SFI Sustainable Forestry Implementation

With support from Federal Ministry of Food and Agriculture by decision of the German Bundestag

**Forest Policy Report** **SFI/2022**

# Challenges and Options in NFI data quality assurance: development of a draft manual on data quality control

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Kyiv, December 2022

unique land use

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## About the Project "Sustainable Forestry Implementation" (SFI)

The project "Technical Support to Forest Policy Development and National Forest Inventory Implementation" (SFI) is a project established in the framework of the Bilateral Cooperation Program (BCP) of the Federal Ministry of Food and Agriculture of Germany (BMEL) with the Ministry of Environment and Natural Resources of Ukraine (MENR). It is a continuation of activities started in the forest sector within the German-Ukrainian Agriculture Policy Dialogue (APD) forestry component.

The Project is implemented based on an agreement between GFA Group, the general authorized executor of BMEL, and the State Forest Resources Agency of Ukraine (SFRA) since October 2021. On behalf of GFA Group, the executing agencies - Unique land use GmbH and IAK Agrar Consulting GmbH - are in charge of the implementation jointly with SFRA.

The project aims to support sustainable forest management in Ukraine and has a working focus on the results in the Forest Policy and National Forest Inventory.

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# Content

# 1. INTRODUCTION

Data quality assurance of the National Forest Inventory (NFI) is one of the most important components of the data collection process at the inventory plots, which aims to ensure that forest inventory data are scientifically justified and collected in compliance with the established requirements and with a known level of accuracy.

Data quality assurance involves quality control and quality assessment. Quality control helps to determine whether the specified requirements for data collection are met. It covers many operational processes of data collection, including data collection methods, staff training, field inspection of plots, checking the completeness of collected data and identifying errors, following the procedure for reporting errors, etc. The quality assessment establishes the variability and accuracy of the collected data and determines their compliance with the approved data collection methodology (rules).

This report presents the preliminary results of the study of the problem of ensuring the quality of NFI data and provides proposals for the development of a draft manual on quality control of NFI data in Ukraine.

The report was prepared based on the analysis of real field data of the Ukrainian NFI collected within Ivano-Frankivsk region in 2021 by the specialists of the NFI Centre of the "SE Ukrderzhlisproekt" and kindly provided for research aimed at improving the quality assurance processes of NFI results.

The work was carried out using Field-Map software developed by the Institute for Forest Ecosystem Research (IFER, Czech Republic) and used in a number of European countries as a basic NFI technology. Processing and analysis of the Ukrainian NFI data was carried out using the Field-Map Inventory Analyst (FMIA) module and other software products.

The author expresses his gratitude to the specialists who provided significant assistance in organising and conducting this study, in particular, to the following researchers of the URIFFM: Ph.(Candidate of Agricultural Sciences) Pyvovar Tetiana Serhiyivna, PhD in Agriculture Pasternak Volodymyr Petrovych, leading engineer Oleh Mykolaiovych Radchenko, chief technical advisor of the SFI project Vitaliy Fedorovych Storozhuk, general director of the State Enterprise "Ukrderzhlisproekt" Viktor Anatolijovych Melnychenko, director of the Centre of NFI of Ukraine, Ph. Shevchuk Oleksandr Vasylovych; Head of IFER Ph. Martin Czerny and IFER staff member Petr Blazek.

# 1. Basic principles of data quality assurance of the NFI of Ukraine

Implementation of the National Forest Inventory (NFI) in Ukraine requires clear planning and implementation of a system of quality assurance and control of NFI work and data.

The Law of Ukraine "On Amendments to the Forest Code of Ukraine on Conducting the National Forest Inventory" defines the legal definition of the NFI, the conditions for its conduct, specifies the sources of funding and outlines the areas of use of the inventory results. In April 2021, the Cabinet of Ministers of Ukraine approved the Procedure for Conducting the National Forest Inventory. One of the important tasks in the implementation of the NFI is to develop and implement a system of quality assurance and quality control. In the process of organising work control, important components are

- verification of compliance with the requirements of the technology and methods of work performance established by the Procedure;
- timely identification and elimination of deficiencies in the work of field inventory teams;
- detection and correction of data errors;
- Ensuring completeness and integrity of data and documentation of NFI activities.

During the quality control of the NFI work, the scope, content and quality of the field work performed, the preparation procedure and the composition and completeness of the NFI documentation should be checked.

The quality of the National Forest Inventory (NFI) is determined by its ability to provide data that:

1) allow assessing the state of the country's forest resources with a certain level of accuracy,

2) allow detecting changes with a certain level of reliability, and

3) are comparable in space and time.

To achieve these requirements, a system of quality assurance of the NFI data is essential. An important component of such a system is data quality control, which should be carried out at different stages of the NFI: before the start of fieldwork (training), during fieldwork (including control re-measurements and verifications) and after completion.

The purpose of quality control is to ensure that the data collected meet the requirements. The results of quality control should also provide the feedback needed to develop realistic measurement quality targets, revise data collection

methods to reduce errors, improve training and assist in the interpretation of results.

To illustrate the problem of ensuring and controlling the quality of NFI data, consider the possible options for the ratio of reliability and accuracy when assessing indicators, as shown in Fig. 1: (a) accurate but not reliable, (b) inaccurate and not reliable, (c) reliable but not accurate, (d) accurate and reliable.

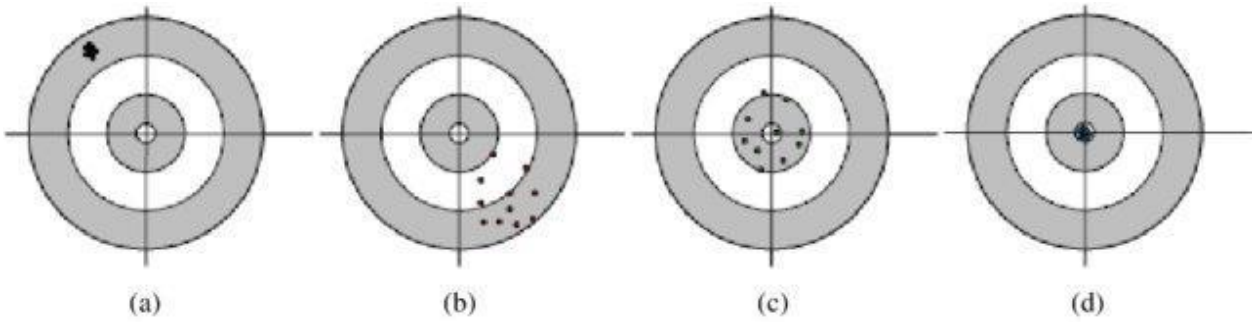


Fig. 1 Options for the ratio of reliability and accuracy in indicator assessment (source: FCPF Carbon Fund Methodological Framework, 2016).

The purpose of developing the data quality control manual for the Ukrainian NFI is to achieve results that will ensure proper reproducibility of the NFI indicator determination by all field specialists in accordance with option (d).

During the collection of NFI information, data control rules should be applied that limit the entry of erroneous data and promote the correctness, consistency and accuracy of the data collected. Key components of data quality control procedures:

- Verification means checking the data type, controlling whether the entered data matches the expected data type defined for a particular field.
- Range check and constraint check: checks whether the entered value falls within an acceptable range of values. Checks for the absence of a record.
- Cross-checks: checks whether the data entered in different fields is consistent with a set of underlying assumptions. For example: diameter-to-height ratio, age-to-height ratio, etc.

Foreign experience in ensuring the quality of work with the NFI, for example, the experience of implementing the NFI in the Federal Republic of Germany and most countries of Europe and North America, involves re-measurement of forest inventory plots.

