CNFI

Centre of National Forest Inventory
of Ukrainian State Forest Management
Planning Association

How much forest resources do we have in Ukraine?

Data, Methodology and Output of the Remote Sensing-based Forest Inventory 2023

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SFI Sustainable Forestry Implementation

unique land use

IAK AGRAR CONSULTING

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The National Forest Inventory (NFI) is common standard for assessing forest resources in support of the national forest policy in nearly all European countries. The implementation of a NFI in Ukraine is violated by the ongoing Russian invasion, which hampers the collection of required field data. In particular, large areas were not controlled by the Ukrainian government in 2023. It was also impossible to collect NFI data in many places close to the front lines or in areas contaminated by unexploded ordnance/ landmines, radiation, etc.

To a significant extent, this situation can be overcome by technological advances in the combined use of field sampling data and remote sensing observations. Satellite imagery provides wall-to-wall coverage of large areas and additional information to support modeling approaches to retrieve forest information even in inaccessible areas. Therefore, a concept for the implementation of a Remote Sensing-based Forest Inventory (RS-Inventory) was developed to estimate the forest resources of all of Ukraine, using collected sample plot data from accessible forest areas and forest management planning information, in combination with satellite images.

The concept of the RS-Inventory assumes the use of sample plots collected in the NFI program, using a regular nationwide sampling design. For Oblasts of Ukraine where field sampling is not possible due to the war (Chernihiv, Kharkiv, Luhansk, Donetsk, Zaporizhzhia, Kherson Oblasts, and Autonomous Republic of Crimea), forest stand characteristics were obtained from the most recent (less than 5 years) forest management planning (FMP) data sets. The combination of both NFI and FMP data, and satellite observations provided the basis for the implementation of the national forest assessment through mapping and statistical modeling procedures.

This brochure presents an overview on data sources, methodology, output maps, and estimates of the RS-Inventory within Ukraine. More details can be found under https://nfi.lisproekt.gov.ua/en/. This is the first complex assessment of Ukraine’s forests, which has been made possible by integrating expertise from different fields, including field sampling, statistical assessment, remote sensing, and modelling.

Objectives

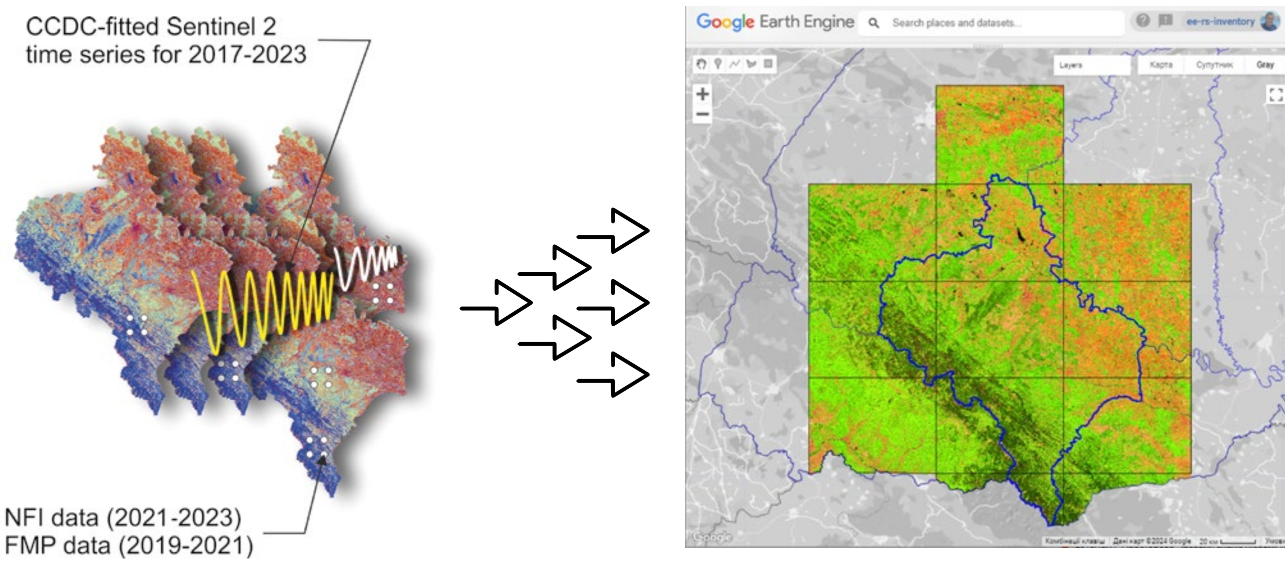
From a management perspective, the RS-Inventory supports a wide range of applications. Given the limitations of field data collection using traditional methods throughout Ukraine, the RS-Inventory provides a cost-effective forest monitoring protocol even for hard-to-reach areas. This approach is not intended to replace the NFI data collection, but to complement it with regularly updated forest statistics and maps for use in decision-making at the national level.

The specific objectives were as follows:

- Harmonize forest monitoring in Ukraine with best practices used in Europe and other developed countries.
- Support NFI reporting with limited resources.
- Provide the first spatially explicit assessment of forest resources in Ukraine.
- Develop forest maps.
- Improve the capacity for continuous forest monitoring and decision making in Ukraine.

