“Prepare for printing”). For the plus stand, a separate layer of labels is formed for the location numbers of the tree, compartment and subcompartment, and object area on the map. After selecting the appropriate scale, the scheme can be printed (Fig. 5).

The data entry form for plus trees consists of four panels for entering information and a group of command buttons (Fig. 6). The “+” and “x” buttons are used to create a new unit (plus tree) and delete it, respectively. The button «Скидання координат на початок» (“Reset coordinates to the beginning”) is used to cancel the unit movement. If the changes have not been saved, a confirmation message appears when you close the window. To continue working, the changes should be saved or not. Figure 6 shows an example of making changes.



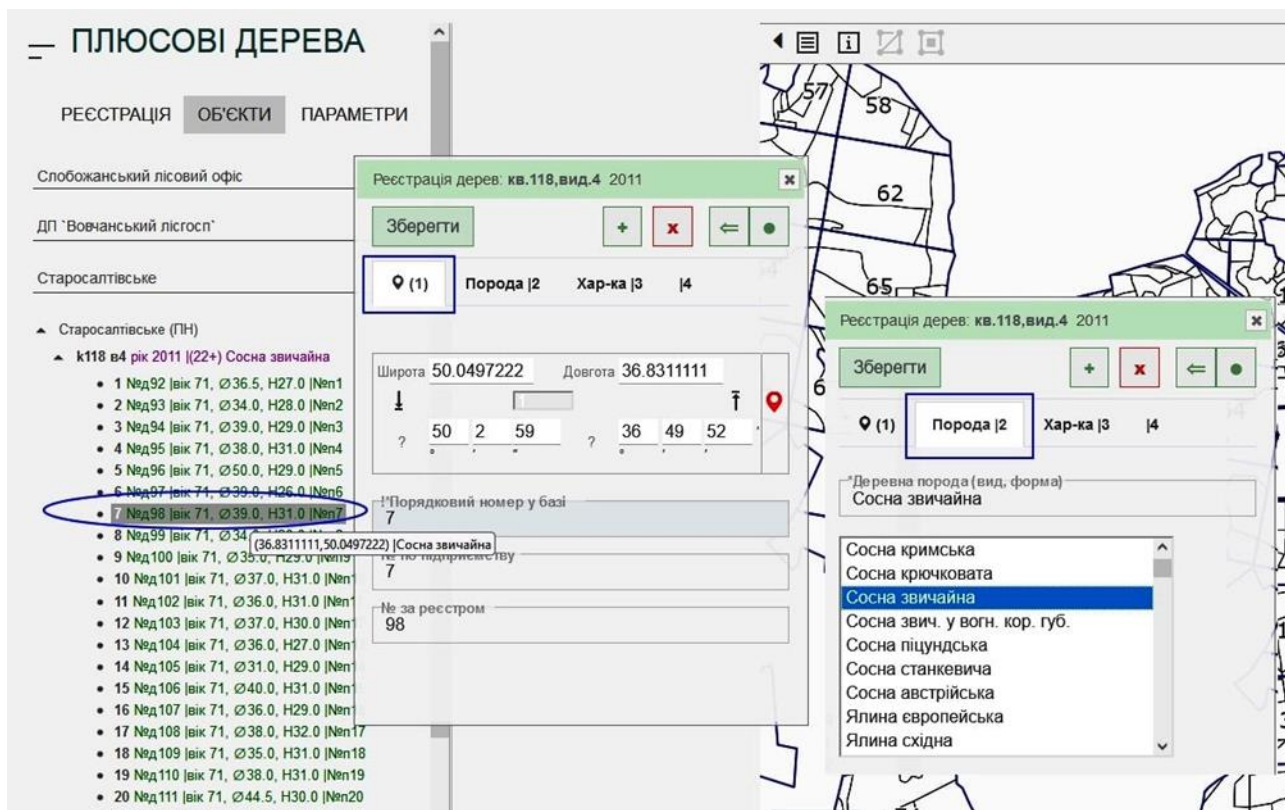
**Fig. 4 – Data entry form for subcompartment in which there are plus trees**



**Fig. 5 – An example of a printable scheme for the location of plus trees**

The first panel contains elements for setting coordinates and entering plus tree numbers by State Registry and enterprises (regional branches). In addition, each tree is assigned a sequence number in the database. The attribute «№ п/п» (“No.”) is a part of the primary key and cannot be changed. It is set during the initial entry and is a unique number in the database within mother unit, in this case, a plus stand. When entering the data of a new plus tree, another sequence number is generated by the software, which can be changed before entering it into the database. When entering into the database, the uniqueness of the key is checked, and if a duplicate is found, you will be asked to enter a different number.