In accordance with the best foreign practices, the NFI of Ukraine should include the following components of the system of quality assurance and control of field work:

- Scheduled control re-measurements and surveys of inventory plots to assess the compliance of the values of indicators established by field teams with the accuracy standards defined by the Procedure for conducting the national forest inventory (2021);
- regular supervisory inspections of field teams to ensure compliance with the work technology during the measurement of inventory plots, which is defined by the Methodological Guidelines for conducting field work on the National Forest Inventory of Ukraine (approved by the Scientific and Technical Council of the SFRA of Ukraine on 10.03.2021, Protocol No. 1).

The volume of annual control re-measurements of forest inventory plots should be at least 5% of the total number of plots identified for measurement in the current year. At the same time, not less than 4% of the total number of forest inventory plots measured by a separate inventory group shall be subject to control re-measurements.

Control re-measurements should be carried out by control groups using data collected by the inventory group, but without the participation of the latter (the so-called "Cold Check"). The number of plots to be inspected is determined by the rule that control re-measurements are carried out on one forest inventory plot from the inventory tract selected for control, while the rest of the forest inventory plots of this tract are subject to control inspections.

Supervisory inspections are carried out in the presence of members of the inventory team during their field work. The introduction of supervisory inspections expands the circle of persons who can control field works with NFI.

An important element of the quality control system for NFI work should be the introduction of a regulatory document on control and supervision of field work on the national forest inventory. Such a document should contain detailed procedures for re-measurements and inspections, forms of documentation, regulate ways of quality assurance and resolving disputes.

Conclusions on the quality of the field team's work should be provided by the control group using the form of a comparative statement (comparing the indicators collected by the field team with the indicators of the control group), the form of acts of control and verification of the work performed (indicating certain results and steps to improve them), as well as the form of a supervisory inspection act (which will serve as the basis for payment for the work performed).

During the control of the work of field inventory teams, the presence of errors in the determination of the NFI indicators is established. The Procedure for Conducting National Inventory sets error limits and significance indicators for each indicator. Depending on the complexity of its definition or measurement, as well as the importance of its correct establishment, each NFI indicator has been

assigned a corresponding numerical level of significance, similar to the way it is implemented, for example, in the Italian NFI. The combined use of the accuracy assessment system and the weighting of the significance of the indicators allows for the calculation of a comprehensive assessment of the quality of the work performed by the field team. A comprehensive assessment is the percentage of correctly determined values obtained as a weighted average for groups of indicators of different significance. Its use will allow to establish a certain level of quality by regulation, below which the contractors should be required to carry out a complete re-measurement of the inventory plots at their own expense.

It is important to ensure the quality of work from the very beginning of the NFI in order to be able to adjust the procedures for obtaining information at the initial stage of data collection. Since data collection and primary processing cannot be fully controlled by the customer, quality assurance requires a high level of technical support and proper motivation on the part of the contractors.

The availability of selective quality control should ensure public confidence in the results of the NFI. For the effective implementation of the quality control system, detailed methodological guidelines for conducting field work have been developed, the number of control groups has been justified, and it is planned to organise their work and conduct targeted field control activities from the very beginning of field work.

The members of these groups should be trained and prepared to conduct the control checks in advance. After the first supervisory checks, it should be possible to identify which field teams are performing well and which need to be adjusted in terms of quality of work.

## 2. Information collected at the NFI plots in Ivano-Frankivsk oblast and methods of its analysis

In Ukraine, in 2021, field data collection on the National Forest Inventory plots was started, and during the field period, 909 plots were surveyed using Small Forest software adapted for field data collection on the NFI plots of Ukraine.

The field materials of the NFI collected within Ivano-Frankivsk region in 2021 were kindly provided by the National Inventory Centre of the State Enterprise "Ukrderzhlisproekt" (CNIL) for scientific and methodological research to ensure the quality of the NFI results.

The employees of the CNIL have done a great deal of work on the implementation of the CNIL in Ukraine, organisation and conduct of field work on the CNIL plots, especially considering the current realities of Russia's military aggression against Ukraine, significant destruction of the building of the Ukrderzhlisproekt in Irpin, and the fact that some of the CNIL employees are defending the Motherland in the Armed Forces of Ukraine.

Using the primary field database of the 2021 NFI plots for Ivano-Frankivsk region (235 plots), which was received from the CNIL, the structure of the NFI database was analysed and compared with the requirements of the Procedure for conducting NFI (approved by the Resolution of the Cabinet of Ministers of Ukraine of 21 April 2021, No. 392), as well as with the methodological guidelines for conducting field work on NFI in Ukraine.

Errors identified in the field database of plots were recorded and corrected in the course of further calculations of NFI Indicators.

During the analysis of primary NFI data, preliminary calculations of derived NFI indicators were made, including modelling the heights of the accounting trees, calculating tree volumes, average taxation indicators, and classifying indicators in accordance with the forms of reporting tables approved by the CMU. Aggregated data for parts of the inventory plots were calculated, including total stocks, age of the dominant species, completeness, etc.

# 1. Conversion of NFI field materials to Field-Map software

The Field-Map software and measuring complex is a full-featured geographic information system that runs on field and office computers and provides communication with various electronic measuring devices for the automated formation of a geodatabase of indicators determined in the forest. Field-Map was specially developed at the Institute for Forest Ecosystem Research (IFER, Czech Republic https://www.ifer.cz/) as a basic technology to support NFI, and over time, its scope has been significantly expanded to address a variety of forestry-related tasks.

In Ukraine, the Field-Map software and measurement system was localised and adapted to the forestry regulatory and reference framework within the framework of the Czech-Ukrainian project "Transfer of advanced methodological and technological knowledge in the field of forest ecosystem inventory and monitoring (TechInLis)" (see https://www.ifer.cz/project-detail/?id=42004) and its implementation in Ukraine began in 2005.

During the field data collection at the NFI plots in Ukraine in 2021, the Small Forest software developed by developed by I.L. Aleksiyuk on the Android platform, although the "Guidelines for conducting field work on the NFI of Ukraine" developed by URIFFM together with the CNFI (approved by the Scientific and Technical Council of the State Forest Resources Agency of Ukraine, Protocol No. 1 of 10.03.2021) are focused on the use of Field-Map software when conducting field work on the NFI plots of Ukraine. The Field-Map technology proved to be a successful tool during pilot regional forest inventories in Sumy and Ivano-Frankivsk regions and was therefore recommended for use in the NFI. However, at the time of the start of field work on the Ukrainian NFI, Field-Map technology could not be imported to Ukraine, and the management of the CNIL decided to adapt the Small Forest software for the needs of field data collection in the Ukrainian NFI.

The Small Forest software used for field data collection in the Ivano-Frankivsk oblast on NFI plots was not made available for review upon request to the CNIL, and no information on the functionality of Small Forest or user manual was found in the public, so the specifics of the application and functionality of this software product were not analysed during the research.

Unfortunately, it was not possible to get acquainted with the Small Forest software that was used for field data collection at the NFI plots in Ukraine, although the website https://www.lisovporyadnyk.org.ua/smallforest_/ states that Small Forest software is non-governmental and distributed free of charge. In further research, it would be preferable to receive access to the Small Forest software and documentation to evaluate its functionality and effectiveness in collecting field data at Ukrainian NFI plots.

The Ivano-Frankivsk Oblast NFI database for 2021 was received from the CNFI in MS Access format. In the process of analysing this database, we explored ways to convert it to Field-Map, conducted quality control of NFI data and tested the capabilities of the Field-Map Inventory Analyst module for calculations and preparation of reporting results for NFI in Ukraine.