Satellite imagery

This RS-Inventory utilized Sentinel 2 satellite time series acquired from 2017 to 2023. To eliminate random variations in spectral data caused by remote sensing conditions, the time series were screened from snow, clouds, and cloud shadows and temporally "smoothed" using the Continuous Change Detection and Classification (CCDC) algorithm (Zhu & Woodcock, 2014). This procedure captured cyclical patterns of vegetation phenology at 20 m image resolution, providing important data for improved forest mapping (e.g., phenology-based classification of tree species). Given the large volume of satellite information and computationally intensive algorithms, image processing was performed in the Google Earth Engine cloud computing platform (Gorelick et al., 2017).

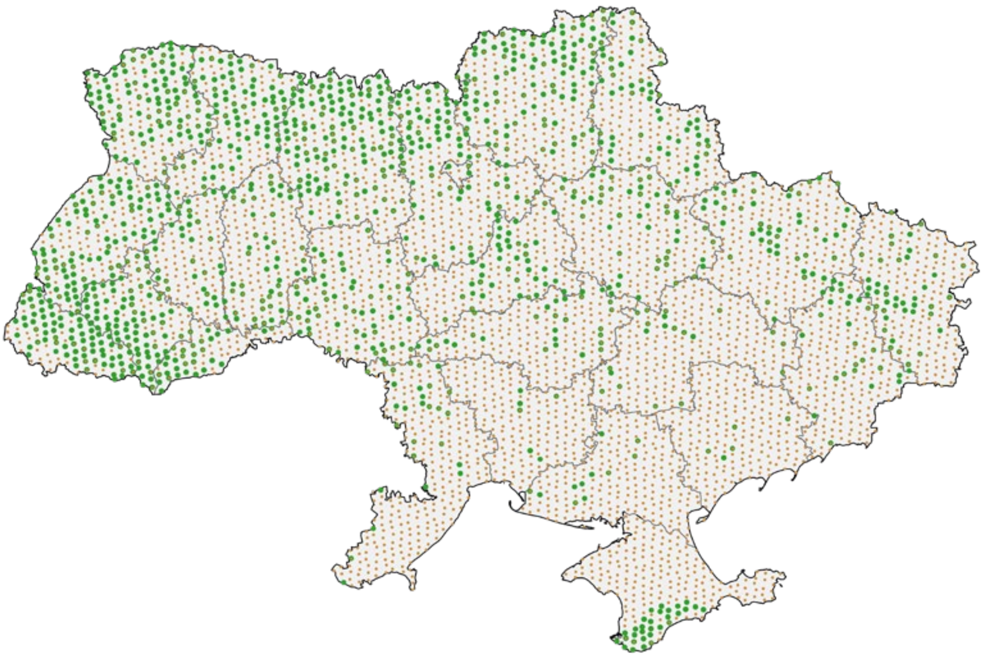


National Forest Inventory

The RS-Inventory used NFI plot data collected in 2021-2023 in 18 Oblasts of Ukraine. In the framework of the NFI, field work was conducted in accessible forest areas on about 4,100 sample plots. Out of these forest stand characteristics from approximately 3,000 sample plots were used as reference data to create maps of these characteristics within forested areas using satellite imagery.

Information on forested and non-forested land cover types observed on each sample plot was used to create a forest map for 2023 (i.e., "forest mask"). This was collected by visually interpreting all NFI plots using Google Earth Pro high-resolution images.

The figure shows the NFI sampling grid of Ukraine. Forested NFI plots are shown as green dots.



Forest Management Planning

FMP data, collected shortly before the invasion, was used for seven Oblasts where NFI field data could not be collected due to the ongoing war. The data structure of the FMP is similar to that of the NFI, but mainly represents average forest attributes observed within an entire forest stands rather than at a discrete point (i.e., sample plot). A subset of forest stands intersecting the NFI grid was used as a complementary reference dataset. The need to include both data sources in this work was driven by the situation in Ukraine, where many areas are not accessible for safe field visits due to the war (temporarily occupied areas, areas along the front lines, contaminated areas, etc.).

Other types of information included gridded layers of topographic features and climatic variables, boundaries of administrative Oblasts of Ukraine, ecozones, and war-affected areas.

NFI plot data

Plot ID	*Attribute 1*	*Attribute 2*	...
Plot #1			
Plot #2			
...			

FMP forest stand data

Stand ID	*Attribute 1*	*Attribute 2*	...
Stand #1			
Stand #2			
...			

Data processing workflow

1 Collecting field observation data
Per-hectare estimates of forest attributes for NFI sample plots and FMP data.

2 Mapping forests and dominant species
Random Forest machine learning algorithm (Breiman, 2001).

3 Forest attributes mapping
Gradient Nearest Neighbor (GNN) predictive mapping technique (Ohmann & Gregory, 2002).

4 Accuracy assessment using independent observations
Leave-one-out cross validation for mapping forests and dominant species (James et al., 2013).
Seven first independent neighbors for GNN imputation model (Ohmann & Gregory, 2002).

5 Statistical estimation procedure
Map-based assessment of forest area using confusion matrices (Olofsson at al., 2014).
Model-assisted estimation of continuous forest characteristics (McConville et al., 2020).