The second panel is intended for selecting a species name of trees from the list provided.



**Fig. 6 – Editing information about Scots pine plus tree No. 3**

The third panel of the data entry form contains mandatory attributes that are marked with “\*” (Fig. 7). These are the total height of the plus tree and its diameter at a height of 1.3 m. The fourth panel contains other tree characteristics.

Before saving the entered data, it is provided validation (verification) to correct any errors that may have been made when filling out the form. The attributes are checked for compliance according to the ranges presented in Table 1.

*Table 1*

**Criteria for checking the correctness of entering the characteristics of plus trees (attributes)**

Attributes	Criteria
Sequence number in the database	range 1–999
Tree number at the enterprise (regional branch)	range 1–999
Tree number in the State Register	range 9999
Age, years	range 1–400
Total height of the tree, m	range 3.0–50.0
Tree diameter at 1.3 m height, cm	range 3.0–150.0
Trunk volume, m <sup>3</sup>	range 1–9999
Excess of height over the average indicators of the stand, %	range -20.0–90.0
Excess of diameter over the average indicators of the stand, %	range -20.0–90.0
Height of the knotless part of the trunk, %	maximum 70
Crown projection diameter, m	maximum 100
Condition, points	maximum 5
Tree category, points	maximum 2

The menu of the website page «Плюсові дерева» (“Plus Trees”) consists of the following four items:

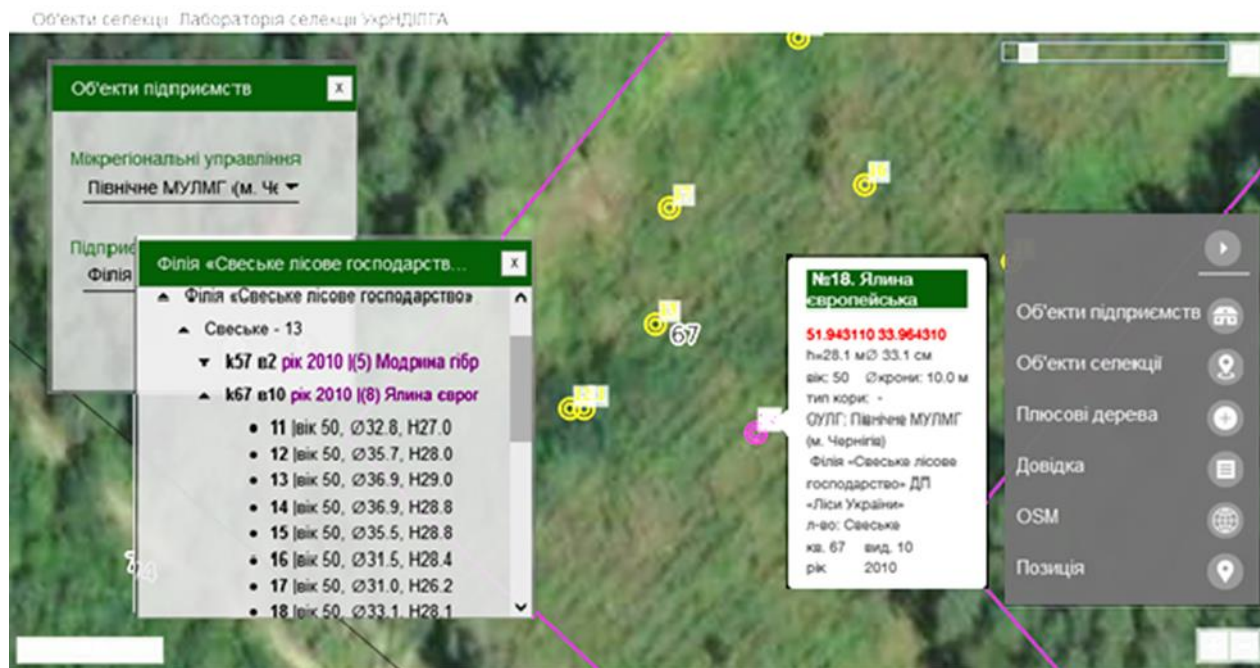
- Save
- List of plus trees
- List of trees by Interregional forestry and hunting departments (IFHD)
- Export - GeoLIS file

**Fig. 7 – An example of entering the height and diameter of a plus tree (highlighted by the frame) and other characteristics**

On the Webpage «Карта об'єктів селекції» (“Map of tree improvement units”), an electronic map of the branch’s territory with information on plus trees linked to the geographical context is available on request. A complete list of plus trees available in the database, by branches and forestries, tree species, years, etc., can be obtained through the menu item «Склад плюсових дерев» (“Plus tree composition”). It is possible to display and print similar information for the relevant region through the item «Склад по МУЛМГ» (“Composition by IFHD”) (Fig. 8). Such information is needed, first of all, to check the scope and status of data entry.