The research stages included:

- Analysis of the structure of the database provided by the CNIL in MS Access, comparison with the structure of the NFI database in Field-Map and with the requirements of the Procedure for conducting the NFI of Ukraine;
- modification of the structure of the NFI database in Field-Map, control of directories and values;
- preparation of an xml document describing the correspondence of tables and fields of the two databases for import into Field-Map;
- conversion of distance into horizontal distance, azimuth and distance into x, y coordinates in the primary database;
- step-by-step transfer of data to Field-Map (using the Import2FieldMap application);
- creating shapefiles of boundary lines (part boundaries) for plots with parts (using the DB2shapefile application);
- transfer of shapefiles of boundary lines to the corresponding plots, polygonisation of all whole (from one part) plots, creation of microplots (using scripts);
- plot-by-plot analysis of the correctness of the parts: control of the presence of multipolygons of plots with several parts, change of numbering of parts with control of their relative position on the map and database with description of parts, control of the total area of parts for each plot;
- importing data into the Parts and Microplots (scripts in Firebird desktop);
- importing data into tables subordinated to the Parts and Microplots (Field-Map Data collector);
- Uploading the complete designed network of NFI plots to Field-Map.

As a result of the work carried out, the NFI database for Ivano-Frankivsk oblast was transferred to Field-Map, structured and prepared for further use in office and field conditions (Fig. 1, Fig. 2, Fig. 3).

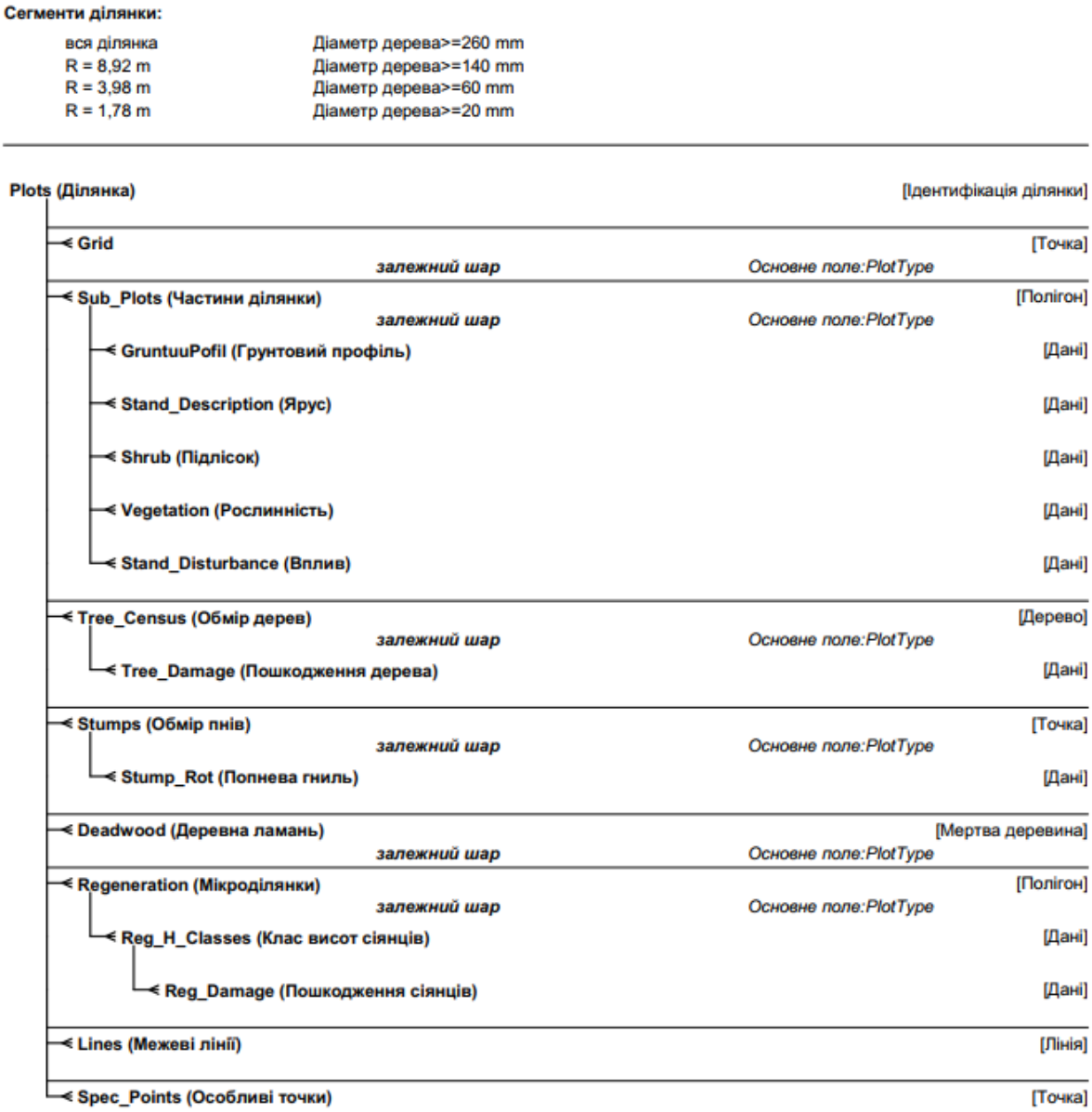


*Figure 1. Reduced structure of the Ukrainian NFI database in Field Map Project Manager*

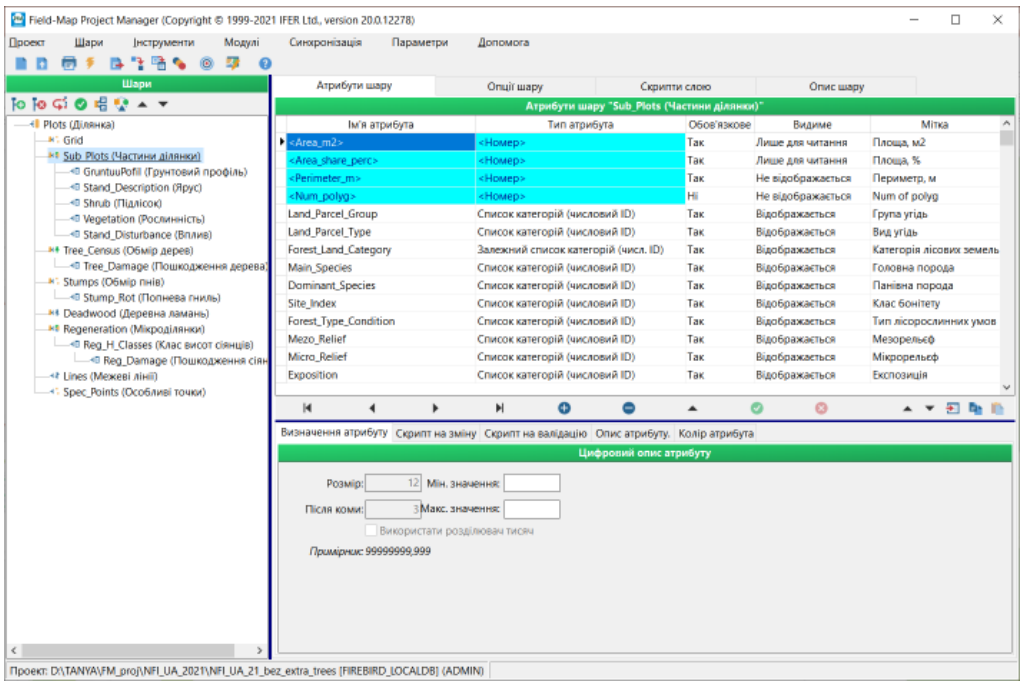


*Figure 2. Database of Ukrainian NFI in a field computer in Field Map Project Manager*