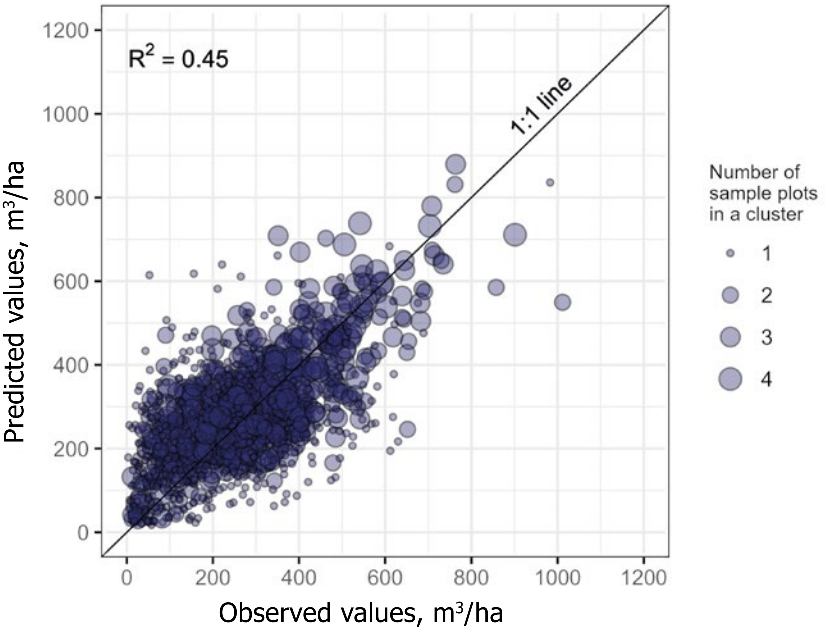
The RS-Inventory used the biophysical definition of forest as an area covered by woody vegetation with a predefined minimum canopy cover (> 50%) observed at 20 × 20 m pixel level regardless of its legal status. Accordingly, the forest maps and derived statistics included some categories (e.g., other wooded land, urban tree cover) that are not considered as forests according to Ukrainian regulations or common international definitions. The forest area according to the official definition can only be extracted using GIS analysis within the boundaries of the forest fund.

Testing model performance

Classification and predictive models have been evaluated using a variety of statistical procedures. The optimal model was selected based on the highest accuracy for categorical variables (land cover types, dominant species), and the best ability to provide precise results for continuous forest attributes: basal area, growing stock volume, average age, average diameter, average height, stand density, live biomass, and accumulated carbon.

The available reference data allowed to obtain results with the required accuracy for (I) the national level, (II) individual climatic ecozones according to Gensiruk (1992), and (III) war-affected areas. The aggregated results for these spatial domains constitute the main output for 2023. However, the results for administrative Oblasts are available in the form of maps and estimates obtained at the 20-meter spatial resolution.

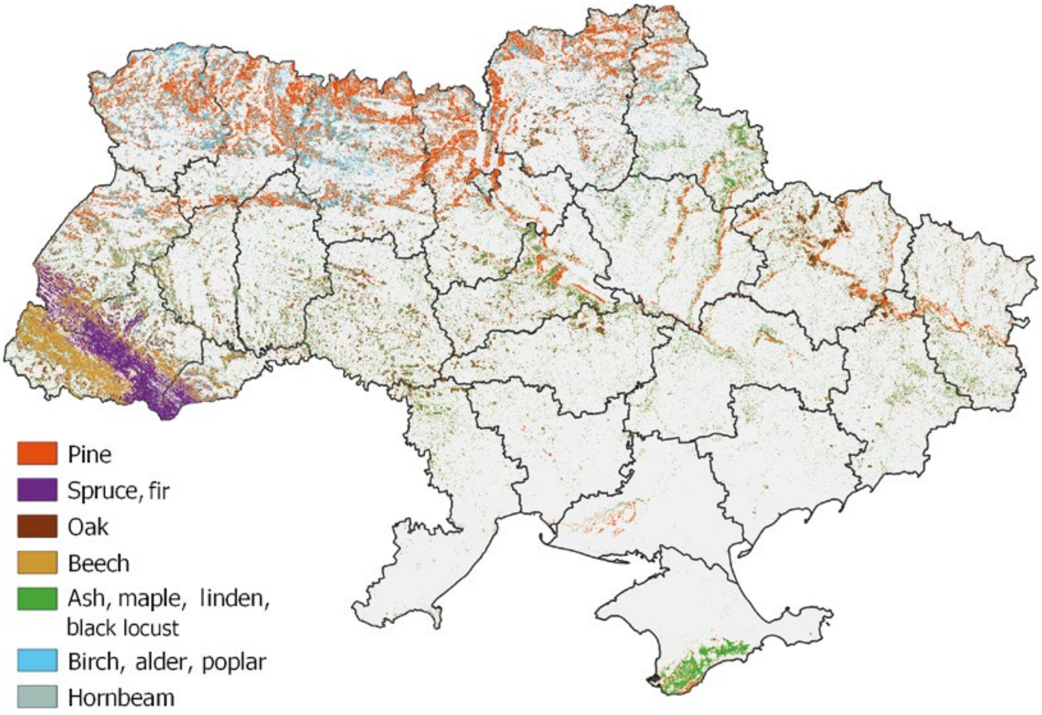
A comparison of observed and predicted values for each variable of interest was used to gain general insight into model performance. An optimal model was selected after detailed examinations using a variety of accuracy metrics.