Using the menu item «Експорт- файл.geojson» (“Export file.geojson”), it is possible to export data in the GeoJSON format. This format is appropriate for storing and transferring data. This file contains information on? all the plus trees. In addition to their tree coordinates, the file contains the following attributes: enterprise (branch) name, forestry name, compartment, subcompartment, age, species name, height, diameter, and crown projection diameter. The fragment from the file is [«{'id': '4~2', 'type': 'Feature', 'geometry': {'type': 'Point', 'coordinates': [33.8916, 48.53125]}, 'properties': {'bark': 'Л-Г', 'fory': 'П`ятихатське', 'age': 90, 'species': 'Дуб звичайний', 'crown': 12.0, 'height': 23.5, 'diameter': 39.2, 'forestry': 'Верхньодніпровський ЛГ'}}»].





**Fig. 8 - Web page «Карта об'єктів селекції» (“Map of tree improvement units”): an electronic map with information on plus trees and a list of plus trees on the territory of the branch “Svesa Forestry”**

During the testing of the developed database structure and the working out of the instructions for its use, information on plus trees in seven regions of Ukraine (Kharkiv, Poltava, Sumy, Dnipro, Zaporizhzhia, Luhansk and Donetsk) was entered, which is about 25% of the plus tree fund. In addition, the design of the webpages was finalized in parallel with the data entry.

The developed software can be useful to both scientists and forest managers. Its use will simplify the search for plus trees in forest stands for their inventory, survey, as well as in cases where it is necessary to collect seeds or cuttings for the seed orchards or progeny tests in forest enterprises or at forest seed centers. For scientists, it will provide an opportunity to systematize large data sets on the plus trees characteristics and their analysis and generalization, in particular with the aim of improving methodical approaches to the plus trees selection.

**Conclusions.** A data schema was created to store both attribute and geographic information on forest tree species tree improvement units in Ukraine. The schema considers the complex structure of coordinated units and includes the developed algorithms for data verification which will allow the effective use of the proposed database for the plus tree accounting.

The database stores the basic information from the Passports of Plus Trees or information on their selection/inventory from the reports of the URIFFM Department of Tree Improvement for previous years. At present, the database contains information on plus trees in seven regions of Ukraine (Kharkiv, Poltava, Sumy, Dnipro, Zaporizhzhia, Luhansk and Donetsk), which is about 25% of the country's plus tree pool.

Based on the database, a web page was created that provides information on selected plus trees, including their location in the subcompartment, as well as summary information on plus trees in a particular enterprise (regional branch) or a region.

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**ЗАСТОСУВАННЯ ГІС-ТЕХНОЛОГІЙ ДЛЯ ОБЛІКУ ПЛЮСОВИХ ДЕРЕВ**

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Наведено результати одного з етапів робіт зі створення бази даних селекційних об'єктів лісових деревних видів України, який стосується обліку плюсових дерев. Метою досліджень було вдосконалення впорядкування інформації щодо плюсових дерев, їхнього обліку, обстеження та використання як селекційних об'єктів за допомогою безкоштовного програмного забезпечення (Python, JavaScript) та використання реляційної бази даних PostgreSQL з модулем PostGIS. На основі методики формування бази плюсових дерев складено інструкцію для користування розробленого та опрацьованого програмного забезпечення. Створено вебсторінку, яка за відповідним запитом демонструє інформацію про плюсові дерева, зокрема їхнє розташування на території виділу, а також зведені відомості щодо плюсових дерев у певному лісовому господарстві або області. На цей час до бази внесено інформацію про плюсові дерева семи областей України (Харківська, Полтавська, Сумська, Дніпропетровська, Запорізька, Луганська і Донецька), що становить близько 25 % фонду плюсових дерев країни.

К л ю ч о в і с л о в а : лісові генетичні ресурси, база даних, портал, вебсторінка, селекційний об'єкт.

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