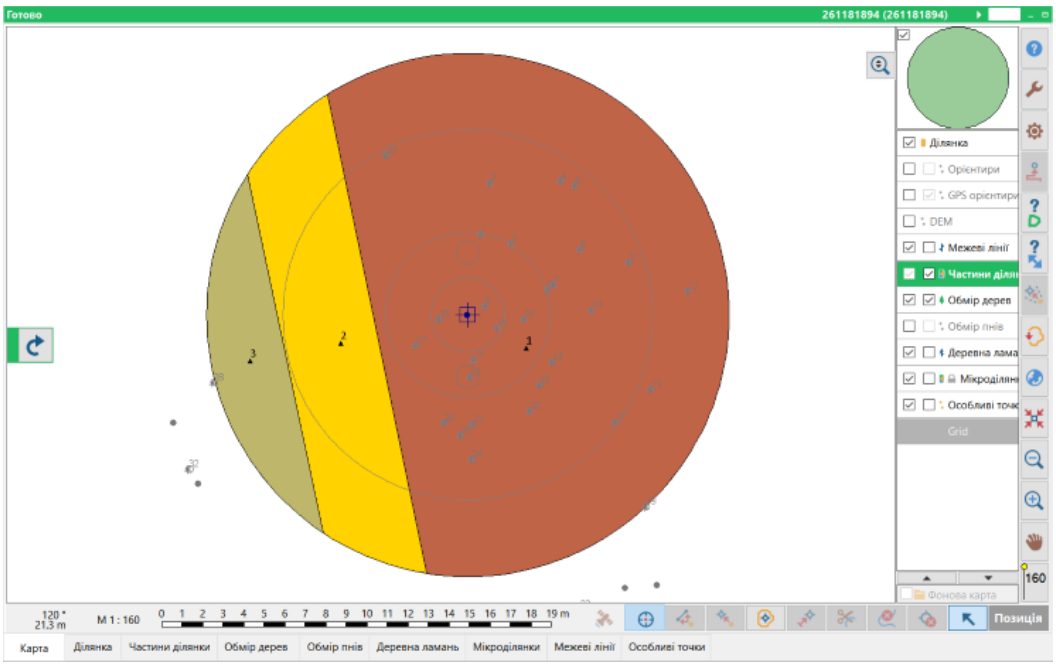


*Figure 3. Data from the 2021 NFI of Ivano-Frankivsk Oblast on a field computer in the Field-Map Data Collector software.*

To analyse the quality of NFI data collected in Ivano-Frankivsk Oblast in 2021, more than 100 tasks were generated and performed using the Field-Map Inventory Analyst software to statistically calculate most NFI reporting tables (Fig. 4). The obtained results were compared with the previous results of the CNIL calculations.

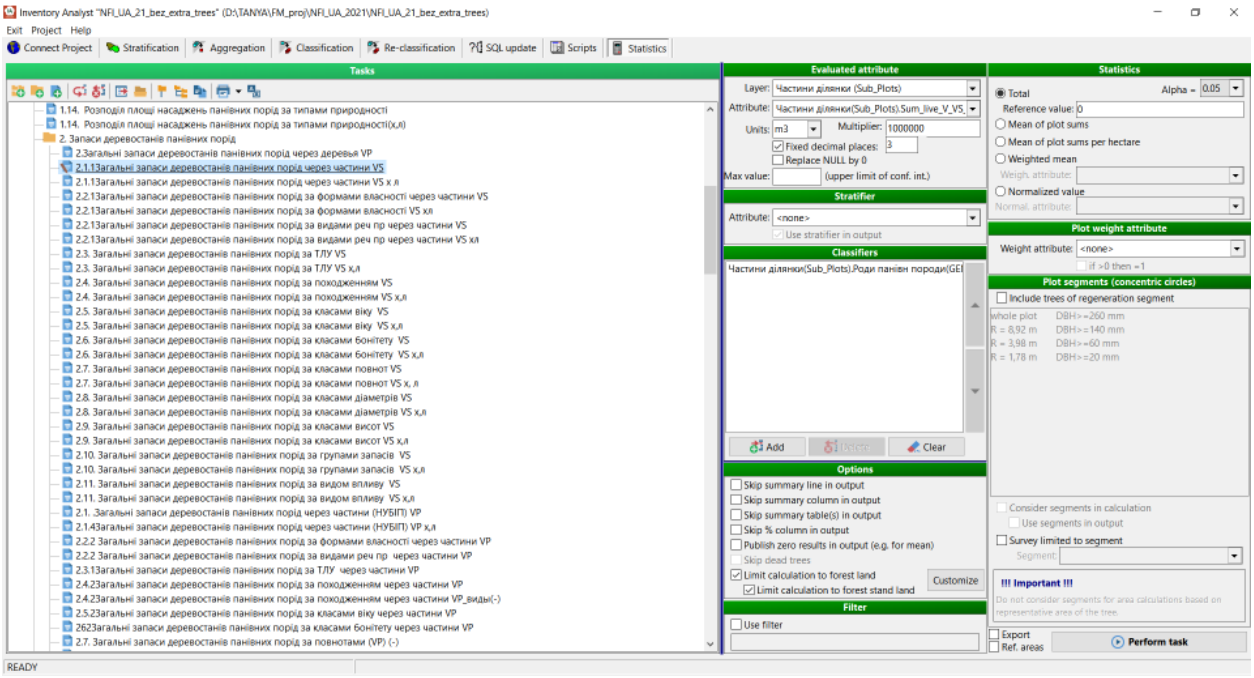


*Figure 4. The window of the Field-Map Inventory Analyst software module with tasks for statistical analysis of the NFI data.*

Important for the NFI are Field-Map technological solutions that provide independent off-line work for field teams at inventory plots and synchronisation of their data with the central NFI database when field computers are connected to the Internet. At the same time, the project structure on the server is updated by synchronising metadata. Thus, the field data collected with the Small Forest software product was first converted to Field-Map, and then the data from all field teams can be combined into a server project, which will allow storing all the NFI data in a single central database, dividing the project between field teams and managing their work (monitoring the field work of each field team), and automatically synchronising local databases with the NFI server database.

Today, Field-Map is used as a basic technology for field data collection and information management of National Forest Inventories in 10 countries, including the Czech Republic (Forest Management Institute), Slovakia (National Forest Centre), Ireland (Forest Service, Depart. of Agriculture, Food and Marine), Iceland (Icelandic Forest Service), Belgium (Agentschap voor Natuur en Bos), Hungary (National Food Chain Safety Office), Republic of Cabo Verde (Ministry of Rural Development), Bulgaria (Ministry of Agriculture and Food, South Central State), Denmark (Centre of Forests, Landscape and Planning), as well as in the state forest inventory of Russia.

Why is Field-Map software used in so many national forest inventories? A key feature of Field-Map is the software's flexibility, which allows users without programming skills to customise the database structure in Field-Map to meet the requirements of the data collection methodology. In addition, the Field-Map

developers provide prompt technical support for users through the website (https://field-map.com/), which contains technical documentation and a detailed description of the software functionality (https://field-map.com/?verze=en&page=keywords&id=&subject=&origpage=), as well as a multilingual hotline for official users (including Ukrainian-speaking).

Ukraine has accumulated considerable experience in using Field-Map technology to solve various problems in the forestry industry, nature conservation and landscape gardening, including:

- onducting forestry research,
- basic forest management of forestry enterprises,
- -regional and local forest inventory,
- inventory of nature reserve fund objects,
- inventory of green spaces and parks in settlements,
- allotment and taxation of logging areas,
- creation of a central database for forest monitoring,
- creation of the central geodatabase of the State Enterprise "Ukrderzhlisproekt", etc.

Field-Map technology is used in educational processes, it is included in the curricula for training forestry specialists at the forestry faculties of Kyiv ( NULES), Lviv (NLTUU) and Kharkiv (KNAU). Students of these educational institutions have the opportunity to master the Field-Map technology in practice and further work with it to solve various tasks of the forestry industry.

## 3. Results of using the Field-Map software for quality control of the NFI data

The methods of data quality control of the NFI Ukraine included:

- use of the "Database query tool" in Field-Map Data Collector, use of the "Data validation" function and control of tree species filling for trees, control of missing or zero values of tree diameters, tree heights, all quantitative indicators, large diameters and large heights; missing heights in the update;
- query system in MS Access.