Accuracy of the tree species maps

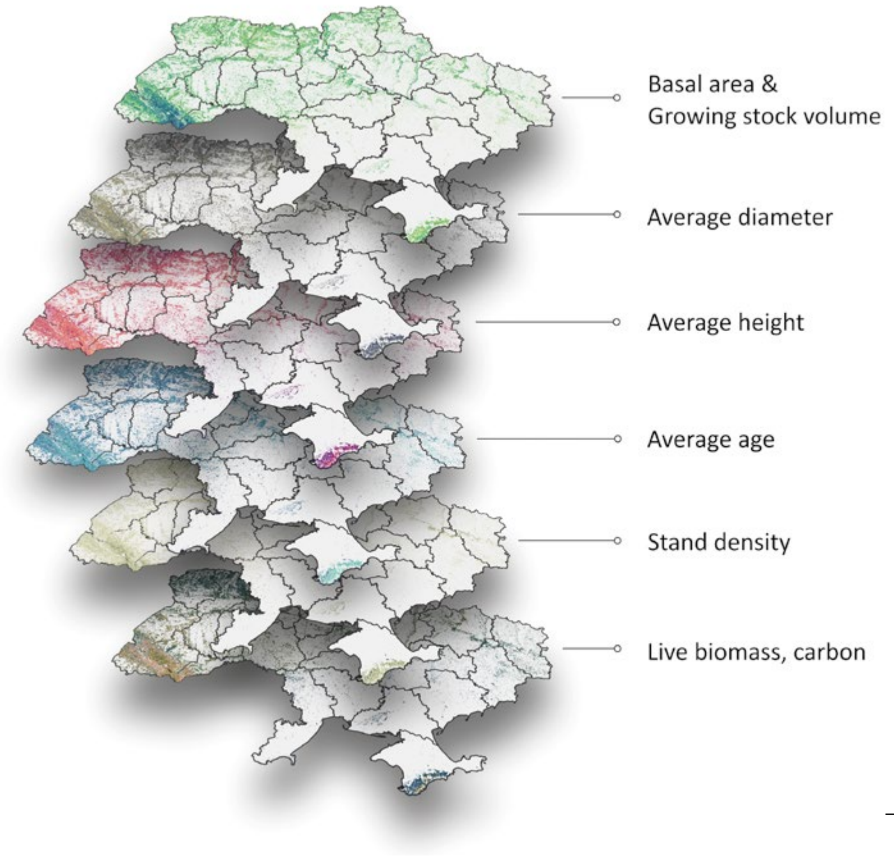
The developed approach showed good potential for mapping stands with a predominance of coniferous species (accuracy was higher than 85%). The overall accuracy of tree species classification was 75%, and 95% for groups of coniferous and deciduous species.

It should also be noted that the accuracy results and area estimates refer to classified pixels, not forest stands, which may lead to misinterpretation of the data compared to official forest information. There are still some limitations in separating many deciduous species (such as maple from linden or ash) or in accurate identifying the dominant species within mixed stands. This is a task for further improvement of the mapping methodology as new field data or more advanced methods become available.



From sample plots to forest characteristics

Unlike traditional NFI, RS-inventory reports not only tabular results but also produces maps of the spatial distribution of forest characteristics. Adding a spatial component to the estimates expands the role of the NFI as a standard tool for collecting national forest statistics into a powerful tool for forest policy making. Mapped forest characteristics at 20-meter resolution demonstrate the great potential of using Sentinel 2 imagery to further study of forest ecosystem properties and their responses to climate change. This also illustrates the important role of a combined use of the NFI and remotely sensed data to address the impacts of natural and human-caused disturbances on forest ecosystem functions, resilience, and dynamics.



Forest resources of Ukraine

The RS-Inventory results for all forests of Ukraine revealed the total forest area of 11.2 million ha, or 18.6% of the total area of Ukraine, out of which 1.7 million ha have been affected during the war.

Volume of growing stock depends on the structure of forests determined by age, density, tree species, and other forest attributes. The growing stock of all Ukrainian forests amounts to 2.81 billion m^3, and the average growing stock is 251 m^3/ha. Thus, the forest area and growing stock are higher than expected from previous studies. Growing stock also varies among tree species, e.g., it is significantly higher for coniferous forests (299 m^3/ha) than for deciduous forests (226 m^3/ha).

Regarding total growing stock Ukraine is behind Germany, Sweden and France at the fourth place in the European country ranking (excl. Russian Federation).

If one would calculate total amount of wood in the forests of Ukraine as a massive wooden tower from the Earth to the Moon, it would have a diameter of about three meters.