The stages of the quality control of the NFI data using Field-Map included:

- analysis of completeness of data in the database - identification of missing or atypical data;
- analysis of the integrity of the reference books, absence of duplications, comparison with the Procedure and Methodology;
- verification by means of Field-Map - transfer of the subplot ID number to the attributes of trees and microplots. Control of compliance with subplot ID in trees;
- queries to detect "extra trees" - trees that are outside the plot or whose diameter does not meet the boundary requirements for certain subplots. Adding a "include in analysis" field;
- data control using the Database query tool in Field-Map Data Collector: control of filling in tree species for trees, control of missing or zero values of tree diameters, tree heights, all quantitative indicators, large diameters and large heights, control of missing heights in the update.

As a result of Field-Map application, the following main errors were identified in the NFI database of Ivano-Frankivsk oblast for 2021, which negatively affect the quality of NFI results:

**Mapping errors related to the imperfection of the GIS component and data entry control in the Small Forest programme:**

- when building GIS layers based on X and Y coordinates, it was found that this data was incorrect for all mapped objects, as the wrong formula was used to convert the measured distance and azimuth. There is also no conversion of distances to horizontal distance, which is important in mountainous conditions;
- due to the fact that the NFI data entry programme does not calculate the area of parts in the case of 2 or more parts, but contains only the coordinates of the boundary lines between the parts, it is necessary to use external programmes to calculate the area;

- complicated system of identification of multipolygons of parts (for example, plantations are divided by a road), which causes errors in entering data on parts of the plot. Due to the peculiarity of the input program, descriptive data about the multipolygon is entered only in one of the parts, and the other (from the multipolygon) remains blank, although each part has its own numbering. When working with data, it is often difficult to determine which part of the data belongs to which multipolygon without mapping (an image). Incorrect identification of polygons leads to incorrect classification of forest categories and calculation of areas for NFI reporting;
- absence of the function of assigning trees, microplots to plots by GIS (data on plot number is entered manually by executors, mistakes are possible, especially given the lack of clarity with multipolysons);
- in the data entry programme, the default values in the blank fields of the database are "-1" for qualitative and "0" for quantitative attributes, which causes problems in calculations (for example, most trees had a height of 0).

**Incorrect entry of accounting trees located outside the NFI plot into the database:**

- Due to the imperfection of the GIS component of the Small Forest software, 211 "extra" accounting trees that do not meet the distance and diameter requirements were entered into the NFI database during the fieldwork - thin trees were mistakenly included in larger subplots, or the accounting trees were located outside the plot (non-tariff trees) (Fig. 5). This error is critical, as it leads to overestimation of the number of trees, stocks, and fullness. This may be partly due to the use of measured distance instead of horizontal distance, as well as the failure to take into account the diameter when mapping the tree, but also to the failure of contractors to follow the rules for assigning trees to circular subplots. It is advisable to develop a specific programme to control tree mapping;
- One extra recorded tree on a plot, depending on its diameter, leads to an increase in the total estimated number of trees at the level of Ivano-Frankivsk oblast by values ranging from 62,800 thousand (with a diameter of 26 cm or more) to 3.1 million extra trees (with a diameter of 2-6 cm), which causes corresponding proportional changes in stock estimates;
- Some regeneration units were found to be non-compliant with the requirements for the size of regeneration on microplots. 11 renewal units with heights of 1.3 m and above were entered into the database by mistake, 3 of which have a diameter greater than 2 cm. Given the small area of the restoration assessment (1 $m^2$), each extra restoration unit leads to an increase in the estimated density of restoration by 10,000 units per hectare.

**Problems with the definition of "forest" and "non-forest" land:**

- most statistical calculations of the NFI results are based on the category "forest land" and " forest covered land", and this affects the correctness of the definition of forest areas and all related indicators. Plots classified as "forested" were identified on which there were no recorded trees (the tree table was empty), but there was a taxation description of forest elements. Due to the absence of tree and regeneration data for these plots, it is not possible to calculate the completeness, stock, and classify these data as plantations of dominant species. A single approach should be applied to such cases - indicate the category "not covered with forest".

**Errors in assigning records (trees, breaks, stumps, microplots) to the appropriate parts of the inventory plot:**

- Cases of mapping broken outside the plot, which leads to overestimation of deadwood stocks in calculations, and errors in assigning trees and bracken to parts of the plot were identified;
- It is also very important to correctly identify the dominant species for a part (most reporting tables include distributions by dominant species). Inconsistencies in the dominant species in the table "Parts" were found - for example, "field maple" is indicated, while in the list of forest elements there is only "sycamore".

**Problems with the structure of the database and handbooks:**

- the database structure has a "Part number" indicator in the "Trees, Stumps and Breakage" tables, but it is absent in the "Renewal" table. It is advisable to add it;
- the database contains unnecessary attributes with missing data, as well as unnecessary identifiers in the microplots, woody debris, and stumps tables that duplicate other identifiers in these tables (List of unnecessary fields: In the tables l_ven_ (Zana); l_Uha (Area1, Area2, Area3, Area4, Koef, GeoMet); Laman_ (Id); Pni_(Id); Ponovlen_ (Id));
- a problem was detected when transferring data (origin, age, diameter, height) from forest elements (Jarus) to the description of parts (l_Uha_), since the forest element that is the dominant species is not marked in the Jarus table. The way to solve this is to make changes to the database: add a field in the forest element table that will display whether the forest element is the dominant species. (For example: in several cases, in the description of forest elements in one part there were records for the same tree species but in different tiers - and this caused a problem in determining the dominant species and transferring its characteristics: age, diameter, height and origin);

- there are problems with transferring "age" data from the "forest elements" table to "age" in the "trees" table - the link is made by plot number, part number, layer and tree species, and from tariff trees, but for 333 trees the age could not be transferred, the probable reason is that the species is not in the forest elements, or there are several combinations of part - layer - species. Perhaps this indicator should be better transferred automatically by software. Or apply a certain type of modelling based on the age of tariff trees, height or diameter;
- there are duplicate records in the UserGrupa and User1 directories - different IDs, but the same content, which violates the rule of unambiguity when selecting a category from the directory;
- there are no reference books in the database for the indicators Ogolenost, ZmitestGoriz, layering, type of rot (stumps). These fields have no data in the respective tables (all "-1");
- the list of reference books (in the transferred Excel Reference Books file) does not contain the reference book Drying Factor (trees), although it is available in the database.
- there is a duplication of records - the same species (raspberries, blackberries) are listed in the undergrowth and vegetation directories, and there are cases when both were filled in;
- in the table of regeneration height classes, there are shrub species (prickly hawthorn; Swida alba (L.); Cornus sanguinea; common hazel), although there should be only tree species. - problem with the directories or with the observance of the methodology by the performers;
- The tree damage type (XDAMAGE_TYPE) directory contains an unknown element -100 - a "+" value that is not in the table.

**Data entry errors due to incorrectly selected handbook items:**

- the dominant species was mistakenly indicated for the category of land - "Timber", although there are no trees on the site (1 case).
- a probable error in the assignment of trees to stand layers was detected. For most of the trees, it is indicated that they belong to 1 layer, or 1 layer and understory, while according to the height data, it appears that the trees should belong to different layers (I and II). Probably, the problem with the layers caused a problem with the completeness, which was overestimated based on the results of calculations for the accounting trees. In addition, the tree table mistakenly indicated the Drywood layer for living trees (13 cases);
- error in filling in the origin of the forest element (for example, spruce - vegetative origin - 1 case);
- mistake in the region (one plot from Ivano-Frankivsk region is marked as Lviv region);

- plot status - (incorrect interpretation of the values of the handbook by the executors), probably not a clear description in the methodology. This indicator - for the first year of survey, there should be only 300 - New plot, and for repeated surveys, all 3 options are possible. This indicator is needed to track the dynamics of repeated surveys. Erroneous records for 51 plots;
- For three trees, it was indicated that they are dead trees (class 200 of the GiveSuche guide and sanitary condition classes 5 and 6) and at the same time data on the presence of damage (broken roots) were entered, although this should not apply to dead trees;
- For two plots with regeneration units (in the table of regeneration height classes), the description of microplots mistakenly states that there is no regeneration.

**Forms for surveying NFI plots are not fully filled in - there are empty mandatory fields:**

- the age of the dominant species for forest elements was not indicated; for the forest category of land, the main characteristics of the stand, TLU, were not indicated; user data were often missing (for the 2nd and next parts of the plot);
- not all elements of the tree line had the number of the part where they are located. It is necessary to supplement with actual data, since the assignment of data to parts is important for the calculation, which is carried out through the part number;
- There are no records of microplots (1 plot in forest conditions) - even if there is no update, they should be filled in.
- Plot 261157933 has no data on stump heights.
- In the table "Description of stands" (forest elements) - the values of absolute completeness (BAS element) are not filled in, or "0" is indicated.

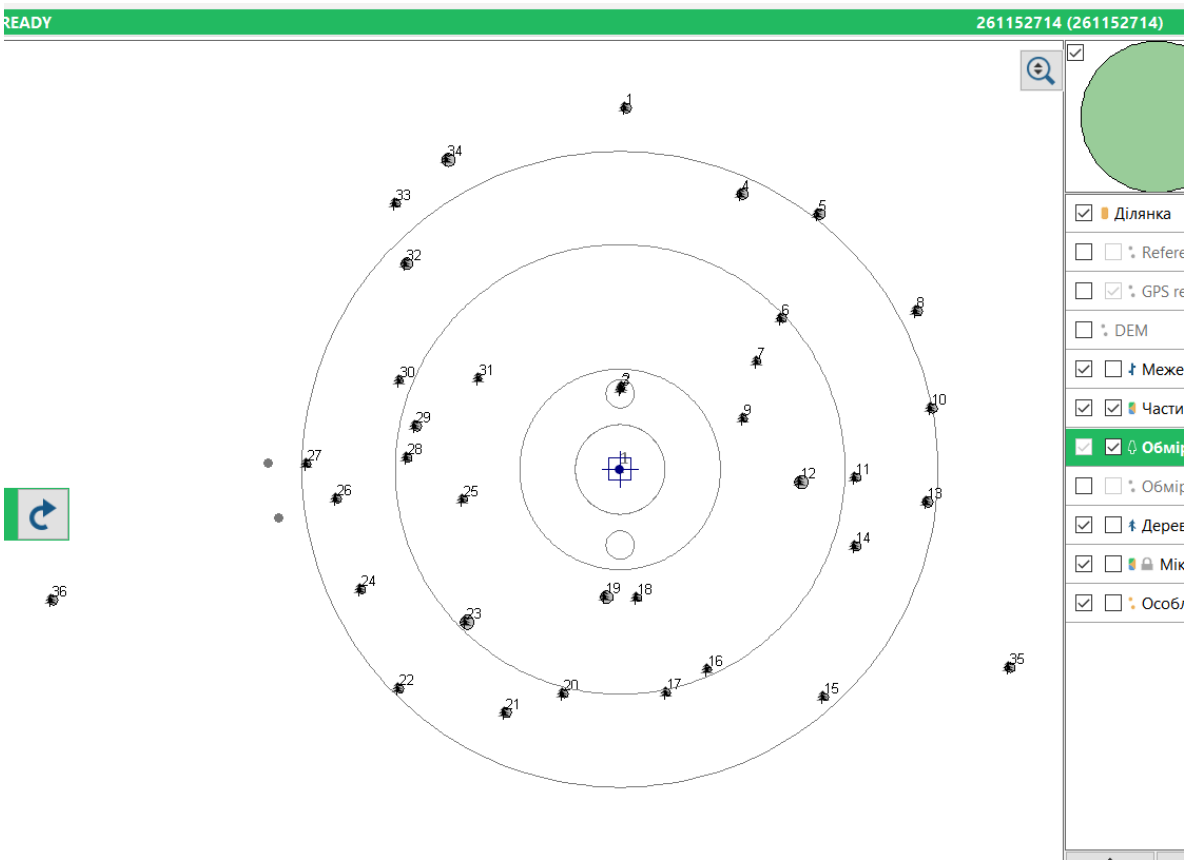


*Figure 5. Example of visualisation in Field-Map of "extra" trees located outside the inventory plot (trees 1, 5, 8, 10)*

The use of Field-Map technology for field collection of NFI data will reduce the number of errors associated with tree mapping, polygonisation and multipolygons, thanks to built-in controls - reducing the percentage of missed values and incorrectly entered values. In addition, thanks to the synchronisation function, Field-Map ensures that field data is transferred directly to the central database on a daily basis.

After verification of the field data of the Ukrainian NFI collected in 2021 within Ivano-Frankivsk region, calculations were made using the Field-Map Inventory Analyst software for the verified field survey database and reporting tables were obtained, as provided for by the Procedure for conducting the Inventory of Forests (approved by the Resolution of the Cabinet of Ministers of Ukraine of 21 April 2021, No. 392). Fig. 6 shows the results of calculations of the reporting table 2.1 - Total stocks of dominant species (by groups of species and genera), which contain statistical results of determining the permissible errors.

| Групи порід | Sum_live_V_VS | | |
|---|---|---|---|
| | млн. m3 | (α = 0,05) | % |
| Хвойні | 131,42 | (107,74 – 155,09) | 59,0 |
| Твердолистяні | 80,99 | (63,62 – 98,36) | 36,4 |
| М'яколистяні | 9,15 | (4,16 – 14,15) | 4,1 |
| Інші породи | 1,14 | (0,03 – 2,24) | 0,5 |
| Разом | 222,70 | (203,02 – 242,37) | 100,0 |

| Роди панівн породи | Sum_live_V_VS | | |
|---|---|---|---|
| | млн. m3 | (α = 0,05) | % |
| Сосна | 1,14 | (0,00 – 2,63) | 0,5 |
| Ялина | 109,33 | (86,53 – 132,14) | 49,1 |
| Ялиця | 20,94 | (9,51 – 32,37) | 9,4 |
| Дуб | 14,22 | (6,90 – 21,54) | 6,4 |
| Бук | 54,53 | (37,98 – 71,08) | 24,5 |
| Граб | 8,80 | (3,63 – 13,97) | 4,0 |
| Клен | 3,44 | (0,07 – 6,81) | 1,5 |
| Береза | 0,71 | (0,00 – 1,59) | 0,3 |
| Вільха | 1,24 | (0,00 – 2,79) | 0,6 |
| Липа | 4,64 | (0,90 – 8,37) | 2,1 |
| Верби др. | 0,52 | (0,00 – 1,53) | 0,2 |
| Інші | 1,14 | (0,03 – 2,24) | 0,5 |
| Осика | 2,05 | (0,00 – 4,84) | 0,9 |
| Разом | 222,70 | (203,02 – 242,37) | 100,0 |

*Figure 6. Total stocks of dominant tree species in Ivano-Frankivsk region, 2021.*

The use of Field-Map Inventory Analyst for statistical calculations of the NFI reporting tables, which are provided for by the current NFI Procedure of Ukraine, shows that the significant advantages of this software module include

1) Built-in system for calculating auxiliary indicators: modelling heights, assigning trees to parts, calculating part weight coefficients, representative tree areas, representative number of trees, assigning the category "Not covered with forest" for areas without trees and renewal.

2) Built-in system for aggregating data from subordinate layers to the level of higher-level layers: for example, total volume of breaks on the plot.