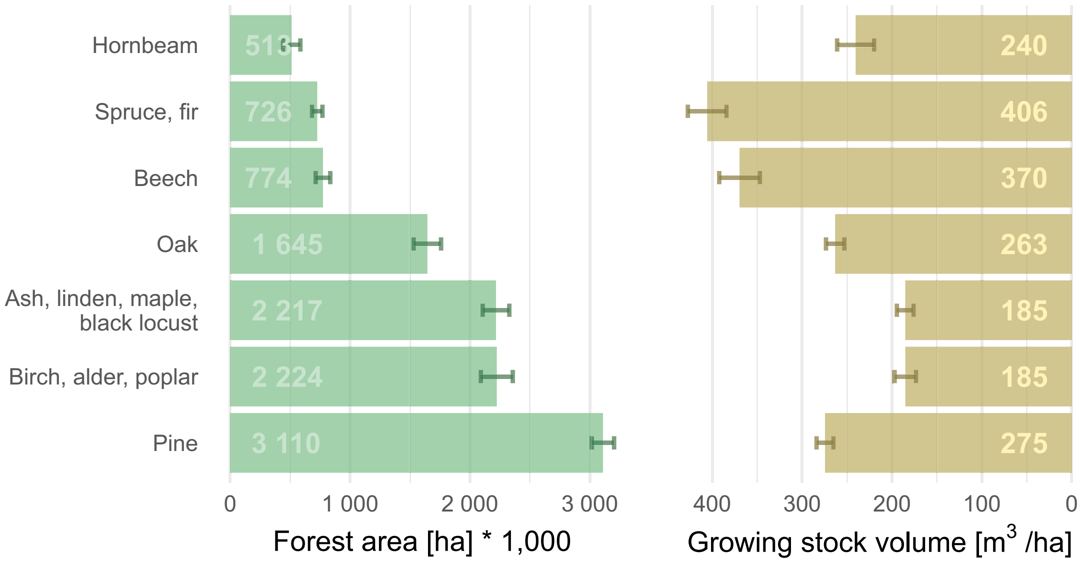
Carbon storage in the forests correlates significantly with growing stock. According to the RS-Inventory, the total volume of carbon accumulated in Ukrainian forests, including roots, branches, leaves, and stems, was estimated at 944 million t or 3.46 billion t CO_2-equiv., which is about 10 times the volume of annual GHG emissions of whole Ukraine. Nature-based climate change mitigation strategies using carbon sequestration and storage processes in forest ecosystems have the potential to significantly reduce greenhouse gas (GHG) emissions.

The estimates of the RS-Inventory with 95% confidence intervals are provided in the Annex.

Dominant tree species

Forests in Ukraine consist of about 30 tree species. Two thirds of the forest area is dominated by deciduous tree species. The most common species are oak and beech. Beside this , groups of species with low (birch, alder, poplar, willow) and high (ash, linden, maple, black locust) life expectancy dominate together 40% of the total forest area with almost equal share of these groups. Most of Ukrainian forests (28%) are dominated by pine.

With over 406 m³/ha, growing stock is the highest in the forest dominated by spruce and fir, followed by beech (370 m³/ha), pine (275 m³/ha), and oak (263 m³/ha). These are the most valuable commercial tree species with the highest productivity.

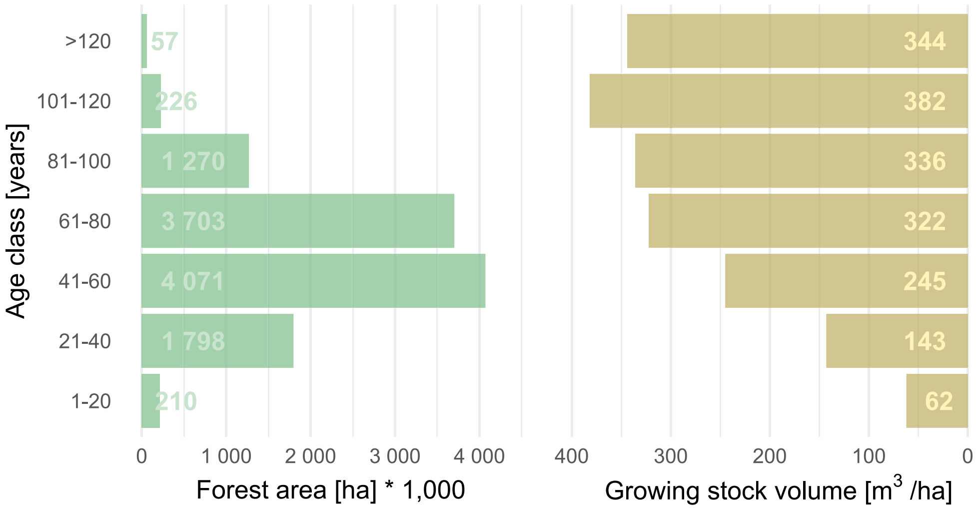


Forest age structure

The age class structure in Ukraine shows a high share of middle age stands, characterized by high annual increment in cubic meters per hectare. At the same time, the first age class shows only 210 thousand hectares, or 1.9% of the total forest area. This is a very low proportion in terms of the sustainability of forestry in an age class approach. In addition, considering that a significant area of this age class comes from natural succession on agricultural land, this partly explains the increased extent of the total forest area now revealed compared to the previous analysis.