3) Built-in system of classification of quantitative data and reclassification of qualitative data, which allows adding new classifiers based on existing data without programming.

4) Convenient system for formulating statistical data processing tasks, with the ability to save the algorithm.

5) Built-in function for calculating statistical indicators: sum, mean, normalised mean and confidence intervals.

6) Possibility to enter fixed final values of area, quantity, volume (since all calculations cannot be performed in one project, the final values from the main project (e.g., area of forested land) were used for calculations in the auxiliary project when calculating the regeneration characteristics.

7) Possibility to create profiles for oblasts and for the whole of Ukraine, with the introduction of relevant areas and setting filters

8) Most of the tasks of statistical processing of Ukrainian NFI data are already implemented in FMIA.

At the same time, the existing structure of the Ukrainian NFI data base, which combines concentric circles and segments, does not allow using FMIA alone without involving additional programs and intermediate calculations. Potentially, some intermediate calculations can be automated using scripts in FMIA, but this task requires some experience in such work, and may be a task for the future for specialists with the appropriate qualifications. For the comprehensive and efficient use of Field-Map technology in the field collection of data at the NFI plots, their subsequent analysis and reporting, it is necessary to improve the structure of the Field-Map project database, refine methods and test the calculations of the NFI indicators of Ukraine based on the array of real NFI data.

**Typical NFI tasks that are solved with the help of Field-Map technology:**

- The Field-Map technology covers almost all stages of the NFI (preparatory, field and desk) and provides effective solutions for: developing the NFI design, forming the NFI observation methodology, creating the structure of the NFI database, conducting field work at the NFI plots, controlling and ensuring the quality of NFI data, processing the results and publishing NFI reports. Typical tasks that the Field-Map software and technology complex helps to solve:
- Preparation of the inventory design based on the NFI data collection methodology
- Formation of the structure of the NFI database
- Compilation of background maps (including remote sensing materials, vector and raster maps, WMS)
- Generation of NFI inventory plots centres
- Preliminary classification based on remote sensing data
- Navigation to the centre of the NFI inventory plots
- Locating the centre of the NFI inventory plot

- Field surveys on the NFI inventory plots
- Mapping of tree positions
- Mapping of subplots
- Recovery of tree identifiers
- Automatic entry of mapping and measurement results from electronic devices into the NFI database
- Efficient entry of descriptive attributes into the NFI database
- Verification of the completeness and reliability of the collected data on the NFI plots
- Preliminary processing of the collected data directly at the NFI plots
- Formation of the central NFI database, maintaining its integrity and relevance through synchronisation
- Technological solutions for independent verification of the quality of collected NFI data (verification of completeness, reliability, repeated measurements at the NFI plot with the formation of comparative data)
- Calculation of derived attributes directly on the NFI plot
- Post-stratification, classification, reclassification of NFI indicators
- Statistical processing of field data of the NFI
- Preparation of reports on the NFI according to user-defined templates.

## 4. Recommended measures to ensure the quality of the NFI data

Currently, the NFI activities in Ukraine have already started and include quality control at the level of selective field re-measurements and control checks. However, the work with the transferred data for Ivano-Frankivsk oblast revealed existing errors that were not detected and corrected, which indicates the need to improve the quality control system for the NFI data.

Data quality assurance and control should be carried out at different stages of the NFI: before the start of fieldwork, during fieldwork (including control re-measurements and checks) and after the end of fieldwork. The main criteria used to interpret the level of data quality are:

1. Precision - the ability of a method to reproduce the same value

2. Accuracy - the ability of a method to produce the "true" value.

3. Completeness - the amount of reliable, usable data obtained by a method

4. Comparability - the ability to combine data collected in different places and by different performers.

Effective quality assurance will help to prevent a range of problems with data quality, evaluation, analysis and correction.

Preparation for fieldwork

Preparation for fieldwork is critical to minimise any sources of error and ensure that teams have the right training, information and logistical support to fully perform their duties within the time constraints.

The team training is an integral part of the quality assurance system for NFI work and is conducted prior to the start of the current year's fieldwork to ensure that the workforce is properly trained. The purpose of the collective training is to practice the technology of surveying and measuring the NFI plots and to achieve the appropriate level of accuracy in determining the indicators. The training should also include work on errors: consideration of typical errors identified during quality control in previous years of the NFI.

The methodological basis for conducting collective training in Ukraine is the Procedure for Conducting National Forest Inventory (2021) and the Regulation on Quality Control (2020). However, the lack of approved methodological guidelines for conducting the NFI fieldwork remains a significant problem.

The collective training is mandatory for all members of the inventory and control groups who will be involved in the field work on NFI.

Based on the results of the assessment of knowledge and skills after the collective training, each participant of the training should be allowed to conduct work with NFI.

The collective training is conducted annually 2-4 weeks before the start of the current year's NFI fieldwork (late April - May). The main part of the collective training takes place over 5-7 days.

Before the field trip, the senior in the group should:

- Contact the supervisor and the NFI unit to obtain any necessary information and permission.
- Check the location of the plot/inventory tract prior to departure, using available maps and the NFI plot map.
- Plan transport routes and time to the NFI plots scheduled for survey on a given day.
- Prepare a list of received equipment for inventory according to the checklist and check it.

**Quality control during fieldwork.**

Quality control during fieldwork.

Tasks of control and supervision during fieldwork:

- verification of compliance with the requirements for the performance of work set out in the methodological documents;

- timely identification and elimination of faults in the work of field inventory teams;

- identifying and ensuring correction of errors in the information on the indicators of the NFI.

***"Hot check" inspections*** are conducted to assess the accuracy of the field team's measurements and provide immediate feedback that will improve the accuracy of future measurements. Definition: The control team accompanies the field team to the NFI plot and observes the field team's work, paying attention to measurement methods and efficiency, and the accuracy of the estimates. In effect, the control group conducts the measurements together with the field team, assisting them in data collection. This is part of the training, not a performance evaluation. The field teams have the opportunity to ask questions and discuss the assessments made in specific cases with the supervisory team. The control group can also re-measure after the field team's measurements and provide feedback on these measurements. This contributes to better measurement results. It is recommended to conduct "hot" checks, especially with new field teams, at the beginning of the field season.

***"Cold" checks*** are carried out to assess the accuracy of the field team's measurements by re-measuring the plot after 2-4 weeks. The control group re-measures the area previously measured by the field team, compares the results and prepares an evaluation report that is provided to the field team and the NFI unit for discussion. The location of the plot to be cold-tested is determined by the NFI unit. It is important that the field teams do not know which plots will be checked by the control team so that this does not affect their fieldwork. The cold check should take place within 4 weeks of the first measurement. The control group checks the characteristics of the land categories, measures dendrometric variables (such as taxonomic diameter, height).

Some of the plots are subject to cold checking. The control group completes the verification with a copy of the data collected by the field team so that they can directly verify the results. During this process, all errors identified by the control group are entered into the cold check results table. Once the scorecard is completed, a quality and quality control score is automatically assigned, which can be used to evaluate the field team's performance. A score of 100% means that no errors were found, while a score of less than 85% is considered unsatisfactory. On the basis of the information contained in the scorecard, the control team will prepare a cold check report, which will contain the score calculated on the basis of the scorecard, a brief description of the checks, including a list of all relevant errors that were identified, as well as any other comments and follow-up actions. The report should be presented to the field team for discussion.

**Database validation rules**

All data from NFI field surveys are transferred to a central database. Data control rules should be applied to limit the entry of erroneous data and to promote the correctness, consistency and accuracy of the data collected. Validation rules include: data type checking: - matching the data entered to the expected data type defined for that particular field. Range checking and constraint checking: checks whether the entered value falls within an acceptable range of values. Checks for the absence of a record. Cross-checks: checks whether the data entered in different fields matches a set of underlying assumptions. For example. The ratio of diameter to height.

In Germany, to ensure quality control, control groups are formed at the level of the federal government. During the control of the work of field teams, the presence and significance of errors in the determination of NFI indicators (the number of trees on the plot, the values of tree heights and diameters are within the permissible limits, etc.) Error limits are specified for each criterion. Based on the results of the control, a protocol of errors is drawn up, and if they exceed the limits, they must be eliminated by the contractor at his own expense. If the control group

determines that the quality of work is inadequate, the plot shall be re-inventoried at the expense of the contractor.

The statistical inventory data is processed using methods related to stratified, random and sample observation. The main statistics are the total (e.g., forest area, number of trees), the mean or median (e.g., average stock per hectare), and the confidence interval, taking into account the distribution of empirical data.

The standardised mean is calculated by assigning the value to the part of the plot with the presence of the category being assessed. This method is used to calculate data on hectare stocks of individual tree species.

If the number of measured heights of a particular species on the plot is sufficient, then a local model (at the plot level) is used, which is parameterised using the least squares method.

If the number of heights measured is insufficient, then a global model is used (for a particular tree species for inventory plots with similar growth conditions, age, and fullness). If at least one height for a tree of a given tree species has been measured on the plot, then the global model is matched to this data.

The Field-Map software has a special module for quality control of field data, which allows for ''hot'', ''cold'' and ''blind'' checks at the inventory plots, comparing the results obtained by field and control teams and printing a comparison report containing the results of calculations of statistical deviation values and graphical comparisons. This allows analysing the results obtained directly at the NFI plot and making appropriate adjustments to the data collection processes.

## 5. Draft manual for data quality control of the NFI of Ukraine

### 1 Terms and definitions

National Forest Inventory (NFI) is a system of selective statistical surveys of the forest fund of Ukraine aimed at obtaining reasonable generalised information on forests for planning purposes, including strategic planning, forest management, state forest cadastre, and forest monitoring.

NFI observation programme - document(s) that define the composition of data collected within the NFI.

NFI Observation Regulations - document(s) that define actions to be performed within NFI, responsible persons, location and timeframe.

### 2 Symbols and abbreviations

### 3 Purpose of the manual

The guidelines shall provide:

a. Homogeneity, quality and completeness of primary observation data

Responsible for the organisation and control of observations have the opportunity to obtain the necessary information on sensitive areas and related stages of work.

b. Prevention of data loss during processing, transmission and storage

Timely detection, correction and documentation of data defects

c. transparency and reliability of the NFI data quality control system

Facilitates understanding by data consumers of the procedures used and the level of adequacy of the accumulated results of the NFI. When changing those responsible for organising and controlling observations, it should facilitate learning of procedures

d. Reduce the time required for the publication of NFI data

By correcting errors and defects as soon as they are detected, reducing the time required for data analysis and clearing them of accumulated errors after the year's observational data set is completed.

e. Continuously improve NFI observations and respond to changes

Identify procedures and improvements related to the biggest challenges. Responding to changes of external factors that affect data quality and relevance.

## 4 Overview of the NFI data collection process

Should be based on a survey of current NFI processes.

## 5 Observation programme and schedule

The programme and schedule of the NIF observations should not be changed after the start of the fieldwork, and all changes should be confirmed by the responsible persons of the NFI. All participants of the NFI should be informed about the changes before their final approval, as well as about the fact of approval of the changes.

## 6 Implementers

Field and cameral NFI work should be carried out by trained (having completed the necessary training and confirmed skills) performers.

### 6.1 Procedure for selecting and training of implementers

The principles on which the selection of contractors is carried out shall be fixed. The training shall be documented and conducted in accordance with the requirements of the Guidelines for collective training of participants of the National Forest Inventory (2020).

### 6.2 Responsibilities of contractors

Shall be documented and made available to specialists involved in data collection and analysis

### 6.3 Registration order of contractors and storage of information about them

All collected data should be linked to the person who provided a particular stage of data collection. The purpose is to allow the contractor to clarify any uncertainties that may be found in the data.

## 7 Data collection and storage

All steps of the data collection and storage process should be known to all participants in the NFI to ensure horizontal communication:

### 7.1 Means used to preserve the NFI data

#### 7.1.1 Primary observation data

The primary observational data should be stored in a defined manner.

#### 7.1.2 Consolidated observation database

The logical structure, software tools and implementation details should be documented and made available to the NFI participants and data users

according to their roles (access to information on software tools and implementation details may be significantly narrower than to the logical model).

7.2 Storage of primary NFI data

Primary observation data should remain available for a specified period of time (at least until the results of the annual observations as a whole are approved). Any actions to destroy the primary data should be authorised by the staff responsible for maintaining the NFI.

7.3 Procedure for entering new primary data into the database

When entering primary observation data into the database, both the performer who collected the data and the performer who entered it should be recorded. The entry protocols should be available.

7.4 Procedure for making corrections and additions to the database

When making corrections and additions to the database, both the contractor who made the changes and the grounds for them should be recorded. The protocols for making corrections shall be available.

7.5 Rules for checking the logical consistency and relevance of data

Should include both checks of reference integrity (database consistency) (availability of records in relevant directories and database objects - for example, executors) and checks of the correctness of information sets generated by the data being checked in terms of other information sources

7.6 Procedure for detecting contradictions in the data being entered or corrected

If contradictions in the data to be entered are detected, it is necessary to

a. Record the fact of discovery
b. Investigate the causes of the differences
c. Approve the arbitrated (correct, non-controversial) version of the data by the employees responsible for maintaining the NFI
d. Enter the arbitrated data into the data storage

## 6. Summary

1. The analysis of field data collected in Ivano-Frankivsk region in 2021 using the Field-Map software allowed us to identify the main directions for solving the problem of improving the quality of the NFI data in Ukraine by:
    - Making amendments to the NFI methodology, publishing the final version of the methodology;
    - Training of executors with feedback and individual work on identified errors;
    - Conducting control checks and re-measurements of the NFI plots;
    - Application of GIS software together with the means of controlling the formed database directly at the NFI plots (minimum/maximum values, logical checks, control of accounting trees, control of missing values, control and visualisation of mapping of objects at the plots, formation and maintenance of the unified NFI database with the possibility of daily current control of all collected data);
    - Formation of a unified NFI database, with the possibility of ongoing monitoring of the collected data;
    - Documenting in a transparent way the algorithms for calculating the NFI indicators.
2. Usage of modern technologies and means of collecting and processing information, in particular, mobile GIS technologies and remote sensing data, is critical for the development of the Ukrainian NFI.
3. The system solution that forms an integral technological platform for the development of NFI is based on the use of mobile (field) geo-information technology Field-Map (https://www.fieldmap.cz/), which was developed by the Czech Institute for Forest Ecosystem Research (IFER) specifically for NFI and is used in more than 44 countries for forest inventory, mapping, forest management and forest research.
4. Ukraine has significant experience in the application of this technology due to the Czech-Ukrainian project TechInLis, which involved specialists from URIFFM, Ukrderzhlisproekt and forestry universities from Kyiv, Lviv and Kharkiv.
5. The Field-Map technology is a fully functional GIS capable of supporting the entire technological chain, from plot network design to printing of the NFI reports.
6. The quality assurance system for NFI data developed in Field-Map allows for various types of control of NFI work - both directly at the NFI plots and in the

office - to monitor the quality of the collected data. Using Field-Map, it is possible to develop software in accordance with the requirements of the Ukrainian NFI relatively quickly.

7. The proper level of data quality can be ensured by using a high-tech Field-Map system, but it is important to train field team members, teach them how to use the equipment in different conditions, ensure constant coordination of work (any changes should be communicated to all groups simultaneously), and the selected solutions should be tested and tried in advance.
8. The above measures for quality control of the work on the NFI of Ukraine will help to achieve proper quality of the work and ensure the reliability of the collected information on the state of Ukraine's forests.

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