It should be noted that increasing sustainability and protection requirements lead to less clear cuttings and thus to areas for reestablishing a new stand, which should then be identified in the first age class. Age class structured forestry is shifting in many countries to selective cuttings, where trees of different ages grow close together in the same stand. Only 2.5% of the total forest area is over 100 years old. Old stands are especially rich in biomass and biodiversity.

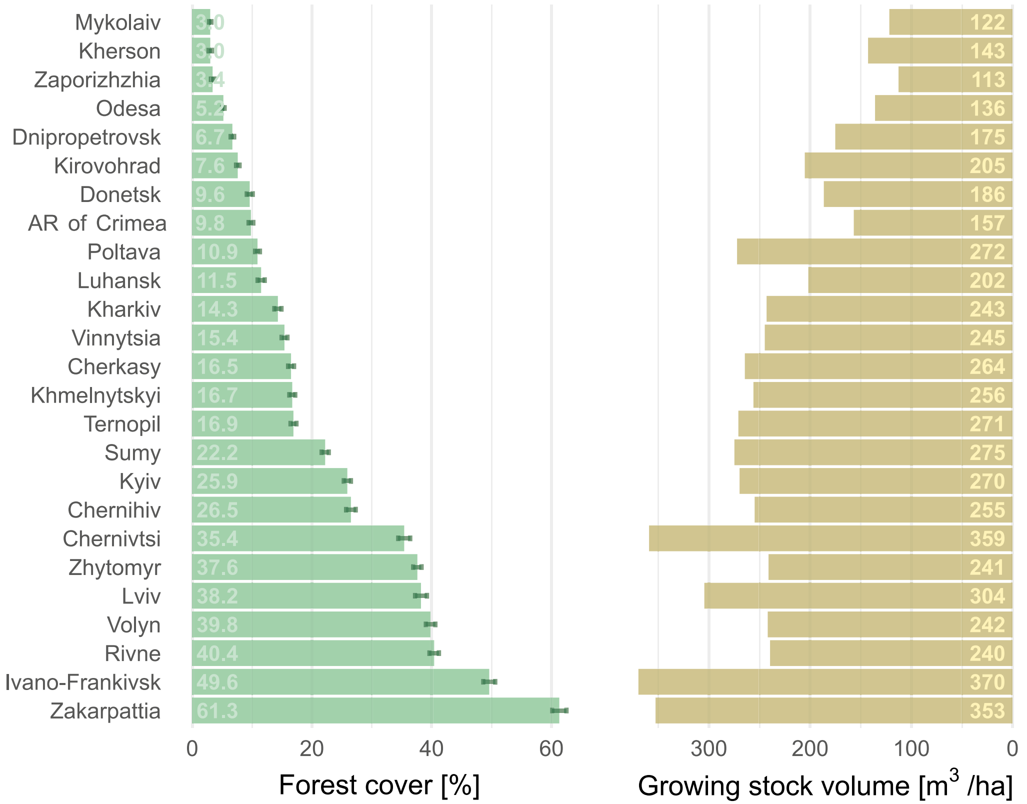
Forests accumulate growing stock up to higher age classes, reaching in the case of Ukraine the maximum at more than 380 m^3/ha for the age class 101-120. In higher age classes, with increasing proportion of cuttings, the growing stock decreases significantly.



Forests at regional level

The forest cover of the Oblasts varies widely. For example, forest cover in Ivano-Frankivsk and Zakarpattia oblasts is 50-60%, while in step regions, such as in Mykolaiv, Kherson, and Zaporizhzhia Oblasts, it is only 3%. Running efficient, sustainable and multi-functional forestry in southern region is a challenge.

Growing stock per hectare varies accordingly. Forests in Ivano-Frankivsk and other Carpathian Oblasts, such as Chernivtsi and Zakarpattia Oblast, in average accumulate more than 350 m^3/ha. In contrast, in the steppe Oblasts (Mykolaiv, Kherson, Zaporizhzhia, and Odessa Oblasts) the growing stock volume is less than 150 m^3/ha.

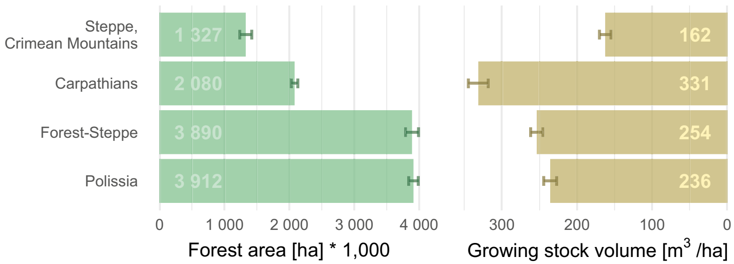


Forests resources by ecozones

The Carpathians have the highest percentage of forest cover (more than 50%) among all the ecoregions of Ukraine, followed by Polissia with a slightly lower value (about 40%).

About 92% of the total growing stock volume are accumulated in the forests of Polissia, Forest steppe, and Carpathians. The mean growing stock volume has the highest value in the Carpathians (331 m^3/ha), while in the Steppe and the Crimean Mountains it only reaches the value of 162 m^3/ha. The forest characteristics are mainly explained by the different climate conditions and forest productivity across Ukraine.

Ecozone map source: Gensiruk (1992).



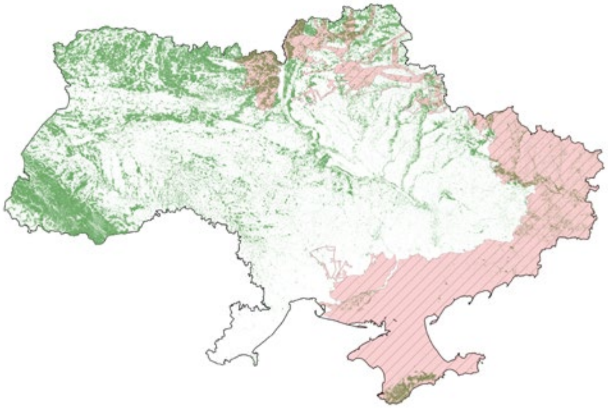
War-affected forests

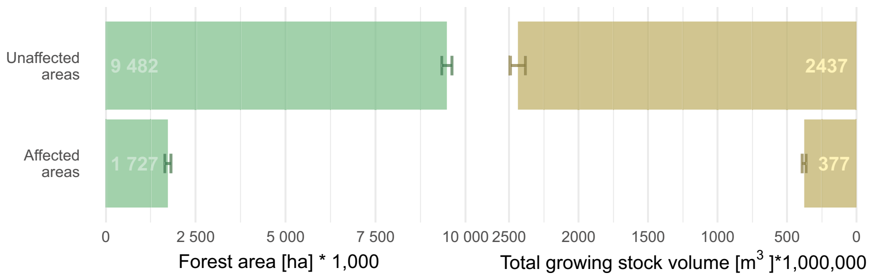
The RS-Inventory found that 1.7 million ha, or about 15% of the total forest area in Ukraine, are affected by the war, mainly occupied by Russia. The war in Ukraine has had multiple impacts on the forest sector, with long-term implications for forest management and forest resource development.

The RS inventory provides a transparent background for spatial assessment of the situation, even in currently inaccessible areas in order to address emerging forest policy issues.

For example, it was found that war-affected forests store about 377 million m^3 of timber, which present a huge loss of state assets.

Map source: DeepStateMap.Live.





This is the first implementation of a remote sensing-based assessment of Ukrainian forests. Examples from countries that have pioneered this approach (e.g., USA, Finland) show that there is a constant need to balance technological advances, research, and operational needs. In this regard, some current limitations of the RS inventory can be identified.

1. A standard output of the forest inventory is estimates and 95% confidence intervals of expected observations for forest area, dominant species, mean and total values of forest attributes. These results have been made available for sufficiently large areas (i.e., country level, ecozones, war-affected areas). For the rest of the territories, the data were prepared in the form of 20-meter resolution raster maps. Still, such maps are an important asset of the RS-Inventory, providing many important input information for the public community, researchers, and practitioners.

2. The approach has enabled the production of wall-to-wall forest maps in Ukraine. The main specific of the current approach is that it mapped all tree vegetation, including natural succession on agriculture land, urban forests areas, etc. This information does not directly address the problem of assessing the State Forest Fund, but can shed light on many other important issues, including the identification of forest regrowth areas outside the forest. The actual forest area can be assessed within the boundaries of forest stands.

3. Sentinel 2 time series showed good performance in mapping forests in Ukraine. However, there are still problems with mapping narrow shelterbelts. Thus, more efforts are needed to better address this issue with more advanced remote sensing technologies.

4. Optical satellite time series have limitations in terms of signal saturation for dense and multi-layered forest stands. This leads to a systematic underestimation of younger age classes. Therefore, integration of active remote sensing capable of penetrating dense canopies seems very promising for more accurate classification of tree species and mapping of forest attributes.

While the RS-Inventory has shown its usefulness in terms of reliable input data, scientifically based methodology and robust outputs on all Ukrainian forests there seem significant potentials to further improve RS-Inventory outputs and broaden its use for forest sector policy making.

Further structuring RS-Inventory outputs. In case of availability of corresponding maps on the legal status of land use in terms of e.g. ownership respectively users (e.g. State Forest Fund) and levels of protection the above presented outputs of the RS-Inventory could be further structured and provide thus a base for specific forest policy approaches.

Retrospective RS-Inventory analysis. Such retrospective analyses can provide insights on changes in forest cover and various structural forest attributes. When comparing these changes with legally planned forestry measures such analysis could reveal the extent of calamities, such as forest fires, illegal activities related to e.g. corruption or damages caused by war activities.

Using RS-Inventory results for modelling potential timber supply. RS-Inventory provides structural forest information that can be used for the modelling of forest development and timber harvesting according to assumed forestry scenarios, e.g. with a focus on nature protection and biodiversity, which might lead to a limiting of timber supply or a postwar recovery scenario which might boost harvesting in order to supply the timber industry.

Using RS-Technologies on a regular base for the National Forest Inventory. While the current RS-Inventory was implemented due to war implications, RS-Technologies have a potential to support NFI in general. Such an approach requires consideration of a slightly lower accuracy in comparison to saving money and time.

RS-Inventory can form the basis of a modern national forest monitoring system in Ukraine. RS-Inventory technologies can be used for a comprehensive monitoring, reporting and verification of Green House Gas (GHG) emissions and removals in forests by sinks.

The national level statistics: mean values

Species (species group)	Estimate	Age (years)	DBH (cm)	HT (m)	GSV (m^3/ha)	LB (t/ha)	Carbon (t/ha)	CO_2-equiv. (t/ha)
All species	Mean values	57.1	27.6	19.9	251.0	179.3	84.3	308.9
	95% CI of means	0.9	0.4	0.2	4.9	3.7	1.8	6.4
All coniferous	Mean values	57.5	28.8	20.7	299.4	168.3	79.1	290.0
	95% CI of means	1.4	0.6	0.4	8.9	5.3	2.5	9.1
All deciduous	Mean values	56.8	27.0	19.5	225.9	185.0	86.9	318.7
	95% CI of means	1.1	0.5	0.3	5.8	5.1	2.4	8.8
Pine	Mean values	56.2	28.3	20.3	274.6	155.7	73.2	268.2
	95% CI of means	1.5	0.6	0.5	9.4	5.8	2.7	9.9
Spruce, fir	Mean values	63.3	30.7	22.2	405.7	222.4	104.5	383.3
	95% CI of means	3.2	1.2	0.8	21.5	12.0	5.6	20.7

Species (species group)	Estimate	Age (years)	DBH (cm)	HT (m)	GSV (m^3/ha)	LB (t/ha)	Carbon (t/ha)	CO_2-equiv. (t/ha)
Oak	Mean values	73.9	32.9	21.9	263.3	224.0	105.3	386.0
	95% CI of means	2.3	1.0	0.5	10.2	9.0	4.2	15.5
Beech	Mean values	74.2	35.7	24.7	369.7	353.6	166.2	609.3
	95% CI of means	3.4	1.5	1.0	22.6	21.3	10.0	36.7
Ash, linden, maple, black locust	Mean values	52.6	23.5	17.0	185.3	152.9	71.9	263.6
	95% CI of means	2.1	1.0	0.5	9.3	8.6	4.1	14.9
Birch, alder, poplar	Mean values	43.5	23.8	18.5	185.2	121.7	57.2	209.8
	95% CI of means	2.1	1.1	0.6	11.9	8.8	4.2	15.2
Hornbeam	Mean values	52.0	23.9	18.9	240.5	218.0	102.5	375.6
	95% CI of means	3.5	1.9	1.2	20.6	19.4	9.1	33.4

DBH – stand diameter; HT – stand height; GSV – growing stock volume per hectare; LB – live biomass (trunks, branches, foliage, and roots). CI - confidence interval.

The national level statistics: total values

Species (species group)	Estimate	Area (ha)	GSV (million m³)	LB (million t)	Carbon (million t)	CO_2-equiv. (million t)
All species	Total values	11209004	2813.76	2009.22	944.38	3462.46
	95% CI of means	166099	54.92	41.47	20.18	71.74
All coniferous	Total values	3835955	1148.47	645.53	303.42	1112.42
	95% CI of means	86580	34.14	20.33	9.59	34.91
All deciduous	Total values	7373048	1665.29	1363.69	640.96	2350.04
	95% CI of means	86580	42.76	37.60	17.70	64.88
Pine	Total values	3109940	853.89	484.06	227.52	834.16
	95% CI of means	92643	29.23	18.04	8.40	30.79
Spruce, fir	Total values	726016	294.58	161.47	75.90	278.26
	95% CI of means	43615	15.61	8.71	4.07	15.03

Species (species group)	Estimate	Area (ha)	GSV (million m³)	LB (million t)	Carbon (million t)	CO_2-equiv. (million t)
Oak	Total values	1644950	433.14	368.43	173.17	634.89
	95% CI of means	114163	16.78	14.80	6.91	25.50
Beech	Total values	773897	286.12	273.65	128.62	471.57
	95% CI of means	60755	17.49	16.48	7.74	28.40
Ash, linden, maple, black locust	Total values	2217394	410.83	339.12	159.39	584.43
	95% CI of means	110993	20.62	19.07	9.09	33.04
Birch, alder, poplar	Total values	2223998	411.87	270.72	127.24	466.54
	95% CI of means	133157	26.47	19.57	9.34	33.80
Hornbeam	Total values	512809	123.34	111.77	52.54	192.62
	95% CI of means	72702	10.56	9.95	4.67	17.13

GSV – total growing stock volume; LB – total live biomass (trunks, branches, foliage, and roots). CI - confidence interval.

User friendly web-interface

The RS-Inventory provides information on forest resources that can be used for management decisions at various levels. This information has been made widely available to the public so that data on forest condition are now transparent.

The standard approach is to provide access to such datasets through user-friendly web interfaces. End users can easily select the data and obtain the desired results relevant to geographic regions and variables of interest. Rather than using prepared distribution tables, users can construct their own data queries and obtain the tabular and graphical outputs they need.

The website of the modern forest monitoring instruments can be accessed via
https://nfi.lisproekt.gov.ua/en/